PlantLab student scientists

GROWING THE FUTURE

Teacher Guide for Investigations and Applications

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PLSS 2023 – 6th —8th Curriculum Plan

Curriculum Unit Overview: Plant Investigations and Applications

Introduction:
Welcome to an exciting educational journey that delves into the captivating realm of plant science and its practical applications. This curriculum unit has been meticulously crafted to acquaint both educators and students with the cutting-edge developments in plant science, drawing upon the expertise of the Missouri Botanical Garden (MBG), a world-renowned leader in this field. With a team of scientists spanning across 35 countries and the discovery of approximately 200 new plant species each year, MBG offers a unique opportunity to explore the intricate world of plant life, ranging from entire ecosystems to the most minute genetic variations.

The "PlantLab Student Scientists: Investigations and Applications" curriculum immerses participants in the fascinating realm of plant science. Leveraging the wealth of knowledge housed at the Missouri Botanical Garden, it serves as a platform for educators and students to delve into the realms of plant biodiversity, conservation, and the practical application of the engineering cycle in plant investigations. Through hands-on data collection and analysis, students are encouraged to develop critical thinking and problem-solving skills.

This unit is designed to bridge the gap between theoretical knowledge and real-world applications, igniting the spark for future careers in STEM fields, particularly in plant science and conservation. Our holistic approach equips students with the tools to tackle global challenges with innovative and sustainable solutions. Join us in exploring the wonders of plant science and its vital role in shaping the future.

Objective: The primary objective of this curriculum unit is to seamlessly integrate plant science investigations with the engineering cycle, providing students with a holistic understanding of the subject. Through this interdisciplinary approach, students will not only explore the wonders of plant life but also develop crucial skills in data collection, interpretation, and the application of evidence. The overarching goal is to equip students with the ability to innovate and propose solutions to real-world challenges.

Key Components:

Biodiversity Conservation:
- Examine how MBG experts contribute to biodiversity conservation on a worldwide scale.
- Connect the importance of baseline understanding of plants to conservation efforts.

Integration of Engineering Cycle:
- Learn how to apply the engineering cycle to plant science investigations.
- Understand the iterative process of problem-solving and innovation.

Data Collection and Interpretation:
- Gain hands-on experience in collecting and analyzing plant-related data.
- Develop skills in interpreting scientific information for meaningful insights.

Application to Real-World Challenges:
- Explore case studies where plant science has informed innovative solutions.
- Encourage students to brainstorm and propose their own ideas for addressing global challenges.

Benefits for Educators and Students:

Real-World Relevance:
- Connect classroom learning to the impactful work of MBG scientists.
- Bridge theoretical knowledge with practical applications in the real world.

Skill Development:
- Cultivate critical thinking, data analysis, and problem-solving skills.
- Foster an understanding of the iterative nature of scientific and engineering processes.

Inspiration for Future Scientists:
- Motivate students to pursue careers in science, technology, engineering, and mathematics (STEM) fields.
- Showcase the diverse opportunities within the realm of plant science and conservation.

In embracing this curriculum unit, educators and students alike embark on a captivating journey that combines scientific inquiry with practical applications. By exploring the rich world of plant investigations and applications, students will not only deepen their understanding of the natural world but also cultivate the skills necessary to contribute meaningfully to the challenges of tomorrow.

PLSS 2023 – 6th —8th Curriculum Plan

Investigations and Applications

Investigations and Applications

Science Notebooks Overview for PlantLab Student Scientists—Investigations and Applications

Science notebooks are an essential tool for our budding scientists to document their learning journey throughout the school year. These notebooks serve as a personalized space for students to record observations, conduct experiments, analyze data, and reflect on their scientific discoveries. The science notebook is not just a collection of notes; it's a dynamic and interactive record of the scientific process. Science notebooks provide a platform for students to bridge the gap between theoretical knowledge and real-world application. By incorporating hands-on experiments, observations, and reflections, students gain a holistic understanding of how scientific principles are applied in practical scenarios. This connection to real-world applications enhances the relevance and significance of scientific learning.

Beyond the immediate academic benefits, science notebooks contribute to cultivating a lifelong appreciation for science. Through active participation, students develop a sense of curiosity, wonder, and enthusiasm for exploration. This enduring passion for scientific inquiry extends beyond the classroom, influencing their personal and professional lives. The creation of a science notebook is not merely an academic exercise; it is a transformative tool that empowers students to actively engage with the scientific process, develop critical skills, and build a foundation for a lifelong journey of learning and discovery. As educators, fostering an environment that recognizes and celebrates the importance of science notebooks contributes significantly to the holistic development of our students.

Purpose of Science Notebooks:

1. **Record Keeping:**
    - Science notebooks are a place for students to document their thoughts, questions, and findings during class activities, experiments, and investigations.
2. **Critical Thinking:**
    - Encourage students to engage in higher-order thinking by asking questions, making predictions, and drawing conclusions based on evidence. The notebook serves as a tool for developing and refining these critical thinking skills.
3. **Reflection:**
    - Students will reflect on their understanding of scientific concepts, identify misconceptions, and evaluate the effectiveness of experiments. Regular reflection helps reinforce learning and promotes metacognition.
4. **Communication:**
    - Science notebooks provide a platform for students to communicate their ideas, observations, and findings to others, fostering peer-to-peer learning and collaboration.

Investigations and Applications

Components of Science Notebooks:

1. **Table of Contents:**
    - The first page should be dedicated to a table of contents, allowing students to organize and easily locate entries in their notebooks.
2. **Title Page:**
    - Create a title page where students can personalize and decorate their notebooks. This page may include their name, grade, and a creative representation of what science means to them.
3. **Investigation Pages:**
    - The heart of the notebook! Students will document each investigation, experiment, or lab activity. Include sections for:
        - Objective or purpose
        - Materials and methods
        - Data collection (tables, charts, graphs)
        - Observations
        - Analysis and conclusion
4. **Vocabulary Section:**
    - Reserve a section for key vocabulary words related to each unit of study. Students should include definitions and, when applicable, illustrations or examples.
5. **Sketches and Diagrams:**
    - Encourage students to include visual representations of concepts, diagrams of experiments, and labeled sketches to enhance their understanding and retention.
6. **Reflection Pages:**
    - Allocate space for regular reflections, where students can ponder what they've learned, identify challenges, and set goals for improvement.
7. **Question Pages:**
    - Dedicate pages for students to jot down any questions that arise during class or as they review their notes. This can serve as a starting point for class discussions or future investigations.
8. **Home-Science Connection:**
    - Foster a connection between science and students' everyday lives. Encourage them to document real-world examples of science concepts they encounter outside the classroom.

Tips for Success:

- Emphasize the importance of neatness, organization, and attention to detail in science notebooks.

- Schedule regular notebook checks to provide feedback and monitor student progress.
- Promote a positive and collaborative environment, encouraging students to share their findings and insights with their peers.

  By integrating science notebooks into our curriculum, we aim to cultivate a love for scientific inquiry, critical thinking, and effective communication in our 6th-grade scientists. Happy experimenting!

Maintaining a science notebook encourages the development of a growth mindset—a belief that intelligence and abilities can be developed through dedication and hard work. As students encounter challenges, make mistakes, and revise their hypotheses, they learn that setbacks are integral to the learning process. This mindset fosters resilience and a willingness to embrace challenges as opportunities for growth

Introductory Science Notebook lesson

Title: "Scientific Inquiry Adventure"

Objective: Students will explore the scientific method through a series of interactive activities, documenting their observations and conclusions in a creatively designed science notebook.

Next Generation Science Standards

Science and Engineering Practices

- Asking Questions (SEP1): Science notebooks encourage students to ask questions as they observe, explore, and conduct experiments, aligning with the practice of developing and using models.
- Constructing Explanations and Designing Solutions (SEP6): Students use science notebooks to document their thought processes, explanations, and the design of experiments, helping them develop and communicate scientific explanations.

Crosscutting Concepts (CCCs):

- Patterns (CCC1): Students can use science notebooks to identify and document patterns in data, observations, and experimental results.
- Cause and Effect (CCC2): Analyzing experimental outcomes and documenting cause-and -effect relationships within the science notebook supports understanding of this

crosscutting concept.

- Systems and System Models (CCC4): Science notebooks can be used to illustrate and describe systems, helping students understand the relationships and interactions within scientific phenomena.

Disciplinary Core Ideas (DCIs):

- Physical Sciences - PS1.A: Structure and Properties of Matter: Using science notebooks to record observations and data from experiments related to the properties of matter aligns with this DCI.
- Life Sciences - LS1.A: Structure and Function: Students can document their observations and findings related to the structure and function of living organisms in their science notebooks.

Science and Engineering Practices - Engaging in Argument from Evidence (SEP7):

- Science notebooks provide a space for students to construct and present arguments based on evidence gathered through experiments, observations, and data analysis.

Science and Engineering Practices - Obtaining, Evaluating, and Communicating Information (SEP8):

- Science notebooks support the practice of obtaining, evaluating, and communicating information by providing a platform for students to organize and convey their scientific ideas.

Science and Engineering Practices - Developing and Using Models (SEP2):

- Science notebooks can be utilized to sketch and describe models that represent scientific phenomena, supporting students in developing and using models as part of the scientific process.

Students will be able to

- Students will be able to define science as the systematic study of the natural world and scientists as individuals who use observation, experimentation, and analysis to understand and explain phenomena

Materials Needed:

- Science notebooks
- Various household items (e.g., cups, water, paper, magnets, etc.)
- Markers, colored pencils, and other art supplies
- Chart paper or whiteboard for class brainstorming

Investigations and Applications

Lesson Outline:

1. Introduction :
    - Begin with a class discussion on the scientific method. Use chart paper or the whiteboard to create a collaborative mind map of the scientific method components (question, hypothesis, experiment, data collection, analysis, conclusion).
    - To help introduce science notebooks, the following script was created
        - Teacher: Good morning, future scientists! Today, we embark on an exciting adventure as science explorers. (Holds up the mysterious box.) What's in this box will unlock the secrets to becoming extraordinary scientists. Are you ready?
            - Scene 1: The Quest for Knowledge
                - Teacher opens the box, revealing science notebooks for each student.
                - Teacher: Behold, your very own science notebooks! These will be your companions on our journey through the fascinating world of science. But before we dive in, let's talk about our guide, the scientific method.
            - Scene 2: The Scientific Method Showcase
                - Teacher uses a visual aid or a large poster to illustrate the steps of the scientific method.
                - Teacher: Imagine the scientific method as our treasure map, guiding us through the uncharted territories of science. First, we ask questions – the spark that ignites our curiosity. What do you want to explore? What questions keep you up at night?
                    - Students share their questions.
                - Teacher: Excellent! Now, we move to step two: forming hypotheses. What do you predict the answer to your question might be?
                    - Students share their hypotheses.
                - Teacher: Wonderful! Now, onto step three: designing experiments to test our hypotheses. This is where our science notebooks come into play.
            - Scene 3: Science Notebooks in Action

- Teacher demonstrates how to set up the science notebook for an experiment.
- Teacher: Open your notebooks to the first blank page. Write down your question, your hypothesis, and the materials you'll need for your experiment. This is the starting point of your scientific journey.
  - Students follow along, setting up their own notebooks.
- Scene 4: The Hands-On Experiment
- Teacher introduces a simple, hands-on experiment related to the current science unit.

2. Activity 1: "Mystery Cups" :
   - Place various items in cups and cover them. Each cup contains a different object.
   - Students work in pairs. They observe, ask questions, and form hypotheses about the content of their cups
   - After making predictions, students reveal the contents and compare their hypotheses with the actual items.
   - In their science notebooks, students document the steps of the scientific method for this activity.
3. Activity 2: "Water Absorption Experiment" (:
   - Provide different materials (paper, cotton balls, plastic, etc.) and water.
   - Students predict which material will absorb the most water.
     - Conduct the experiment, record data, and draw conclusions.
     - Encourage creative data representation such as charts or graphs in their science notebooks.
4. Reflection and Discussion
   - Have a class discussion on the challenges and successes students experienced during the experiments.
   - Ask students to reflect on the importance of each step of the scientific method in guiding their investigations.
5. Artistic Science Notebooks :
   - Distribute art supplies and guide students in decorating their science notebooks. Encourage creativity, incorporating elements related to their experiments.

Exploring the Wonders of soil

Investigations and Application
Exploring the wonders of Soil—What is Soil?

What is Soil: Educator Background Information

When we look at the needs of a plant, most plants need four main ingredients for growth and survival. These ingredients include: sunlight, water, air and soil. In this chapter of the curriculum students will be engaged in learning about and looking at soil. Throughout the curriculum soil will be defined as the upper layer of the earth in which plants grow, typically consisting of two major components. organic remains (living: plants and animals) and inorganic particles (nonliving: rocks and minerals). To further define organic, this qualifies as the living component of the soil. Primarily made up of decaying humus, it also includes the root systems of plants, as well as invertebrates, fungi and soil bacteria. Many of these soil organisms form beneficial partnerships with plants, providing them with nutrients. Good soil practices feed and provide a refuge to these organisms. A healthy humus component also serves to retain more air and moisture within the soil due to small cavities in its texture. Inorganic components include the mineral component of soil Primarily made up of eroded rocky sediments, it can include particles characterizes as sand, silt, clay, and even small stones. The chemical, biological and mechanical breakdown of bedrock and exposed stone provides plants with base status minerals, but cannot by itself provide a fertile medium for more complex plants. Groundwater can also be considered part of the inorganic component. Soils naturally occur and will vary widely across locations with differing geography and geology. In the United States alone, there are 23,000 soil series, 500 of those soil series are found in Missouri. No matter the soil series, soil health is vital to human life through the food that we eat (humans eat a lot of plants either directly or indirectly) and for the ecosystem services it provides. From the human perspective, soil has been the bedrock of agriculture practices throughout the humanity. Soils have allowed humans to use it as a medium for which we grow agricultural food products for human consumption. For healthy quality consumable food, food crops need a health soil to provide the needed nutrients, support, water and oxygen. In the natural world, soil health or soil quality is a direct function of the organic content. Soil quality is a function of the organic content, which is the bulk of the bioavailable nutrients available to the plants through soil that comes via living organisms and processes while appropriate moisture levels depend on the absorbance, water retention and aeration associated with more porous biological materials. The bioavailable nutrients that are available to plants through the soil comes through living organisms and processes, while appropriate moisture levels depend on the absorbency, water retention and aeration associated with more porous biological materials.

Sand, silt and clay are inorganic materials. Sand is made up of larger particles with can be seen with the naked eye. It has a coarse feel and allows water to move through very quickly. Silt particles are too small to see with the naked eye. Silt is often found in places that have flooded and dried out again. Clay is made up of very tiny particles. The particles fit together so closely that it is diffuculut for water to flow through. The best kind if soil for plants allows water to move through slowly enough so that some of it stays in the soil for plants to use. Water moves too quickly through sand, but clay

Exploring the Wonders of Soil

Real world connections/careers:
Studying soil opens up a diverse range of career opportunities, as soil science plays a crucial role in various sectors, from agriculture and environmental conservation to urban planning and research. Here's an overview of potential careers for individuals with expertise in soil: Wetland specialist, Watershed technician, Hydrologist with Board of Health, Environmental technician State soil and water quality specialist, Soil Conservationist, County Agricultural Agent, Landscaping business, Farming, On-site evaluation, Crop consultant, Soil scientist, mapping and interpretation, U.S. Department of Agriculture, Research technician, Conservation planner, District marketing manager for an agricultural firm, County conservationist, Crop production specialist

Next Generation Science Standards
MS-PS-2 Analyze and interrupt data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred

Students will be able to:
- Understand nature of soil, soil profile soil horizons, organic matter
- Describe the importance of organic materials in soil

Student Vocabulary:

A Horizon - The layer called top or surface soil; it is found below the O horizon and above the E horizon.
B Horizon - Also called the subsoil - this layer is beneath the E Horizon and above the C Horizon. It contains clay and mineral deposits (like iron, aluminum oxides, and calcium carbonate) that it receives from layers above it when mineralized water drips from the soil above and is usually brownish or reddish due to the iron oxides,.
C Horizon- the layer beneath the B Horizon and above the R Horizon. It consists of slightly broken-up bedrock. Plant roots do not penetrate into this layer; very little organic material is found in this layer.
E Horizon - This eluviation (leaching) layer is light in color; this layer is beneath the A Horizon and above the B Horizon. These are present only in older, well-developed soils,
Horizons—top or surface soil organic matter
inorganic particles— Components of the soil that come from the weathering of various rock types
O Horizon - The top, organic layer of soil, made up mostly of undecomposed leaf litter and humus (decomposed organic matter).
Organic materials – the living components of the soil, primarily made up of decaying leaves, animal droppings and other decaying matter
Organic particles—Components of the soil that come from the plants and animals inhabiting the area
R Horizon - The unweathered rock (bedrock) layer that is at the base of the soil profile. Unlike the above layers, R horizons largely comprise continuous masses (as opposed to boulders) of hard rock that cannot be excavated by hand.

Exploring the Wonders of Soil

What is soil

Soil—the upper layer of earth in which plants grow, typically consisting of mixture of organic remains and inorganic particles
Clay— Clay soil is a type of soil characterized by fine particles with a diameter smaller than 0.002 mm. It has a smooth, sticky texture when wet and tends to become hard and compact when dry. Clay soil has high water and nutrient retention but poor drainage.
Sand— Sand soil is a soil type composed predominantly of coarse particles ranging from 0.05 mm to 2 mm in size. It feels gritty and does not hold water well, resulting in good drainage. However, it has low nutrient retention and fertility.
Loam—Loam soil is a balanced mixture of sand, silt, and clay particles, providing a crumbly and well-structured texture. It offers a compromise between the properties of sand, silt, and clay, with moderate water retention, good drainage, and nutrient-rich characteristics. Loam soil is often considered ideal for plant growth.

Exploring the Wonders of Soil—What is Soil (engage)

- Introduce the topic of soils through the following teacher lead script
    - Good morning, class! Today, we're going to dig deep into the fascinating world beneath our feet. Can anyone guess what we're talking about?
        - Allow students to share guess with partners or as a whole group
    - We're going to explore something that's a bit softer and more nurturing. Today, we're diving into the incredible world of soil! Let's get started.
    - Display the following text for students "Soil: The Skin of the Earth."
        - Soil is like the skin of the Earth, providing support and nutrients for plants to grow. Without soil, our world would be very different. Now, who can tell me what soil is made of?
            - Student response may be Dirt?
    - Exactly! But let's use the word "soil" instead of "dirt." Soil is a mixture of minerals, organic matter, water, and air. It's a living, breathing ecosystem right beneath our feet.
    - Inform students that we have prepared a simple soil demonstration through a simple experiment for us.
        - Here, I have three jars of soil from different places.
            - Soil types can be collected at different locations of the schoolyard campus or use the common soil types: Loam, Clay and Sandy
                - Loam Soil:
                    - Loam soil is often considered the ideal soil type for gardening and farming.
                - It is a balanced mixture of sand, silt, and clay particles, with roughly equal proportions of each.
                - Loam soil is well-draining, retains moisture well, and has good aeration.
                - It provides a fertile environment for plant growth, as it has a good balance of nutrients and minerals.
                - Gardeners and farmers prefer loam soil for its versatility and ability to support a wide range of plants.
            - Clay Soil:

        - Clay soil is composed of very fine particles, which means it retains moisture extremely well.
        - It has poor drainage and can become compacted easily, leading to issues with root development and aeration.
        - Clay soil tends to be nutrient-rich, but it can be challenging to work with due to its heaviness and tendency to become hard when dry.
        - Amending clay soil with organic matter can improve its structure and make it more suitable for gardening.
    - Sandy Soil:
        - Sandy soil is composed of larger, coarse particles and has excellent drainage.
        - It does not retain moisture well, which can be a disadvantage in dry climates.
        - Sandy soil is easy to work with and warms up quickly in the spring, making it suitable for early planting.
        - However, it tends to be low in nutrients and may require frequent fertilization.
        - Mixing organic matter into sandy soil can help improve its water-holding capacity and nutrient content.
- We're going to observe and compare them in our student science notebooks.
- Now, let's take a closer look at these soils.
    - In your science notebook create a chart for features noticed. This could be the color, texture, and any visible materials.

Soil Properties	Sample 1	Sample 2	Sample 3
Texture			
Drainage			
Color			

Exploring the Wonders of Soil

- As students are exploring the soils and documenting information into their science notebook, engage the class in a discussion about the importance of soil composition for plant growth.
    - Alright, imagine you're a plant, and the soil is like your cozy home. Now, let's talk about why that home (soil) is so important for your growth, just like it is for plants:
        - Nutrient Buffet: Think of soil as a magical buffet for plants. It's filled with all the nutrients that plants need to grow big and strong. Just like you need different foods to stay healthy, plants need different nutrients from the soil to grow leaves, flowers, and roots.
        - Hydration Station: Soil is like a giant water bottle for plants. It holds water and gives it to the plants when they get thirsty. Just like you need water every day, plants need it too to help them make food and stay turgid (meaning they stand up straight and don't wilt).
        - Roots' Cozy Bed: Picture plant roots as cozy beds in the soil. They need a comfortable and secure place to anchor themselves and grow. The soil provides the support that roots need to hold the plant in place and keep it from falling over.
        - Breathing Room: Plants need to breathe, too! Just like you breathe in oxygen, plants take in oxygen through tiny openings in their roots. The soil helps create spaces for air to reach the roots so that the plant can "breathe" and stay alive.
        - Nutrient Transformation: Imagine the soil as a kitchen where the nutrients get transformed into a plant-friendly form. Helpful microorganisms in the soil act like chefs, changing nutrients into a version that plants can easily absorb and use.
        - pH Playground: Picture soil as a playground with different areas for different games. The pH of the soil (how acidic or basic it is) is like the type of game the soil can play. Some plants like a more "sour" soil, while others prefer it more "sweet." The soil helps balance this out.
        - Protection Hub: Soil acts as a superhero shield, protecting plants from extreme weather and harmful things. It keeps the plant roots safe and sound, just like your house protects you from the rain, wind, and cold.

            - So, in a nutshell, soil is like a plant's best friend – providing food, water, a comfy bed, fresh air, and even protection. Without soil, plants would be like guests at a party with no snacks or a bed to rest in – not a very happy situation!
        - Soil is not just a place for plants to anchor their roots; it's also a habitat for many living organisms like earthworms, insects, and microorganisms. These tiny creatures play a crucial role in maintaining healthy soil.
- Begin by discussing what clay soil is and where it can be found. Use pictures or soil samples to illustrate.
    - Show examples of clay art or pottery to inspire students and explain how clay has been used for art and practical purposes throughout history.
    - Take the students outside to collect clay soil. Ensure that you have permission to do so and that it is a suitable location.
        - In pairs or small groups, have students gather clay soil from a designated area using plastic buckets or containers.
            - Encourage them to dig a few inches below the surface to find clay-rich soil.
        - Discuss safety rules, including not disturbing plant life or the environment while collecting soil.
    - Return to the classroom with the collected soil.
    - Provide each group with a sieve or strainer and a plastic bucket containing their clay soil.
        - Instruct students to break up the soil clumps and pass the soil through the sieve, removing rocks, sticks, and debris.
        - Gradually add water to the sieved clay soil while stirring until it reaches a clay-like consistency. Demonstrate proper mixing techniques.
            - Allow the clay to sit for a few minutes to absorb water.
    - Have students test the clay's texture by trying to mold it into small shapes or figures. Discuss how it feels and behaves. Encourage them to describe its texture, malleability, and color.
        - Discuss the differences between their homemade clay and store-bought modeling clay.
    - Provide students with plastic sheeting or disposable tablecloths to work on.
        - Encourage them to use their homemade clay to create small sculptures, beads, or other artistic projects. Provide tools like spatulas, plastic knives, and wooden sticks for shaping and decorating.

  - Discuss various techniques for shaping, scoring, and attaching clay pieces.
  - Have students share their clay creations with the class. Ask each group to describe their project, explain their creative choices, and share any challenges they encountered.
    - Encourage peer feedback and discussion about what they've learned.
- Ensure that all materials are properly cleaned and stored.
- Remind students to wash their hands thoroughly.
- Ask students to document their clay-making experience in their journals or sketchbooks. They can write about the process, their thoughts, and feelings during the activity.
  - Encourage students to reflect on how working with clay soil was different from using commercial clay.
  - Optionally, ask them to research and write about famous clay artists or pottery traditions.

Exploring the Wonders of Soil—What is Soil (explain)

- Alright, fellow soil scientists! Imagine this: You have a special invitation to embark on a thrilling adventure, a journey where you become explorers of a hidden world right beneath your sneakers. Today, we're not just talking about dirt; we're diving into the mysterious, magical realm of soil. Get ready to be soil safari adventurers, uncovering the secrets and wonders that make the Earth's skin so incredibly fascinating! Are you excited? Let's dig in!
  - Begin the lesson with a brief discussion reminding students about the importance of soil for plant growth. Use the analogy of soil being like a house for plants, providing everything they need to thrive. Discuss key concepts like nutrients, water retention, aeration, and support.
    - To help explain the role of sol and its effects on plants, students will be conducting two different investigations. Investigations can be done during one whole class period, however, it may be easier to divide the activities up over multiple days
      - Activity 1—Soil Exploration
        - Divide the class into small groups and provide each group with a grass seed, soil samples (sand, clay, loam), magnifying glasses, and plastic plant pots.
        - Ask students to observe and feel each type of soil, noting differences in texture, color, and moisture content in their student science notebook. Have them discuss their observations within their groups
        - Instruct each group to spread their grass seed in each specific type of soil and record their predictions about how the plant might respond to each type of soil in their student science notebook. Note the seed does not have to be buried in the either soil type
          - Have students water each pot each day of the investigation, making sure that every pot gets the

same amount of water each day for the duration of the investigation.

- For a more accurate test, use de-ionized water during watering. De-ionized water ensures that no nutrients are being given to help the seed grow. All nutrients would be gained from soil exposure..
- Invite students to create a graph in their student science notebook to track seed growth over the course of two weeks

Average height of grass	Soil Type		
	Sand	Clay	Loam
Day 1			
Day 2			
Day 3			
Day 4			

- After two weeks, invite students to gently pull the grass from each soil type. Students can calculate the average root length for each soil type.
- In their student science notebooks, students can organize their data by using graphs to better understand their investigation
    - Create a bar graph to show the average root length for each type of soil.
        - If the soil has space for air and water, the roots can spread very quickly, but if the soil particles are close together, the roots will be find it hard to spread.
        - Ask students to indemnify while soils have the most air and water space and which have the least
    - Using a line graph, chart the growth of each pot of grass each day.

            - The more nutrients a plant can from the soil, the faster it can grow.
        - Which soil type was best for growing the grass seed

- Discuss the role of soil in water retention and drainage. Emphasize how different soils can affect a plant's access to water.
    - Soil as a Sponge:
        - Absorbing Water (Retention):
            - Just like you can pour water on a sponge, soil can soak up water when it rains or when we water plants.
            - The tiny spaces in the soil act like the holes in a sponge, and they trap the water.
        - Holding onto Water (Retention):
            - Once the soil has soaked up water, it holds onto it, just like a sponge holds onto the water it absorbed.
            - This is really important for plants because they can then take a sip of water whenever they get thirsty.
        - Giving Water to Plants:
            - When a plant needs a drink, it sends its roots into the soil. The roots act like straws, sucking up the water stored in the soil.
            - This water gives the plant the nutrients it needs to grow big and strong.
        - Draining Water (Like a Leak):
        - Now, imagine squeezing a sponge. Water starts to drip out, right? Well, when it rains a lot, or when we water plants too much, soil can let go of some water too.
            - This is like the soil saying, "Oops, I have too much water now. I need to let some go so I don't drown the plants!"
    - Soil as a Playground for Water:
        - Water Slides in Soil:
            - Think of the soil as a playground with lots of slides. The water slides down through the soil, just like you slide down a slide at the park.
            - These slides are like the spaces between soil particles that let the water move down.
        - Slow and Fast Slides:
            - Some parts of the soil let the water slide down really fast, and some parts slow it down. This is good because it means the

- water can spread out and reach all the plant roots.
  - Avoiding Puddles:
    - Imagine you're out and you sat on a bench that was wet. No one likes wet jeans. Well, plants don't like their roots to sit in puddles either!
    - The soil helps the water move away so the plant's roots don't get too soggy.
- Remember, soil is like a superhero for plants. It gives them a drink when they're thirsty, but it also knows when to let go of extra water. So, just like you take care of your toys, soil takes care of plants!

- Preparation for investigation:
  - Label each container with the type of soil it contains: "Sand," "Clay," and "Loam."
  - Fill each container with the corresponding soil type.
  - Observation Setup:
    - In your notebook, create a table with three columns: "Soil Type," "Initial Observation," and "After Watering Observation."
      - Initial Observation:
      - Observe and describe the appearance of each type of soil in its dry state. Note the color, texture, and any other characteristics you observe.
    - Watering Process:
      - Using a watering can or dropper, gently water each type of soil. Be consistent with the amount of water you use for each soil type.
      - Observation After Watering:
        - After watering, observe how each type of soil reacts. Look for changes in color, texture, and any visible signs of water absorption. Note if there are any puddles or if the water seems to drain away.
      - Recording Observations:
        - In your notebook, record your observations in the "After Watering Observation" column. Use descriptive words to explain what happened to each type of soil after watering.
    - Questions for Reflection:
      - Which soil type seemed to absorb the water quickly, and which one took more time?
      - Did any of the soils form puddles on the surface? If so, which ones?
      - How did the appearance of each soil type change after watering?
      - What do you think these observations tell us about how different soils retain water?

- Conclusion: Reflect on your findings and think about why water retention is important for plants. Consider how the characteristics of different soils might impact the growth of plants. What could be the benefits or challenges associated with each type of soil?
    - Invite students to reflect on thier findings and think about why water retention is important for plants. Consider how the characteristics of different soils might impact the growth of plants. What could be the benefits or challenges associated with each type of soil?

Exploring the Wonders of Soil—What is Soil (elaborate)

- Alright, let's imagine you're an environmental detective exploring the mysteries of your community's soil. Here's why knowing the soil type is like having a superpower:
    - Different plants have different preferences for soil. Some like it sandy and loose, while others prefer it dense and full of nutrients. Knowing the soil type helps us figure out which plants will thrive in our community.
        - Imagine if you knew which areas of your community's soil were like sponges that soak up water and which were like slides, letting water slip away quickly. This knowledge helps us manage water wisely—making sure plants get just the right amount and preventing flooding.
        - If you or your neighbors love gardening, understanding the soil type is like having a secret recipe. Some plants might need a special kind of soil to grow their best, and knowing what's in the ground helps you create a perfect home for them.
        - Soil isn't just a house for plants; it's a neighborhood for tiny creatures like worms, insects, and microorganisms. Different soils are like different neighborhoods, and by knowing what's in our soil, we can understand and protect these little residents.
        - Believe it or not, soil can affect the weather! Knowing the soil type helps scientists predict things like how fast rainwater will be absorbed or if there's a risk of landslides. It's like having a weather crystal ball for your community.
        - Builders and engineers need to know about the soil to construct sturdy buildings. Some soils are strong and supportive, while others might be a bit shaky. Understanding the soil helps us create safe and durable structures.
        - Our soil holds stories about the environment. By studying the soil, scientists can learn about the history of an area, including past climates and the types of plants and animals that lived there. It's like a time-traveling adventure without leaving your community!
            - In a nutshell, knowing the soil type in our community is like having a treasure map. It helps us discover the best spots for plants, manage water wisely, create beautiful gardens, understand our little soil neighbors, predict the weather, build safely, and explore the environmental history of our home turf!

Exploring the Wonders of Soil

What is soil

- In the following lessons, we will be learning about soil and its role in the environment'
  - Ask students: can the terms soil and dirt be used interchangeably?
  - To help dispel common misconceptions of soil introduce students to the topic of soil
    - Common misconceptions
      - Students often believe that soil and dirt can be used interchangeably
      - Define soil for students as the upper layer of earth in which plants grow, typically consisting of mixture of organic remains and inorganic particles
      - To assist with dispelling these misconceptions, provide students with the opportunity to view the included diagram of a soil profile

    - Soils are a mixture and that it is vital in supporting ecosystems (sustain plant and animal life) support agriculture, regulates and partitions water and filters water as it flows
- Discuss the importance of clean water and why it's crucial to remove impurities . Introduce the concept that soil can act as a natural filter, cleaning water as it passes through. Discuss how this process is similar to what happens in the ground when rainwater moves through soil.
  - Imagine soil as a giant superhero sponge that helps keep our water clean. Here's how it works:
    - Water and the Sponge:
      - Think about when you spill something on the table at home. If you use a sponge to clean it up, the sponge soaks

up the liquid, right? Soil does something similar with rainwater.

- Rainwater Adventure:
    - When it rains, water falls from the sky, and some of it lands on the ground. Now, pretend the ground is like a sponge. The rainwater doesn't just sit on top; it starts to soak into the soil.
- The Filtering Action:
    - Now, here's where the superhero part comes in. The soil acts like a filter. Just like a strainer that keeps pasta in and lets water out, soil holds onto things it needs, like water, and lets go of things it doesn't need.
- Dirty Water Challenge:
    - Let's say there are tiny bits of dirt or leaves in the water. The soil catches these bits and holds onto them, preventing them from getting into our rivers and lakes.
- Underground Adventure:
    - The rainwater, now a bit cleaner after its adventure through the soil, keeps moving downward, like a secret underground river. This water eventually reaches the underground water storage called groundwater.
- Water for Plants:
    - But that's not all! The water in the soil is like a superhero drink for plants. Plant roots slurp up this water, and it brings along some nutrients from the soil, making the plants happy and healthy.
- Cleaning Up Pollution:
    - Soil doesn't just filter rainwater; it also helps clean up some of the yucky stuff we might put on the ground, like oil or chemicals. The soil works to break down and trap these pollutants, keeping them from spreading.

- Soil acting as a filter may be a new concept for the students—demonstrate how this works by conducting the following demonstration
- Begin by discussing the importance of clean water and the role of water filtration.
- Ask students to share any knowledge they have about water treatment processes.
    - Water treatment plants work hard to make sure the water that comes out of our taps is safe to drink. It's like giving the water a thorough bath to remove any impurities and make it clean and healthy for us to use!

- Introduce the concept that soil, a natural resource, plays a crucial role in filtering water.
    - To elaborate on this process, we will conduct a simple investigation.
        - Divide students into small groups and provide each group with containers, different types of soil, gravel, coffee filters or cheesecloth, and a funnel.

        - Instruct students to make predictions in the student science notebook about which soil type they think will be the most effective in filtering dirty water. Encourage them to think about the properties of each soil type.
    - Guide each group in setting up their water filtration system. They should layer the materials in the containers, placing the coffee filter or cheesecloth on top, followed by a layer of gravel, and then the soil.
        - Pour the dirty water through the filtration system and into a clean container. Use the funnel to control the flow.
    - Use a stopwatch to time how long it takes for the water to pass through the filtration system.
        - Ask students to use pipettes or droppers to collect samples of the filtered water at different intervals and observe any changes in clarity.
            - Have each group record their observations, including the time it took for the water to filter through and any changes in water clarity.
            - Encourage students to analyze their data and discuss the effectiveness of each soil type in filtering water.
            - Facilitate a class discussion on the factors influencing water filtration, such as particle size and soil composition.
- Gather the class and have each group share their results and conclusions.
    - Discuss the real-world applications of soil water filtration, including its role in groundwater recharge and the challenges posed by soil erosion and pollution.
    - Have students create a poster or chart summarizing their findings to share with the class.
    - Extension Activity: Challenge students to explore how human activities impact soil health and, consequently, water filtration. This could involve researching the effects of deforestation, agriculture, or urban development on soil quality and water filtration processes. Students can present their findings in a short report or class presentation.
- Our model loosely simulates what scientists call a soil horizon. A soil horizon is a layer of soil parallel to the Earth's surface, with distinct characteristics that differ from the layers above and below it. Soil horizons are often labeled using letters, with each letter indicating a specific horizon. The arrangement of these horizons is collectively referred to as the soil profile.
    - You can easily find illustrations and descriptions of soil horizons by searching on reputable educational websites, soil science organizations, or government agricultural resources.
        - Consider checking websites such as the United States Department of Agriculture (USDA), the Soil Science Society of America (SSSA), or educational platforms like Khan Academy or Britannica. You can use a search engine with terms like "soil horizons" to find detailed images and explanations of soil profiles.

- While students are viewing the profile, inform students that in soils there are 6 major horizons
    - A horizon is soils horizontal layers; these layers are called horizons. They range from rich, organic upper layers (humus and topsoil) to rocky layers (subsoil, regolith and bedrock).
- If desired by the educator, students can be asked to include the following information into their student science notebook
    - O Horizon - The top, organic layer of soil, made up mostly of undecomposed leaf litter and humus (decomposed organic matter).
        - Define Organic materials for students as the living components of the soil, primarily made up of decaying leaves, animal droppings and other decaying matter
        - Show students the YouTube video entitled Fruit and Vegetable Decomposition, Time-lapse video posted by webiocosm
            - https://youtu.be/c0En-_BVbGc
    - A Horizon - The layer called top or surface soil; it is found below the O horizon and above the E horizon. Seeds germinate and plant roots grow in this dark-colored layer. The A layer will contain the highest amount of decomposed organic matter and soil life mixed with minerals (sand, silt, and clay)
        - These minerals are inorganic particles. Define inorganic particles to students as the mineral components of the soil.
        - Most soil contains a combination of different particles because different types of bedrock weather unevenly. Inorganic materials are divided into categories: clay, slit, sand and are divided by size of the particles, not color
    - E Horizon - This eluviation (leaching) layer is light in color; this layer is beneath the A Horizon and above the B Horizon. These are present only in older, well-developed soils,
    - B Horizon - Also called the subsoil - this layer is beneath the E Horizon and above the C Horizon. It contains clay and mineral deposits (like iron, aluminum oxides, and calcium carbonate) that it receives from layers above it when mineralized water drips from the soil above and is usually brownish or reddish due to the iron oxides,.
    - C Horizon- the layer beneath the B Horizon and above the R Horizon. It consists of slightly broken

-up bedrock. Plant roots do not penetrate into this layer; very little organic material is found in this layer.
- R Horizon - The unweathered rock (bedrock) layer that is at the base of the soil profile. Unlike the above layers, R horizons largely comprise continuous masses (as opposed to boulders) of hard rock that cannot be excavated by hand.
    - Be sure to point out to students that the components of soil are derived from the living things at the surface and the bedrock at the bottom, but try to avoid giving the impression that inorganic materials "move up" This does not happen, if anything they move down as soil depletion and erosion

- After reviewing the different horizons in a soil profile, provide students with the opportunity to collect samples of soil with a garden trowel and soil probe while in their schoolyard brining along their student science notebook
- If soils can not be collected by students, educator can collect soils that were taken with a soil probe sampling tool (provided in kit) prior to the beginning of the lesson and placed in a bag for students to select and observe.

    - If educator is collecting, it would be beneficial for students to observe different samples collected at different locations. Be mindful to mark a bag with the sampling location to differentiate samples taken from different areas
        - Follow the steps to take a sample with a soil probe
            - Gently brush aside any mulch or debris
            - simply push the probe into the soil to the desired depth
            - lift up to remove the soil core
            - Place core in a baggie
            - sampling depth can be up to 12 inches

- If a soil probe is not available, take a sample with a garden trowel
    - To do this, cut out a triangular wedge soil and set it aside
    - With students utilizing their student science notebooks, instruct students to record the following information about their soil sample
        - measure the depth of their sample in cm
        - Conduct and record detailed observations of soil sample
        - Describe any noticeable color variations
        - Students may observe that some samples of soil seem to be darker than others
            - Some samples may even transition in color
                - A darker soil color often indicates that there is an increate in humus or decomposed organic matter
- Allow students to observe the soil samples by encouraging students to touch and feel the soil and its horizons
    - Discussion questions: While looking at the soils, ask students "what do you think the soil is made out of"
        - Did any soil sample contain small rocks?
        - Did any soil samples contain clay?
            - In educator desires to conduct a simple procedure to estimate the percent of clay (as well as sand and silt) in a sample follow the below step
    - Using a mason jar, fill the sample half way to the top with a soil sample
    - Add room temperature water to the jar until the soil sample looks and feels like mud
    - Tap jar on table for soil to settle
    - Using tape or a marker, on the outside of the jar mark the height of the soil inside the jar
    - Add a teaspoon of water softener to the soil sample (Borax)
    - Add additional water to the jar until the jar is completely full
    - Shake until soil mixed together
    - After 1 minute, mark the level of soil with tape or a marker at the bottom of the jar. This mark will represent the amount of sand that is in the sample

- Wait 30 minutes and mark the height of soil
- The second mark will be the silt content of the soil

- To find the percentage of sand, divide the depth of the sand (bottom of jar to first line) by the total depth of the soil (initial mark) After settling the soil contents may be higher than the first mark, if this is the case use the new height for the total depth of soil)
- The percentage of silt is found by the depth of the silt (mark made after 30 minutes) divided by total depth of the soil
- To find the percentage of clay, add the percentage of sand with percentage of silt and subtract by 100
    - In the St. Louis area, we should see clay soil (percent clay 40%-100%) rather than loam (28%-50% silt) or sandy soil (85%-100% sand)
    - As soil settles, it separates into its constituent components based their density. Stones and sand sink to the bottom rapidly, silt and clay follow more gradually, but the organic component which consists of formerly living material is largely more porous and often floats until the water drains. Organic material also contains the majority of the soils nutrients since living plants and animals concentrate it in their tissues. Did any soil samples contain humus or organic matter? What colors of soil did you notice

- Inform students that in order to test if the darker soil truly contains a higher amount of organic matter, we will perform an experiment using our soil core samples and combining hydrogen peroxide.
- We will use hydrogen peroxide (*H202*)
  - when introduced to the soil, the present organic matters carbon will bond with oxygen (O2) to form CO2 (carbon dioxide) bubbles
      - The intensity of bubbling and length of the reaction will reflect how much life is in the sample soil core.
  - If students took their own soil sample, allow students to search for a location on the schoolyard that is different from current sampling location or utilize another student groups procured sample (area between sidewalk and road, school garden, school lawn)
    - If samples are taken by the teacher prior to the lesson, provide student groups with different sample locations
      - Multiple sample locations, will allow students to observe and record data related to soils with high organic matter and low organic matter.
- "Today, we're embarking on an exciting journey to explore one of the Earth's most vital resources - soil.
  - Soil is often referred to as the 'skin of the Earth,' and its importance cannot be overstated. It's the foundation of our ecosystems and a lifeline for agriculture. Let's take a moment to understand why soil is so crucial."
    - Ecosystems: "In natural ecosystems, soil serves as a habitat for countless organisms, from microscopic bacteria to earthworms and insects. These organisms play essential roles in nutrient cycling, decomposition, and maintaining the overall health of the ecosystem. Think of soil as the living, breathing, and bustling city beneath our feet."
    - Plant Growth: "For agriculture, soil is the birthplace of our food. It's where plants anchor their roots, draw nutrients and water, and grow into the crops that sustain us. The quality of soil directly impacts crop yields, and understanding its composition is vital for sustainable farming."

- Nutrient Storage: "Soil is like a nutrient bank. It stores essential elements like nitrogen, phosphorus, and potassium that plants need to grow. These nutrients are released gradually to nourish plants, ensuring they have what they need to thrive."
- Filtering and Purifying: "Soil acts as a natural filter, cleaning water that passes through it. This function is crucial for maintaining clean water sources for both ecosystems and human consumption."
- Carbon Storage: "Additionally, soil stores a significant amount of carbon, helping mitigate the effects of climate change by reducing the amount of carbon dioxide in the atmosphere."

- As you can see, soil is a dynamic and essential component of our planet's ecosystems and agriculture. Today, we'll investigate one aspect of soil - its reaction with hydrogen peroxide - to gain a deeper understanding of its composition and how it behaves in different conditions. This knowledge will help us appreciate the hidden world beneath our feet and its impact on the world above
- Procedures to conduct the soil content experiment with H202
    - Place soil samples into paper cups, ensuring that they are labeled with the location (if testing multiple samples).
    - Distribute safety goggles to students for protection during the experiment.
    - Provide each group with a tablespoon, a predetermined amount of hydrogen peroxide, and a stopwatch.
    - Instruct students to pour hydrogen peroxide into the cup until the soil sample is covered (approximately 4-5 tablespoons).
    - Start the stopwatch when hydrogen peroxide is added and have students record the time it takes for bubbling to occur.
    - Using a coffee stirrer, instruct students to mix the soil and hydrogen peroxide.
    - Record the time it takes for bubbling to cease.
- Recording Observations (
    - Instruct students to create a new page in their science notebooks for recording observations.
    - Demonstrate how to record observations, using a sample entry format provided in the instructions.
    - Allow students to record observations for each soil sample location.
- Data Analysis
    - After recording observations, facilitate a class discussion on the results.
    - Discuss whether the reaction rates varied between different soil samples.
    - Encourage students to make hypotheses about why certain soils reacted differently.
- Conclusion and Discussion

- Summarize the key findings of the experiment and relate them to soil quality and composition.
- As students are wrapping up the experiment, probe student understanding by inquiring into why they believe organic matter is important for soil health?
- Thinking about your sampling location, were their lots of plant life growing in sampling areas that had a high organic matter content?
- Did we crate a chemical reaction with the hydrogen peroxide and soil?
- In essence, soil is not just the ground we walk on; it is a dynamic and essential component of the interconnected web of life. Recognizing and respecting the significance of soil in our communities is an investment in the health of our ecosystems, the productivity of our agriculture, and the overall sustainability of the planet we call home.
- Discuss the real-world applications of understanding soil content and its impact on ecosystems and agriculture.

- As an example, observations can be recorded in the following manner:
    - Sample 1 location 1: Description of soil
    - Sample 1 location 1: Predict what you believe may occur
    - Sample 1 location 1: Time for bubbling to occur
    - Sample 1 location 1: Time for bubbling to cease
    - Sample 1 location 1: Observations at 2 minute mark
    - Sample 1 location 1: Observations at 5 minute mark
    - Sample 1 location 2: Description of soil
    - Sample 1 location 2: Predict what you believe may occur
    - Sample 1 location 2: Time for bubbling to occur
    - Sample 1 location 2: Time for bubbling to cease
    - Sample 1 location 2: Observations at 2 minute mark
    - Sample 1 location 2: Observations at 5 minute mark
    - Sample 2 location 1: Description of soil
    - Sample 2 location 1: Predict what you believe may occur
    - Sample 2 location 1: Time for bubbling to occur
    - Sample 2 location 1: Time for bubbling to cease
    - Sample 2 location 1: Observations at 2 minute mark
    - Sample 2 locaion 1: Observations at 5 minute mark
    - Sample 2 location 2: Description of soil
    - Sample 2 location 2: Predict what you believe may occur
    - Sample 2 location 2: Time for bubbling to occur
    - Sample 2 location 2: Time for bubbling to cease
    - Sample 2 location 2: Observations at 2 minute mark
    - Sample 2 location 2: Observations at 5 minute mark

Investigations and Application
Exploring the Wonders of Soil—Collecting Soil Organisms

What are soil organisms: Educator Background Information
Soil organisms constitute a diverse and intricate community of living organisms that inhabit the soil, playing a fundamental role in the health and functionality of terrestrial ecosystems. This hidden world beneath our feet is teeming with microscopic bacteria, fungi, protozoa, nematodes, arthropods, earthworms, and other organisms, collectively forming what is often referred to as the soil food web. Understanding the nature and importance of these soil organisms is essential for comprehending soil health and its implications for broader ecological processes.

Diversity of Soil Organisms:
The diversity of soil organisms is staggering, both in terms of species richness and functional roles. Bacteria, the tiniest of them all, are abundant and serve crucial roles in nutrient cycling. Fungi, ranging from microscopic mycorrhizal networks to visible mushrooms, form symbiotic relationships with plants, aiding in nutrient absorption. Protozoa are single-celled organisms that graze on bacteria and contribute to nutrient cycling. Nematodes, or roundworms, exhibit a wide range of feeding habits, from beneficial predators to plant parasites. Larger organisms like arthropods, including mites and springtails, are involved in the decomposition of organic matter. Earthworms, often considered ecosystem engineers, enhance soil structure through their burrowing activities.

Functions of Soil Organisms:
Nutrient Cycling:
Soil organisms are instrumental in nutrient cycling, the process by which essential elements like nitrogen, phosphorus, and carbon move through the ecosystem. Bacteria and fungi decompose organic matter, breaking it down into simpler compounds that plants can absorb. This decomposition process releases nutrients back into the soil, creating a continuous cycle of nutrient availability.

Soil Structure and Aeration:
Earthworms, among other soil-dwelling organisms, contribute significantly to soil structure. Their burrowing activities create channels for air and water movement, improving soil aeration and drainage. This enhanced soil structure facilitates root penetration and nutrient uptake by plants.

Disease Suppression:
Some soil organisms act as natural allies in the fight against plant diseases. For example, certain bacteria and fungi form beneficial relationships with plants, enhancing their resistance to pathogens. This natural defense mechanism is a key component of sustainable agriculture practices.

Organic Matter Decomposition:
The decomposition of organic matter by soil organisms is a pivotal process in maintaining soil health. As microorganisms break down dead plant material, they release nutrients that support the growth of new vegetation. This continuous recycling of organic matter contributes to the overall fertility of the soil.

Pollutant Breakdown:
Soil organisms also play a role in breaking down pollutants and contaminants, contributing to the purification of soil and water. Certain bacteria have the ability to degrade or transform toxic substances, mitigating the impact of pollutants on the environment.

Importance of Soil Organisms to Soil Health:
Fertility and Plant Nutrition:
Soil organisms are indispensable for soil fertility. Through their activities, they release nutrients locked in organic matter, making them available for plant uptake. The symbiotic relationships formed between mycorrhizal fungi and plant roots further enhance nutrient absorption, promoting healthy plant growth.

Soil Structure and Water Retention:
The activities of soil organisms, especially earthworms, contribute to the development of well-structured soil. This, in turn, enhances water retention and drainage. Soil with good structure allows for the efficient movement of water through the soil profile, preventing waterlogging and promoting optimal conditions for plant growth.

Erosion Prevention:
The roots of plants, along with the stabilizing effect of soil organisms on soil structure, play a crucial role in preventing soil erosion. Erosion is a major threat to soil health, and the intricate network of roots and organisms helps bind the soil particles together, reducing the risk of erosion.

Biological Control of Pests and Diseases:
Certain soil organisms act as natural antagonists to pests and pathogens. For instance, beneficial nematodes can prey on harmful insects, helping to control pest populations. This natural balance in the soil ecosystem contributes to the overall resilience of plants against diseases and pests.

Climate Regulation:
Soil organisms participate in the sequestration of carbon, helping regulate climate by storing carbon in the soil. This process, known as carbon sequestration, plays a role in mitigating the impacts of climate change by reducing the concentration of greenhouse gases in the atmosphere.

Real world connections/careers:
Soil Scientists careers include Wetland specialist, Watershed technician, Hydrologist with Board of Health, Environmental technician State soil and water quality specialist, Soil Conservationist, County Agricultural Agent, Landscaping business, Farming, On-site evaluation, Crop consultant, Soil scientist, mapping and interpretation, U.S. Department of Agriculture, Research technician, Conservation planner, District marketing manager for an agricultural firm, County conservationist, Crop production specialist

Exploring the Wonders of Soil

Soil Organisms

Next Generation Science Standards

- MS-LS2-2 Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.

Students will be able to:

- Students to observe below ground soil organism characteristics and differentiate these characteristics from organisms living above ground
- Students will gain an understanding of the diversity and importance of soil organisms through hands-on activities, observations, and experiments.

Student Vocabulary:

- Adaptation: is the biological mechanism by which organisms adjust to new environments or to changes in their current environment.
- Berlese funnel: is a device that is used to extract insects from soil samples
- Lifecycle—the series of stages in form and functional activity through which an organism passes between successive recurrences of a specified primary stage.
- Macroinvertebrates: any animal lacking a backbone and large enough to see without the aid of a microscope.

Exploring the Hidden World of Soil Organisms (engage)

- Introduce the topic of soil organisms by following the below teacher script
    - Today, we're about to embark on a fascinating journey into the hidden world beneath our feet. Have any of you ever wondered what's going on in the soil beneath the grass and the trees? Well, today, we're going to uncover the mysteries of soil organisms – the tiny, living superheroes that make our soil come alive!
    - Before we dive in, let's start with a quick question. Recall what comes to mind when you think of soil? Feel free to shout out your ideas!
        - Now, imagine you could shrink down to the size of an ant and take a stroll through the soil. What do you think you'd find there?
            - Allow students time to respond—overall hope is that they will discuss microorganism
            - You would probably encounter a bustling city of microorganisms – tiny living creatures that are so small we can't see them without some help. These creatures are like the busy workers of the soil, and they play crucial roles in keeping our environment healthy and thriving.
                - [Teacher displays images of soil organisms on a screen.]
                - Meet some of our soil workers– bacteria, fungi, protozoa, nematodes, and even earthworms. Each of them has a special job in the soil community.
                    - Now, let's talk about bacteria. Imagine billions of them hanging out in a teaspoon of soil. These tiny beings are like the recyclers of the soil, breaking down dead plants and animals into nutrients that plants can use. They're nature's composters!
                    - Next up, we have fungi. These are like the network builders. They form partnerships with plant roots, creating a sort of underground internet that helps plants share nutrients and information. They're like the internet of the soil!
                    - Protozoa, our tiny predators, love to munch on bacteria and keep their populations in check. It's like having little guardians in the soil, maintaining balance.
                    - Now, let's talk about nematodes. Some are good, working with bacteria and fungi to keep the soil healthy. Others, not so much – they can be like tiny troublemakers for plants. But don't worry; we'll learn how everything stays in balance.
                    - Last but not least, the earthworms! They're the architects of the soil, creating tunnels that help with water flow, aeration, and nutrient distribution. It's like they're the construction workers of the underground world.
            - So, as we explore the world of soil organisms in the coming days, remember that every speck of soil is teeming with life, working together to create a healthy environment for plants, animals, and

even us! Are you ready to become soil detectives and uncover the secrets of this hidden world?

- Start the lesson with a captivating video clip or a series of high-quality images showcasing the diverse and often hidden life in soil. These visuals should include close-ups of earthworms, insects, plant roots, and various microorganisms found in soil.
    - Here are some YouTube videos that showcase the diverse and often hidden life in soil, featuring close-ups of earthworms, insects, plant roots, and various microorganisms:
        - "Regenerating Soil Diversity: A Bright Future For Agriculture" by Dr. David Johnson: This video might provide insightful perspectives on soil biodiversity and its importance in agriculture.
        - "Keep soil alive, protect soil biodiversity": This video could offer a comprehensive view on the main drivers and key elements of soil biodiversity.
        - "Regenerating the Diversity of Life in Soils - Webinar with Dr. David Johnson": This webinar might cover various aspects of soil life and its regeneration.
        - "Regenerating the Diversity of Life in our Soils: Hope for Farming and Climate with David Johnson": This video likely discusses the role of soil diversity in farming and its impact on climate.
        - "Episode 1: Reviving Soil Biology with Diversity and Livestock": This episode focuses on the revival of soil biology through diversity and livestock integration.
- Ask open-ended questions to stimulate curiosity: "
    - What do you think is happening beneath our feet right now?
    - Why is soil important for plants and ecosystems?"
- Encourage students to share their thoughts and initial ideas, fostering a sense of inquiry
- Share a brief and intriguing story or fun fact related to soil exploration or a famous soil scientist to pique students' interest. For example:
    - "Did you know that there are more microorganisms in a handful of healthy soil than there are people on Earth? Imagine the bustling community right beneath our feet!"
    - ""Let me introduce you to Dr. Ellen Turner, a renowned soil scientist. Dr. Ellen was curious about what was hidden beneath the soil's surface, just like we are today. She started her journey by simply digging into the ground in search of answers."
        - "What makes Dr. Ellen's story fascinating is that, during her research, she discovered a new species of soil bacteria. These remarkable bacteria have a unique talent - they can break down pollutants found in contaminated soils. Imagine the potential for cleaning up our environment!"

- Today, as we embark on our Soil Safari, we're following in the footsteps of scientists like Dr. Ellen Turner. We're going to explore the hidden world beneath our feet, just as she did, and discover the incredible life that thrives in the soil. Get ready for an adventure!" Exploration
    - Take the class outside to the designated area with accessible soil.
    - Provide a brief overview of safety guidelines for using small shovels or trowels, emphasizing responsible and safe digging practices.
    - Instruct students to work in pairs or small groups and distribute a small shovel or trowel to each group.
        - Encourage students to explore different areas within the designated space and collect soil samples from various spots. Remind them to be gentle while digging to avoid disturbing the soil too much.
        - Encourage students to use clipboards and paper for note-taking, jotting down their initial observations and questions.
    - Once students have collected their soil samples, distribute clear containers or plastic trays to each group.
    - Instruct students to carefully sift through their soil samples in the containers, looking for signs of life such as small organisms, roots, or other interesting features.
        - Provide hand lenses or magnifying glasses to enhance their observations. Encourage them to be patient and thorough.
    - As students make observations, guide them in identifying and discussing the different soil organisms they encounter.
        - Provide reference materials for further research if needed.
    - Gather the class back together and have each group share their initial observations and any questions they have.
- Gather the class back together and have each group share their initial observations.
    - Begin by recapping the exploration phase, reminding students of their hands-on soil investigation and the diverse life they observed.
        - Encourage students to share their findings and observations from the soil samples they collected. Ask questions like:
            - "What did you see in the soil?"
            - "Were there differences between soil samples from different areas?"
            - "Why might that be?"
        - Create an atmosphere where students feel comfortable sharing their observations and insights.
- Re-Introduce the concept that they are on a Soil Safari to discover who lives in the soil. Relate it to the idea of exploring new and exciting ecosystems, just like wildlife safaris in jungles or savannas.
    - Emphasize the importance of soil in supporting life on Earth, not

just for plants but for the entire ecosystem.

        - Discuss how soil provides a habitat for many organisms and serves as the foundation for food webs.
    - Encourage students to reflect on their observations and consider why certain organisms might be found in specific soil types or locations. Help them connect their observations to ecological principles:
        - "Why do you think some soil samples had more visible life than others?"
        - "What factors might influence the types of organisms living in a particular soil?"
        - "How does the presence of plant roots affect soil life?"
- Summarize the key discoveries and insights from the exploration and discussion.
    - Highlight any patterns or differences observed in soil samples from various locations and relate them to environmental factors such as moisture, vegetation, and human impact.
    - Challenge students to continue their Soil Safari beyond the classroom. Encourage them to explore soil in their own yards, local parks, or community gardens.
        - Suggest that they create a soil journal where they document their findings, observations, and questions. This can be an ongoing project.

Exploring the Hidden World of Soil Organisms (explore)

- Begin by revisiting the importance of soil in ecosystems and its role in supporting plant growth.
    - Show an image of a lush forest or a thriving garden and ask students to share what they notice about it.
        - Encourage them to mention the greenery, tall trees, colorful flowers, and diverse plant life.
        - Ask the class: "What do you think is the hidden secret behind this beautiful scenery? Why do these plants and trees flourish so abundantly?"
            - Allow students to share their thoughts and ideas. Some may mention factors like sunlight and water, but guide them towards recognizing the significance of soil.
        - Sunlight and water are essential, but the unsung hero here is the soil beneath our feet.
        - Soil is like the hidden engine that drives the growth of all these plants and trees. Let's explore why."
            - Soil provides a stable foundation for plants, anchoring their roots and preventing them from toppling over.
            - It acts as a reservoir for water and nutrients, storing them for plants to access when needed.
            - Soil is a habitat for a vast community of organisms, from microscopic bacteria to earthworms and insects, all of which contribute to its health and fertility.

        - It plays a crucial role in recycling nutrients, breaking down dead organic matter, and returning it to the ecosystem as nutrients for new growth.
        - Soil also filters and purifies water as it percolates through, making it safe for us to drink.
- Explain that today, students will be exploring soil samples collected by the educator, focusing on identifying and categorizing soil organisms.
    - Provide each student group with a mason jar containing a soil sample collected by the educator.
        - Ensure that the mason jars have mesh covers to prevent larger organisms from escaping.
        - Instruct students to carefully observe the soil sample in the jar.
        - Using their field notebooks, ask them to record the following information:
            - The location from which the soil sample was collected (e.g., schoolyard, nearby park).
                - Specify the exact location from which the soil sample was collected (e.g., schoolyard by the west entrance, nearby park near the playground).
                - Include any relevant details about the surroundings, such as nearby trees, bushes, or landmarks.
            - Estimate the percentage of plant cover in the area where the soil was collected.
                - Encourage students to provide a rough estimate of the ground covered by plants, such as grass, shrubs, or other vegetation. They can use descriptive terms like "sparse," "moderate," or "dense."
            - Note the number of different plant species they can identify in the immediate area.
                - Count and list the number of different plant species they can identify in the immediate area where the soil sample was taken.
                - Ask them to be as specific as possible, naming the plants if they know them or providing descriptions (e.g., tall green grass, small yellow wildflowers).
                    - If students are not physically present at the location where the soil sample was taken and are unable to see the immediate area, you can modify the instructions for this part of the activity as follows:
            - Modified for Remote Learning or Limited Access
                - Instruct students to imagine the location where the soil sample was collected based on any information or descriptions provided.
                - Encourage them to visualize the surroundings, including the types of plants and vegetation that might typically be found in that environment.
                - Ask students to list the different plant species they would expect to find in that area based on their

imagination and any prior knowledge they may have about similar environments.

- If they are unsure about specific plants, they can provide general descriptions or characteristics they would associate with typical plants in such a location (e.g., tall grass, small flowering bushes).

- Instruct students to gather their materials: plastic spoons, field notebooks, pens/pencils, and graph paper.
- Remind them to handle the soil sample and its inhabitants gently to avoid harming them.
- Have students open their field notebooks and create a graph to track the types of organisms they find.
  - Instruct them to draw a table with two columns:
  - Column 1: Label this column "Organism Types" and list the following categories: arthropods, arachnids, marigolds, insects, and isopods.
  - Column 2: Label this column "Number Found" to record the quantity of each type of organism.
- Distribute field guides or provide access to online reference materials that include images and brief descriptions of common soil organisms.
  - Britannica's Soil Organism Entry: This provides detailed information on various soil organisms ranging from microscopic cells to small mammals. It covers their role in maintaining soil fertility, structure, drainage, aeration, and the breakdown of plant and animal tissues. The entry also discusses the beneficial aspects of soil organisms and their classification into groups like protists, microfauna, mesofauna, macrofauna, and megafauna.
  - Explore Soils: This website offers practical guidance on collecting and observing soil organisms. It explains how to prepare for such activities and describes the necessary equipment. The site also provides insights into the diversity of soil mesofauna and their roles in the ecosystem.
  - FAO Soils Portal: This resource from the Food and Agriculture Organization of the United Nations focuses on soil biodiversity and organisms. It discusses the diversity of soil communities and the methods used to describe and study them, including DNA sequencing and morphological comparison.
  - SER Carleton's Background on Soil Biology: This site offers an in-depth look at the various groups of soil organisms, such as fungi, protists, larger fauna like nematodes, arthropods, and worms. It also discusses the critical role these organisms play in soil decomposition and nutrient cycling, particularly nitrogen and phosphorus.
  - Garden & Greenhouse: While this website primarily focuses on greenhouse maintenance, it provides useful insights into the broader ecosystem in which soil organisms play a part. It covers various aspects of soil health and the importance of maintaining a balanced soil ecosystem.

        - Explain to students that these materials will help them identify and document the organisms they find in their soil samples.
    - Instruct students to begin their investigation by using plastic spoons to carefully dig into their soil sample.
        - As they discover soil organisms, encourage them to record their observations in their field notebooks. For each organism, they should note:
            - The type of organism (e.g., beetle, earthworm).
            - Detailed characteristics (e.g., size, color, distinctive features).
            - Any interesting behaviors or movements they observe.
  - Emphasize the importance of comparing their observations with the images and descriptions in the reference materials to confirm identifications.
    - Encourage students to note any unique characteristics that match the reference materials to increase the accuracy of their identifications.
  - As students record the number of each type of organism found, they should update their graph in the field notebook.
  - For each category (arthropods, arachnids, marigolds, insects, isopods), they should place a tally mark or number in the "Number Found" column to represent the count of organisms observed.
- Ask each group to share their observations and findings.
  - Encourage them to discuss the types of organisms they identified and the number of each type found. This allows students to share their data and conclusions with their peers.
- Challenges Faced:
  - Encourage students to talk about any challenges they faced during the identification process.
    - This can include difficulties in using microscopes, making accurate identifications, or interpreting their data. Discussing challenges helps students learn from their experiences and develop problem-solving skills.
- Interesting Findings:
  - Invite students to share any interesting or unexpected findings they came across during the investigation. This can spark curiosity and lead to further exploration of specific topics or organisms.
- Emphasizing the importance of collaboration and sharing findings is crucial in the scientific community. Here's how you can emphasize this concept:
  - Discuss Scientific Collaboration: Explain to students that in the scientific community, researchers often collaborate with each other. They work together to share ideas, data, and findings, which accelerates the progress of science.
  - Sharing of Findings: Highlight the significance of sharing findings openly and transparently. Discuss how scientists publish their research in

scientific journals so that others can review, replicate, and build upon their work.
- Peer Review: Mention the peer review process, where other experts in the field critically assess and validate the research of their peers. This ensures the quality and reliability of scientific findings.

Exploring the Hidden World of Soil Organisms (explain)

- Begin with a discussion on soil as a living entity, vital for plant growth, water filtration, and as a habitat for billions of organisms.
    - Highlight soil's role in supporting plant life, which in turn supports animal life and maintains atmospheric balance.
    - Discuss soil's function in water filtration and as a reservoir for nutrients.
        - Soil as a Habitat:
            - Describe soil as a habitat for an incredible diversity of organisms.
            - Detail the different layers of soil and how each layer supports different types of life, from surface-dwelling insects to deeply burrowed earthworms.
            - Explain the role of microorganisms like bacteria and fungi in nutrient cycling and plant health.
    - Prompt students to think about the types of organisms they might find in soil.
        - Ask questions like:
            - "What types of insects do you think live in the soil?"
            - "Can you guess how microorganisms contribute to soil health?"
        - Discuss the concept of biodiversity and how different environments (like a forest floor versus a garden) might have different soil inhabitants.
- Introduce the concept of soil as a complex ecosystem, home to a diverse range of organisms from bacteria and fungi to insects and worms, each playing a crucial role in nutrient cycling and soil health.
    - Encourage students to hypothesize about the types of organisms that might be found in different soil samples.
    - Preparation and Safety Briefing:
        - Start by discussing the importance of safety and responsibility in environmental sampling.
        - Ensure students wear gloves to protect their hands and understand the importance of not disturbing wildlife or plants unnecessarily.
        - Explain the importance of collecting samples from different areas to study a variety of soil types.
            - Discuss factors that might affect soil composition, such as sunlight, moisture, vegetation, and human activity.
                - Assist students in identifying potential sampling sites, like under trees, near water bodies, open fields, and garden beds.
        - Demonstrate the correct use of spades or shovels.
            - Show how to gently insert the spade into the soil and carefully lift a small amount of soil.
            - Emphasize the need to avoid damaging roots or underground habitats.
    - Collecting Soil Samples:
        - Instruct students to use rulers or measuring tapes to collect a uniform depth of soil, typically the top 5-10 cm.

- Guide them to place the collected soil gently into their bags or containers.
    - Teach them to label each sample with information about the location and characteristics of the collection site (e.g., "Under oak tree near playground, moist, shaded").
- Discuss the importance of taking only what is needed for study to minimize the impact on the sampled environment.
    - Talk about leaving the site as undisturbed as possible, filling in any holes and replacing any moved rocks or vegetation.
- Handling and Transporting Samples:
    - Explain how to carefully handle the samples to avoid mixing different soils or contaminating them.
- Instruct students to securely close their containers and transport them back to the classroom or lab for analysis.

- After completing the soil collection process, we now transition to the next exciting phase of our scientific exploration: constructing and utilizing a Berlese Funnel. This innovative tool will allow us to delve deeper into the hidden world of soil organisms, offering a unique window into the diverse micro-ecosystems residing within the soil samples you've meticulously gathered.
    - Having experienced the hands-on process of collecting soil from various environments, you've set the stage for discovering the intricate life forms that call this soil their home. The Berlese Funnel, a simple yet ingenious device, will be our key instrument in uncovering these hidden organisms.
    - As we embark on this journey of construction and observation, keep in mind the importance of each step in understanding the complex interactions within soil ecosystems. The meticulous effort you've put into collecting these soil samples responsibly is about to bear fruit as we assemble our Berlese Funnels, a crucial step towards unveiling the micro-world thriving beneath our feet.
    - Let's gear up with our collected materials and step into the role of scientists, piecing together our Berlese Funnels with care and precision. This hands-on experience will not only enrich your understanding of soil biology but also enhance your skills in scientific investigation and experimentation.
    - Berlese Funnel Construction and Sample Analysis Instructions
        - Materials Needed:
            - Large funnel or a milk jug with the bottom cut off
                - Cheesecloth
                - Rubber band
                - Clear bottle or jar
                - Screen or mesh
                - Isopropanol
                - Soil samples
                - Light source (like a desk lamp)
                - Microscopes for analysis
                - Tweezers and small brushes for handling organisms
                - Science notebooks for recording observations
    - Berlese Funnel Construction:
        - Preparing the Funnel:

        - If using a milk jug, carefully cut off the bottom to create a large funnel.
    - Place a piece of screen or mesh inside the funnel to support the soil and prevent it from falling into the jar.
    - Pour approximately 2 cm of isopropanol into the clear bottle or jar. This will preserve any organisms that fall into it.
    - Stretch cheesecloth over the mouth of the jar and secure it with a rubber band.
        - This acts as a filter.
    - Place the funnel (or milk jug) securely on top of the jar, ensuring a tight fit to prevent escape of the organisms.
    - Instruct students to gently place their collected soil samples on the mesh inside the funnel.
    - Position a light source above the funnel.
        - The heat from the light encourages organisms to move away from the heat, down through the mesh, and into the jar.
    - Ensure the light is not too close to avoid overheating or drying out the sample too quickly.
    - Let the setup sit for 24-48 hours. This duration allows sufficient time for organisms to migrate into the jar.
- Removing the Funnel and Examining the Jar:
    - After the 24-48 hour observation period, carefully detach the funnel from the jar.
    - Instruct students to observe the jar and note any visible changes or movement in the isopropanol solution.
    - Transferring Organisms for Microscopic Observation:
        - Use tweezers and fine brushes to delicately transfer the collected organisms onto microscope slides.
        - Encourage students to handle each organism with care to avoid damage.
    - Microscopic Analysis:
        - Guide the students in using microscopes to observe the finer details of the organisms.
        - Assist them in adjusting the focus and magnification to get a clear view.
    - Recording Observations:
        - Ask students to record their findings in their science notebooks, including the type of organism (if identifiable), size, number, and any notable features.
    - Discussion Questions:
        - "What types of organisms did you find in your sample? Were there more of one type compared to others?"
        - "How does the diversity of organisms in your sample compare with what you expected to find?"
    - Habitat Reflection:
        - "Based on the organisms you found, what can you infer about the conditions and quality of the soil in your sample area?"

    - "How might these organisms contribute to the soil's health and nutrient cycle?"
- Comparison and Contrast:
    - "Did you notice any differences in the types of organisms found in samples from different locations? What factors might explain these differences?"
    - "How do the organisms in your sample contribute to the larger ecosystem?"
- Scientific Method Application:
    - "How did the process of using the Berlese funnel help you in identifying and understanding soil organisms?"
    - "What challenges did you face during this experiment, and how did you address them?"
- Environmental Impact Discussion:
    - "Why is it important to study soil organisms? What role do they play in environmental health and sustainability?"
    - "How can understanding soil biodiversity influence our approach to environmental conservation and agriculture?

Berlese Funnel Soil Organisms Data Collection Sheet

Investigation Details:

- Date:
- Location of Soil Sample:
- Type of Soil (Sand, Clay, Loam, etc.):

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1 Organism Collection:

1. **Sample 1:**

- Number of Organisms:
- Arachnids (e.g., spiders): ________
- Insects (e.g., beetles, ants): ________
- Other (specify): ________
-

1.

- **Sample 2:**
- Number of Organisms:
- Arachnids (e.g., spiders): ________
- Insects (e.g., beetles, ants): ________
- Other (specify): ________
-
-
- **Sample 3:**
- Number of Organisms:
- Arachnids (e.g., spiders): ________
- Insects (e.g., beetles, ants): ________
- Other (specify): ________
-
-

Organism Description:
Arachnids:

- **1. Species:**
- Description:
-
- **2. Species:**
- Description:
-
- **3. Species:**

- Description:

Insects:

- **1. Species:**
- Description:
-
- **2. Species:**
- Description:
-
- **3. Species:**
- Description:

Other Organisms:

- **1. Species:**
- Description:
-
- **2. Species:**
- Description:
-
- **3. Species:**
- Description:
-

Additional Notes:

- Any observed behaviors or interactions among organisms.
- Unusual or noteworthy findings.

Conditions during the investigation (temperature, humidity, etc.).

Exploring the Hidden World of Soil Organisms (elaborate)

- Begin by revisiting the various types of soil organisms previously identified. Emphasize their characteristics and roles in the soil ecosystem.
    - Create a sense of curiosity by asking, "Can anyone share something interesting or important they remember about the soil organisms we've discussed so far?
- Before dividing students into groups, consider their interests and strengths. Try to create diverse groups where students with varying abilities can collaborate effectively.
    - Assign Soil Organisms with Background Information:
        - Provide each group with a comprehensive packet of information about their assigned soil organism. This one pager should include scientific facts, historical significance, and real-world examples of its role in soil health.
            - Organism 1: Earthworm (Lumbricus terrestris)
                - Scientific Facts: Earthworms are fascinating creatures that vary in size but are typically 6-10 inches long. They inhabit soil and are recognized for their vital roles as soil aerators and decomposers. Earthworms reproduce through hermaphroditic reproduction, meaning they have both male and female reproductive organs.
                - Historical Significance: One of the most famous scientists, Charles Darwin, devoted significant time to studying earthworms. His groundbreaking work, "The Formation of Vegetable Mould through the Action of Worms," published in 1881, emphasized the importance of earthworms in enhancing soil health and structure.
                - Real-World Example: In agriculture, earthworms are employed to improve soil health. Their burrowing activities enhance soil aeration and drainage, making it easier for plant roots to access oxygen and nutrients. Furthermore, their digestion of organic matter contributes to nutrient cycling, enriching the soil with valuable nutrients required for plant growth.
            - Organism 2: Bacteria (Various species)
                - Scientific Facts: Bacteria are microscopic organisms that play critical roles in soil ecosystems. They come in diverse species, and their tiny size belies their enormous importance. Bacteria serve as decomposers and nitrogen fixers, contributing to nutrient cycling in the soil. They reproduce through binary fission, splitting into two identical cells.
                - Historical Significance: The discovery of bacteria dates back to the 17th century when the Dutch scientist Antonie van Leeuwenhoek first observed these tiny organisms under a microscope. His groundbreaking work paved the way for our understanding of the microbial world.
                - Real-World Example: Bacteria break down organic matter in the soil, transforming complex compounds into simpler ones that plants can absorb. Some bacteria, known as nitrogen-fixing bacteria, have the unique ability to convert

atmospheric nitrogen into a form that plants can use. This process, called nitrogen fixation, is crucial for plant growth and soil fertility.

- Organism 3: Fungi (Mycorrhizal fungi)
    - Scientific Facts: Mycorrhizal fungi are microscopic organisms with extensive mycelial networks. They form symbiotic relationships with plants, benefiting both parties. These fungi reproduce through spores, which can be transported through the air.
    - Historical Significance: Mycorrhizal fungi have been integral to ecosystems for millions of years. They represent one of the oldest and most mutually beneficial relationships between organisms on Earth.
    - Real-World Example: Mycorrhizal fungi form mutualistic partnerships with plants, where they assist in nutrient and water absorption. In exchange, plants provide fungi with sugars. This collaboration is especially vital in forest ecosystems, where mycorrhizal fungi facilitate the health and growth of trees by extending their root systems and enhancing nutrient uptake.
- Organism 4: Protozoa (Amoebae)
    - Scientific Facts: Protozoa are microscopic organisms found in soil, with amoebae being one of the most common types. They play roles as predators and decomposers in the soil ecosystem, contributing to nutrient cycling. Protozoa reproduce through binary fission, where one cell splits into two identical cells.
    - Historical Significance: Protozoa have been essential components of soil ecosystems for countless generations, influencing microbial populations and nutrient dynamics.
    - Real-World Example: Protozoa feed on bacteria and other microorganisms in the soil. By preying on these microorganisms, they help regulate their populations, which in turn affects nutrient cycling and the overall health of the soil ecosystem. Protozoa are an important part of the intricate web of life beneath our feet.
- Organism 5: Nematodes (Roundworms)
    - Scientific Facts: Nematodes, also known as roundworms, are microscopic soil organisms that vary in size. They serve multiple roles as both predators and decomposers in the soil ecosystem. Nematodes reproduce through sexual reproduction.
    - Historical Significance: Nematodes have been recognized since ancient times due to their ubiquity in various environments, including soil.
    - Real-World Example: Certain nematodes are beneficial parasites, particularly in agriculture. They prey on harmful insects and pests, effectively controlling their populations and contributing to sustainable farming practices. Their

    - role as natural pest controllers makes them valuable allies for farmers.
- Organism 6: Arthropods (Springtails)
    - Scientific Facts: Springtails are tiny arthropods, typically measuring only 1-2 millimeters in size. They function as decomposers in the soil, breaking down organic matter. Springtails reproduce through sexual reproduction.
    - Historical Significance: Springtails have existed for millions of years, playing crucial roles in nutrient cycling and soil health.
    - Real-World Example: These minuscule creatures are vital for the decomposition of plant material and organic matter in the soil. They contribute to nutrient release, aiding in the enrichment of the soil with essential elements required for plant growth. Their activities play a pivotal role in maintaining healthy ecosystems.
- Organism 7: Actinomycetes (Streptomyces)
    - Scientific Facts: Actinomycetes, specifically Streptomyces species, are filamentous soil bacteria. They serve as decomposers and are renowned for their ability to produce antibiotics. Actinomycetes reproduce through the formation of spores.
    - Historical Significance: Actinomycetes have garnered significant attention due to their antibiotic production, which has been pivotal in the development of antibiotics for medical use.
    - Real-World Example: Actinomycetes play a dual role in the soil ecosystem. They break down organic matter, contributing to nutrient cycling. Additionally, their antibiotic production can suppress harmful soil pathogens, thereby promoting soil health and plant growth.
- Organism 8: Mites (Oribatid mites)
    - Scientific Facts: Oribatid mites are tiny arachnids, typically measuring 1-2 millimeters in size. They function as decomposers in the soil ecosystem. Oribatid mites reproduce through sexual reproduction.
    - Historical Significance: These mites have been integral components of soil ecosystems for centuries, playing a significant role in organic matter decomposition.
    - Real-World Example: Oribatid mites contribute to the breakdown of plant material and organic matter in the soil. Their activities assist in nutrient cycling, making essential nutrients available to plants. They are essential for maintaining soil fertility and ecosystem health.

- For interactive learning resources in soil biology, here are some valuable websites and materials you can explore:
    - Soils 4 Kids: This site offers a variety of soil-related games, experiments, and career exploration resources. It's particularly suitable for different grade levels, from kindergarten to high

school. The resources include fun activities and information on various aspects of soil science (www.soils4kids.org).

- Soil Biology Primer by the Natural Resources Conservation Service: This resource provides an introduction to the living components of soil and their contribution to agricultural productivity, air and water quality. It includes guides and instructions on soil-related topics, along with educational materials (www.nrcs.usda.gov).
- Soils 4 Teachers: This website provides a teacher's guide, lesson plans, and activities focused on soil science. It includes resources for teaching about worms, building a worm bin, and various soil biological communities. The site also features a collection of soil biology movies and test questions for educational purposes (www.soils4teachers.org).
- SERC Carleton - Soil Biology: This module offers learning objectives, essential questions, big ideas, and additional teaching materials about soil biology. It includes PowerPoint presentations and printable materials for educators (serc.carleton.edu).
- Soil for Youth: This platform offers lesson plans and educational resources on soil science, such as understanding the ecosystem functions of soil and exploring different soil types across Canada (soil4youth.soilweb.ca).
- Sustainable Agriculture Research & Education Program: They provide resources and activities related to soil health, including soil respiration measurement and rainfall simulator activities. This resource is especially useful for understanding practical aspects of soil science (sarep.ucdavis.edu).
- Global Soil Biodiversity Initiative: This initiative provides educational resources like coloring and activity books for younger students and information on programs like GLOBE, which encourages hands-on environmental science education (www.globalsoilbiodiversity.org).

- Give each group a set of guided research questions to focus their exploration. For example:
    - Earthworm (Lumbricus terrestris)
        - Life Cycle: Utilize resources like diagrams and videos to visually illustrate the life cycle of earthworms. Encourage students to create a timeline showing key stages in an earthworm's life, from hatching to maturity.
        - Nutrient Cycling: Use articles and infographics to explain how earthworms consume organic matter and transform it into nutrient-rich castings. Discuss the concept of soil enrichment through their activities.
        - Symbiotic Relationships: Share case studies or examples of earthworms' interactions with plants and microorganisms. Encourage students to explore the benefits and complexities of these relationships.
    - Bacteria (Various species)

        - Life Cycle: Show microscopic images and animations to help students understand bacterial reproduction. Discuss bacterial growth and division using provided materials.
            - Nutrient Cycling: Present data on how different bacterial species participate in nutrient cycling. Highlight their roles in breaking down organic matter and releasing essential nutrients.
- Symbiotic Relationships: Use real-world examples of plant-bacteria partnerships (e.g., nitrogen-fixing bacteria). Ask students to examine the mutual benefits in such relationships.
- Fungi (Mycorrhizal fungi)
    - Life Cycle: Share visuals and diagrams depicting the life cycle of mycorrhizal fungi. Discuss how spores are produced and distributed in the environment.
    - Nutrient Cycling: Provide resources illustrating how mycorrhizal fungi assist plants in nutrient uptake. Explain the mechanisms behind this cooperation.
    - Symbiotic Relationships: Use case studies or videos to explore the fascinating partnership between mycorrhizal fungi and plants. Discuss the exchange of nutrients and sugars in detail.
- Protozoa (Amoebae)
    - Life Cycle: Show microscopic images or videos of amoebae, highlighting their unique life cycle. Explain how they adapt to various soil conditions.
    - Nutrient Cycling: Use data and graphs to illustrate protozoa's role in controlling microbial populations and its impact on nutrient cycling. Discuss the link between predation and nutrient release.
    - Symbiotic Relationships: Share examples of protozoa forming symbiotic relationships with other microorganisms. Ask students to analyze the advantages of such interactions.
- Nematodes (Roundworms)
    - Life Cycle: Display images or videos showing the life stages of nematodes. Discuss their reproductive strategies and adaptations to different environments.
    - Nutrient Cycling: Utilize diagrams and charts to illustrate how nematodes influence nutrient cycling by feeding on organic matter. Explore their role in nutrient transfer.
    - Symbiotic Relationships: Present research findings on nematodes' interactions with other soil organisms. Encourage students to examine the impact of parasitic or mutualistic relationships.
- Arthropods (Springtails)
    - Life Cycle: Use visual resources to depict the life cycle of springtails. Discuss their reproductive patterns and how they thrive in soil environments.

        - Nutrient Cycling: Show videos or simulations to demonstrate springtails' contribution to nutrient cycling through the decomposition of organic matter. Explain the importance of their role.
        - Symbiotic Relationships: Share examples of springtails' interactions with plants or other soil organisms. Encourage students to analyze the mutual benefits of these relationships.
    - Actinomycetes (Streptomyces)
        - Life Cycle: Provide diagrams and animations showcasing the life cycle of actinomycetes, including spore formation. Discuss their adaptability to different soil conditions.
        - Nutrient Cycling: Present data on actinomycetes' decomposition of organic matter and nutrient release. Discuss their role in enriching the soil.
        - Symbiotic Relationships: Share information on actinomycetes' interactions with plants and other microorganisms. Explore how these interactions impact soil health.
    - Mites (Oribatid mites)
        - Life Cycle: Show images or videos illustrating the life cycle of oribatid mites. Discuss their reproductive patterns and their role in soil ecosystems.
        - Nutrient Cycling: Use visuals to explain how oribatid mites contribute to nutrient cycling through organic matter decomposition. Discuss their importance in maintaining soil fertility.
        - Symbiotic Relationships: Share examples of oribatid mites' interactions with plants or other soil organisms. Ask students to analyze the significance of these interactions for soil health.
- Explain the collaborative drawing activity in more detail. Emphasize that students will work together in groups to create visual representations that tell a story about their assigned soil organisms' roles and interactions in the soil ecosystem.
    - Ask each group to brainstorm and outline a rough plan for their collaborative drawing, considering how they will visually represent their findings
    - Encourage students to think creatively and emphasize the storytelling aspect of their visual representations. They should consider how to effectively convey the roles and interactions of their soil organisms in the soil ecosystem.
- Provide each group with drawing materials and their assigned soil organism's information sheet.
    - Instruct students to collaboratively create a visual representation of their organism's role and interactions in the soil ecosystem. Encourage creativity and storytelling.

  - Introduce the concept of peer review to the students. Explain that they will have the opportunity to share their drawings with other groups and receive feedback.
  - Emphasize the importance of constructive feedback in helping improve their representations.
  - Provide students with peer review worksheets that outline criteria for evaluation. Review these criteria as a class to ensure understanding.
- Instruct each group to prepare a brief explanation of their drawing to present to another group during the peer review session. This should include key points about their assigned soil organism and its role in the soil ecosystem.
  - Here are discussion questions that you can use to encourage students to share challenges and insights they gained during the collaborative drawing process and to help them think about improvements for their presentations:
  - What were some challenges your group encountered while creating the collaborative drawing? How did you overcome these challenges?
  - Did you face any difficulties in accurately representing the roles and interactions of your assigned soil organism in the soil ecosystem? If so, how did you address these challenges?
  - What insights did you gain about your assigned soil organism's importance in soil health and the environment while working on the drawing?
  - Were there any creative elements or storytelling techniques that you found particularly effective in conveying your organism's role? Can you share an example?
  - How did your group collaborate during the drawing process? Did you divide tasks, and if so, did this division of labor work well for your group?
  - Did you encounter any interesting facts or information about your soil organism that surprised you or that you think would surprise your peers during the peer review?
  - What aspects of your drawing do you believe are strong and effectively convey your message? Why?
  - In what ways do you think you could improve your presentation of the drawing for the peer review? Are there any specific feedback points you received that you plan to address?
  - How will you ensure that your presentation not only informs your peers but also engages them and tells a compelling story about your assigned soil organism?
  - What lessons have you learned from this collaborative drawing experience that you can apply to future group projects or presentations?

Collaborative Drawing Peer Review Worksheet
Group Name:________________________
Drawing Title:______________________
Reviewer Name:_____________________

Criteria for Evaluation:
1. Accuracy (5 points):
Is the information presented about the soil organism accurate and based on research?

Are the key characteristics and roles of the organism clearly depicted?

Score (out of 5): ______

2. Creativity and Storytelling (5 points):
Does the drawing engage the viewer and tell a compelling story about the soil organism's role in the soil ecosystem?

Are creative elements used effectively to convey information?

Score (out of 5): ______

3. Clarity and Organization (5 points):
Is the drawing well-organized and easy to follow?

Are labels, captions, or other text used appropriately to explain the drawing?

Score (out of 5): ______

4. Visual Representation (5 points):
Are visual elements (colors, shapes, symbols) used effectively to represent the soil organism and its interactions in the soil ecosystem?

Do the visuals enhance understanding?

Score (out of 5): ______

5. Collaboration (5 points):
Did the group work effectively together to create the drawing?

Were responsibilities shared, and was there clear communication within the group?

Score (out of 5): ______

6. Overall Impact (5 points):
What is your overall impression of the drawing?

Does it effectively convey the significance of the soil organism in the soil ecosystem?

Score (out of 5): ______

Additional Comments:
[Provide space for written comments and suggestions.]

Investigations and Application
Exploring the Wonders of soil—Weathering

What is weathering: Educator Background Information
Weathering, a fundamental geological process, serves as the sculptor of Earth's landscapes, shaping and reshaping the very foundation upon which life thrives. It is an intricate dance between the elements and the Earth's surface, a symphony of forces that gradually break down rocks and minerals into finer particles. This essay delves into the multifaceted nature of weathering and its profound impact on the Earth's geology, ecosystems, and human activities.

Weathering Defined: Weathering is the process by which rocks and minerals are broken down into smaller particles through physical, chemical, or biological means. It is a continuous and dynamic interaction between the Earth's surface and various environmental agents, including water, wind, temperature changes, and living organisms. These agents work in concert to alter the composition and structure of rocks over time.

Physical Weathering:
Physical weathering, also known as mechanical weathering, involves the physical breakdown of rocks into smaller fragments without altering their chemical composition. This process is driven by external forces such as temperature fluctuations, frost action, and the mechanical action of water and wind. For example, the repeated freezing and thawing of water in the cracks of rocks can lead to the expansion and contraction of the rock, eventually causing it to fragment into smaller pieces.

Chemical Weathering:
Chemical weathering, on the other hand, transforms the chemical composition of rocks through processes like dissolution, oxidation, and hydrolysis. Water, often aided by dissolved gases and organic acids, plays a crucial role in chemical weathering. One of the classic examples is the dissolution of limestone by acidic rainwater, resulting in the creation of intricate cave systems and unique geological formations.

Biological Weathering:
Living organisms contribute to weathering through biological activities. Plant roots, for instance, can penetrate rocks, causing physical disruption, while certain microorganisms release acids that accelerate chemical weathering. The collective impact of flora and fauna on weathering processes underscores the interconnectedness of Earth's living and non-living components.

Impacts of Weathering:
The consequences of weathering extend far beyond the geological realm. One of its significant impacts is the creation of soil, the lifeblood of terrestrial ecosystems. As rocks weather, they release essential minerals and nutrients into the soil, providing a fertile medium for plant growth. The type and rate of weathering in an area influence soil composition, affecting the flora and fauna that can thrive there.
Furthermore, weathering plays a pivotal role in shaping landscapes. From the towering peaks of mountain ranges to the rolling hills and expansive plains, the cumulative effects of weathering over vast spans of time

give rise to diverse landforms. Weathering also influences the formation of sedimentary rocks, contributing to the preservation of Earth's geological history in rock layers.
Human Activities and Weathering:
In the Anthropocene era, human activities have become a significant force influencing weathering processes. Deforestation, urbanization, and industrial activities can accelerate erosion and alter natural weathering patterns. Soil degradation, loss of biodiversity, and changes in water quality are among the consequences of human-induced alterations to weathering dynamics.
Conclusion:
In essence, weathering is a transformative force that shapes the very fabric of our planet. From the grandeur of natural landscapes to the intricate processes supporting life, weathering is an omnipresent and dynamic process that deserves our attention and understanding. As educators, imparting knowledge about weathering fosters an appreciation for the Earth's dynamic processes and encourages responsible stewardship of our planet for generations to come

Real world connections/careers:
Several careers focus on studying the effects of weathering and related geological processes. Here are some examples: geologist, geomorphogist, soil scientist, archaeologist, climatologist,

Next Generation Science Standard

- MS-ESS3-2 Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scale

Students will be able to:
- Conduct a simulation of chemical and mechanical weathering

Student Vocabulary:

- Chemical weathering -as the chemical changes in minerals of the rock. Examples of chemicals causing weathering include carbon dioxide, oxygen, water and acids
- Erosion: the movement of broken down substances from their origin to be deposited somewhere else
- Mechanical weathering is the process of breaking a large rock into smaller pieces without changing the minerals. This can be attributed by frost, ice, plant roots, water sun
- Weathering: the actual breakdown of a substance exposed rocks (rocks that are not underground

Unveiling the Secrets of Weathering (engage)

- Today, we're embarking on a fascinating journey into the heart of Earth's ever-changing landscapes. We're about to dive into a topic that shapes the world around us – the mysterious process of weathering!
- Begin the lesson by providing each student with a small rock or pebble. Encourage them to examine the rock closely, noting its size, shape, and any visible features.
    - Ask students to make predictions about how they think their rocks might change over time due to weathering.
    - Divide the class into small groups, ideally with 4-5 students in each. Aim for a mix of abilities and learning styles in each group to foster collaborative learning.
    - Assign each group to one of the following online resources:
        - Group 1: Walter's Travels - Weathering and Erosion by National Geographic
            - Resource Link: Walter's Travels - Weathering and Erosion
            - Description: This interactive experience from National Geographic guides students through a virtual journey with Walter, a friendly animal character. The journey includes activities and information that simulate weathering and erosion processes. It's designed to be engaging and educational, focusing on various natural forces that cause weathering and erosion and the differences between mechanical and chemical weathering.
        - Group 2: Legends of Learning Weathering and Erosion Games
            - Resource Link: Legends of Learning
            - Description: Legends of Learning offers a series of interactive science games that cover the topic of weathering and erosion. These games are aligned with NGSS and state standards, aiming to enhance student engagement and understanding. The platform allows for a hands-on approach to learning, with concepts including the role of water, ice, wind, and gravity in erosion and weathering processes.
        - Group 3: Wartgames.com Erosion & Weathering Games
            - Resource Link: Wartgames.com Erosion & Weathering Games
            - Description: This collection of free games and activities from Wartgames.com focuses on the concepts of erosion and weathering. The website provides a variety of educational and interactive games designed to help students understand the gradual removal of Earth's crust material and the natural processes that contribute to erosion. It's an engaging way for students to learn about how erosion shapes Earth's landforms.
    - Allow students to explore their assigned resource. Each group should navigate through the simulations, games, and informational content provided in their resource.
        - Provide a structured note-taking template to guide students' exploration. The template should include sections like:
            - Key Terms: Definitions of weathering, erosion, and related concepts.

        - Types of Processes: Differentiate between mechanical, chemical, and biological weathering; types of erosion (water, wind, glacier, etc.).
        - Real-World Examples: Observations from the simulations about how these processes shape various landscapes.
        - Environmental Impact: Notes on how weathering and erosion affect ecosystems and human activities.
- Each group delves deeper into their notes and discussions. Encourage them to identify the most surprising, significant, or intriguing aspects of what they learned.
    - Ask them to consider how the processes of weathering and erosion might impact their own community or environment.'
    - Groups should collaboratively prepare a concise summary of their key learnings. This could be in the form of a short presentation, a digital slideshow, or a poster.
- Encourage creativity: they might create a diagram, a small model, or even a mini-drama to illustrate their points.
    - Each group selects a spokesperson to present their findings. Encourage them to choose someone who hasn't had a chance to speak up in previous activities to foster inclusive participation.
- Prompts for Deeper Analysis and Discussion and Real-world Application:
    - How do weathering and erosion processes impact your local environment? Can you identify any local landmarks or features shaped by these processes?
    - Discuss how human activities can accelerate or mitigate the effects of weathering and erosion.
    - Environmental Impact:
        - How do weathering and erosion contribute to ecological changes or challenges?
        - What role do these processes play in the carbon cycle and global climate change?
    - Historical Perspective:
        - Research a famous landscape shaped significantly by weathering and erosion (e.g., the Grand Canyon). How has it changed over time, and what historical events or legends are associated with it?
    - Future Implications:
        - Predict how continued weathering and erosion might reshape the Earth's surface in the next century. Consider both natural and human-induced factors.
        - Discuss the implications for future urban planning, agriculture, or conservation efforts.
    - Interdisciplinary Connections:
        - How do weathering and erosion relate to other scientific disciplines like biology, chemistry, or physics?
        - Explore the interplay between geological processes and biological ecosystems, such as how erosion can create new habitats.

- Creative Exploration:
    - If you could design a solution to protect a specific area from erosion, what innovative methods or materials would you use?
    - Create a hypothetical scenario where you must manage the effects of erosion in a coastal town or mountainous region.

Unveiling the Secrets of Weathering (explain)

- Begin by engaging students with a brief discussion about mountains.
    - Ask them what they know about the Rocky Mountains and the Ozark Mountains.
    - Encourage them to share any characteristics or features they associate with these mountain ranges.
        - Rocky Mountains:
            - Location: The Rocky Mountains are primarily located in western North America, spanning across the United States and Canada.
            - Elevation: They are known for their impressive elevation, with many peaks exceeding 14,000 feet (4,267 meters) in height.
            - Geological Age: The Rocky Mountains are relatively young in geological terms, formed around 50 to 80 million years ago.
            - Rock Types: Students can mention that the Rockies consist of various types of rocks, including granite, sedimentary rocks, and volcanic rocks.
            - Landforms: The Rockies are famous for their rugged terrain, deep valleys, and stunning mountain peaks.
            - Climate: The climate in the Rockies varies with elevation, with alpine climates at higher elevations and more temperate climates in lower areas.
            - Wildlife: The region is home to diverse wildlife, including elk, bighorn sheep, grizzly bears, and various bird species.
        - Ozark Mountains:
            - Location: The Ozark Mountains are primarily located in the central United States, spanning across states like Arkansas and Missouri.
            - Elevation: While they are not as high as the Rockies, the Ozarks still feature some elevated terrain, with peaks reaching around 2,000 feet (610 meters).
            - Geological Age: The Ozarks are much older than the Rockies, dating back around 300 to 500 million years.
            - Rock Types: Students can mention that the Ozarks are primarily composed of sedimentary rocks like limestone and sandstone.
            - Landforms: The Ozarks are characterized by rolling hills, deep forests, and numerous caves and springs.
            - Climate: The climate in the Ozarks tends to be more temperate, with four distinct seasons and abundant rainfall.
            - Wildlife: The region is rich in biodiversity, with a variety of plant and animal species, including deer, turkey, and unique cave-dwelling creatures

- Encourage students to think about these characteristics and how they might relate to the processes of weathering and erosion, which will be discussed in the lesson
- In today's activity, we will be working with examples that highlight mechanical and chemical weatherin
  - Physical (Mechanical) Weathering:
    - Definition: Physical weathering, also known as mechanical weathering, is the process by which rocks and minerals break down into smaller pieces or fragments due to mechanical forces without any change in their chemical composition. It involves the physical breakdown of rock materials into smaller particles through various natural processes.
    - Examples: Freeze-thaw cycles, where water enters cracks in rocks, freezes, and expands, causing the rock to crack; the action of plant roots growing into rocks, exerting pressure and breaking them apart; abrasion from wind, water, or the movement of rocks against each other.
  - Chemical Weathering:
    - Definition: Chemical weathering is the process by which rocks and minerals undergo chemical reactions with substances like water, acids, or other chemicals, leading to changes in their chemical composition and structure. Unlike physical weathering, chemical weathering involves the alteration of the rock's internal composition.
    - Examples: Acid rain causing the dissolution of limestone or marble statues; the reaction of carbon dioxide in the atmosphere with water to form carbonic acid, which can dissolve minerals in rocks; the oxidation f iron-bearing minerals in rocks, leading to the formation of rust.
      - These definitions highlight the fundamental differences between physical (mechanical) weathering, which involves the physical breakdown of rocks, and chemical weathering, which involves chemical reactions that change the composition of rocks. Both processes play essential roles in the breakdown and alteration of Earth's geological features over time.g
- Our first example is to create a simulation of chemical weathering
  - Chemical weathering is defined as the chemical changes in minerals of the rock.
    - Examples of chemicals causing weathering include carbon dioxide, oxygen, water and acids
  - As an Introduction to chemical weathering provide students the opportunity to view the Chemical Weathering – Hommocks – Earth Science Department video (4:04)
    - https://www.youtube.com/watch?v=6VnVRHIV6j4&t=176
    - Discuss the video clip with the following questions:

        - What is Chemical Weathering? - Ask students to define chemical weathering in their own words based on what they learned from the video.
        - Examples of Chemical Weathering: What examples of chemical weathering were mentioned in the video? How do these examples illustrate the process?
        - Factors Influencing Chemical Weathering: What factors were identified as influencing the rate of chemical weathering? How do these factors work?
        - Impact on Landscape: How does chemical weathering affect the landscape? Can students give examples of local or famous landscapes shaped by chemical weathering?
        - Comparison with Physical Weathering: How does chemical weathering differ from physical weathering? Are there any similarities?
        - Real-World Applications: How does chemical weathering impact human activities, such as agriculture or building construction?
        - Chemical Reactions Involved: What types of chemical reactions are involved in chemical weathering? Can students name any specific reactions or compounds?
        - Environmental Impact: How does chemical weathering interact with the environment? What role does it play in the ecosystem?
        - Rate of Weathering: Discuss factors that might speed up or slow down chemical weathering. How do these factors vary in different environments?
        - Classroom Connection: How can the concepts of chemical weathering be observed or demonstrated in a classroom setting?
- The climate of an area will have a direct impact on the amount of chemical weathering that takes place on rock
- To highlight the chemical weathering process, we will simulate the effect water temperature and water amount has on calcium bearing carbonate minerals (in Missouri this type of rock would be Limestone)
    - Begin student led simulation by providing students a brief overview of the procedures
        - Each group of students will receive beakers, cups, three different temperatures of water (hot, cold, room temp.), stop watch and antacids tablets.
            - The antacids tablets will represent a Limestone rock in the earth's landscape
        - Brainstorm with students if they believe water temperature will have an impact on the time needed for an antacid to dissolve
        - Teacher note: we should witness a doubling of the chemical reaction as we increase the temperature by 10 degrees C

- In student science notebooks, students could set up entry page documenting what they think will happen to the tablet when placed in hot water, cold water or room temperature water. This entry allows for thoughts to be compared later after observation of what occurred when the tablet is added to hot water
    - Describe what you think will happen when the tablet is added to hot water
        - Record the actual temperature of water
        - Estimated length of time until the tablet is dissolved in hot water
            - Actual length of time until the tablet is dissolved in hot water
        - Estimated length of time tablet stopped fizzing
            - Actual length of time tablet stopped fizzing
    - Describe what you think will happen when the tablet is added to cold water
        - Record the actual temperature of water
        - Estimated length of time until the tablet is dissolved in cold water
            - Actual length of time until the tablet is dissolved in cold water
        - Estimated length of time tablet stopped fizzing
            - Actual length of time tablet stopped fizzing
    - Describe what you think will happen when the tablet is added to room temperature water
        - Record the actual temperature of water
        - Estimated length of time until the tablet is dissolved in room temperature water
            - Actual length of time until the tablet is dissolved in room temperature water
        - Estimated length of time tablet stopped fizzing
            - Actual length of time tablet stopped fizzing
- Once student groups have procured materials for simulation and science notebook prompts written the simulation can begin
    - instruct students to pour 50ml of first type of water in a cup
    - Take temperature of water using thermometer and record in science notebook
    - Add one tablet to cup with 50 ml of first selected water temperature
    - Start stop watch once tablet enters the water
    - record observations in science notebook: noting time until tablet completely dissolved and time fizzing ceased. Allow students to note other observations
    - Repeat this process with the second and third water temperatures
    - Provide students with a place to discard tested water
        - Challenge students to think of ways they could increase the rate of dissolving and fizzing

        - Ideas could be: increase water, increase temperature or break up tablets into smaller pieces
- Transition to the simulation of mechanical/physical weathering
    - Introduce mechanical weathering by showing the Physical Weathering – Hommocks – Earth Science Department video to introduce mechanical weathering (begin at 1:50 mark)
        - https://www.youtube.com/watch?v=u_WN2ICRb2M
            - Definition and Examples: What is mechanical weathering? Can you provide some examples of mechanical weathering that were mentioned in the video?
            - Comparison with Chemical Weathering: How does mechanical weathering differ from chemical weathering? Why are both types important in the study of Earth science?
            - Processes of Mechanical Weathering: The video discusses various processes of mechanical weathering. Which process do you find most interesting and why?
            - Environmental Impact: How does mechanical weathering affect the landscape? Can you think of any local examples where mechanical weathering has had a noticeable impact?
            - Human Influence: In what ways can human activities accelerate or decelerate the process of mechanical weathering?
            - Role in Soil Formation: How does mechanical weathering contribute to soil formation? What might happen in an ecosystem with limited mechanical weathering?
            - Climate and Weathering: How does climate affect the rate and type of mechanical weathering? Can you give examples of mechanical weathering in different climatic regions?
            - Geological Time Scale: Mechanical weathering occurs over long periods. How does understanding this process help us interpret the Earth's geological history?
            - Rock Types and Weathering: Are some rock types more susceptible to mechanical weathering than others? Why might this be the case?
            - Personal Observations: Have you observed any signs of mechanical weathering in your surroundings? Describe what you saw and how you think it occurred.
    - Define Mechanical weathering as the process of breaking a large rock into smaller pieces without changing the minerals. This can be attributed by frost, ice, plant roots, water sun
    - Inform students we will conduct a simulation of mechanical weathering using sugar cube and a plastic bottle
        - Instruct students to begin preparing their student science notebook entry
        - Drawing of the 5 sugar cubes at 0 shakes

- Mass in grams of 5 sugar cubes at 0 shakes
- Drawing of the 5 sugar cubes at 25 shakes
- Mass in grams of 5 sugar cubes at 25 shakes
- Drawing of the 5 sugar cubes at 50 shakes
- Mass in grams of 5 sugar cubes at 50 shakes
- Drawing of the 5 sugar cubes at 75 shakes
- Mass in grams of 5 sugar cubes at 75 shakes
- Drawing of the 5 sugar cubes at 100 shakes
- Mass in grams of 5 sugar cubes at 100 shakes

- Begin student led simulation by providing students a brief overview of the procedures
  1. Each group of students will receive a scale, 5 sugar cubes and a plastic bottle
  2. Students are to measure the mass (g) of the five sugar cubes together and record this information in their student science notebook
  3. Students are to draw observed characteristics of the five sugar cubes
  4. Place the 5 sugar cubes in the plastic bottle and shake the bottle 25 times
  5. Remove the sugar cubes and measure the mass (g) of the five sugar cubes together and record this information in their student science notebook
  6. Students are to draw the five sugar cubes after 25 shakes
  7. Repeat this process stopping at 50 shakes, 75 shakes and 100 shakes to record mass and visual descriptions
  8. Once data has been secured for shakes at 25, 50, 75 and 100, have students create a line graph depicting the results.
- Discuss with students that this simulation is an example of mechanical weathering through abrasion.
  - The cubes would collide with each and the resulting reaction is sugar particles were removed from the cube.
  - Rocks too hit against each other and become smooth as its particles fall off
  - Ask students where on earth would they be able to see this reaction?
    - On a local river we could find smooth rocks
      - rocks could have fallen off of a cliff or mountain and as it falls the edges could be broken off.
    - Eventually, the rock could get swept up into a river, where it can hit other rocks to break off additional pieces.
      - Water too can break off rock particles.
    - As the rock remains in the stream for hundreds of years, slowly the rocks become smooth
- Engage the entire class in a reflective discussion about the broader implications of weathering.

- What is weathering, and how does it differ from erosion? Can you give examples of each?
- How does weathering impact our everyday lives? Think about buildings, landscapes, and the environment.
- What are the primary types of weathering, and how do they work? (Hint: mechanical weathering vs. chemical weathering)
- Discuss the role of climate in weathering processes. How does weathering vary in different climates and regions?
- How does human activity, such as construction and pollution, affect weathering processes?
- What are the time scales involved in weathering? How long does it take for significant changes to occur in rocks and landscapes?
- Consider the Grand Canyon as an example. How has weathering shaped the Grand Canyon, and what can it tell us about Earth's history?
- How can an understanding of weathering help in engineering and construction projects?
- What are the environmental implications of weathering, especially in relation to soil erosion and sedimentation in bodies of water?
- Think about the concept of sustainability. How can we use our knowledge of weathering to make more sustainable choices in our lives?
- Explore the connection between weathering and the carbon cycle. How does weathering play a role in removing carbon dioxide from the atmosphere?
- Reflect on the long-term consequences of weathering on geological features. How does it contribute to the formation of mountains, valleys, and coastlines?
- How might future climate change impact weathering processes and the Earth's surface?
- Consider weathering as a natural form of recycling. How does it relate to the concept of resource conservation and preservation?
- In what ways can we educate and raise awareness about the importance of understanding weathering and its implications for our planet?

- Weathering is the gradual process by which rocks and minerals break down over time due to various natural factors. It plays a crucial role in several geological and environmental processes:
    - Formation of Soil: Weathering breaks rocks into smaller particles, leading to the creation of soil. Over time, this soil becomes a fertile medium for plant growth and agriculture.
    - Creation of Landforms: Weathering shapes the Earth's surface by wearing down and sculpting rocks. It contributes to the formation of valleys, canyons, caves, and other geological features.

  - Recycling of Earth's Materials: Weathering recycles the Earth's materials by breaking down rocks and minerals into sediments. These sediments are transported by erosion and eventually become part of new rocks or sedimentary layers.
- Real-World Scenarios:
  - Ecosystems: Weathering provides essential nutrients for plants through the formation of soil, which supports terrestrial ecosystems. It also influences the availability of minerals and nutrients in aquatic ecosystems.
  - Agriculture: Farmers rely on weathering-derived soils for crop cultivation. Understanding the weathering process helps optimize agricultural practices, such as soil management and nutrient replenishment.
  - Human Structures: Weathering affects the durability of human structures, including buildings, roads, and bridges. Engineers must consider weathering when designing infrastructure to ensure long-term stability.
- Importance in Environmental Science and Land Management:
  - Environmental Science: Understanding weathering is fundamental to comprehending ecosystem dynamics, nutrient cycling, and the impact of geological processes on biodiversity. It also plays a role in understanding climate change, as weathering can sequester carbon dioxide from the atmosphere.
- Responsible Land Management: Proper land management requires knowledge of weathering processes to prevent soil erosion, mitigate landslides, and protect against the degradation of valuable natural resources. It informs sustainable land-use practices, including reforestation and soil conservation.

Investigations and Applications
Exploring the Wonders of Soil– Erosion

Erosion Educator Background Information

Erosion is a natural process that shapes the Earth's surface by wearing away soil, rock, or other materials through the action of wind, water, or ice. It plays a crucial role in the formation of landscapes and the sculpting of geological features over long periods of time. This process is part of the broader geological cycle that includes weathering, transportation, and deposition.
Types of Erosion:
Water Erosion:

- Sheet Erosion: Occurs when a thin layer of soil is gradually removed from a large area, often due to rainfall.
- Rill Erosion: Involves the development of small channels or grooves on the surface of the soil as a result of concentrated water flow.
- Gully Erosion: Represents the enlargement of rills into larger, deeper channels, typically caused by the increased volume and velocity of water.

Wind Erosion:

- Deflation: The lifting and removal of loose, fine-grained particles, such as sand and silt, from the Earth's surface by the wind.
- Abrasion: Involves the impact of wind-driven particles against surfaces, resulting in the wearing away of rocks and other materials.

Glacial Erosion:

- Plucking: Occurs when glaciers pick up and transport large pieces of rock as they move over the landscape.
- Abrasion: Similar to wind erosion, glaciers can grind away at the underlying bedrock, shaping valleys and other landforms.

Causes of Erosion:
Natural Factors:

- Climate: Regions with heavy rainfall or strong winds are more susceptible to erosion.
- Topography: Steep slopes are prone to erosion, as gravity facilitates the movement of water and sediments downhill.
- Geological Factors: The type of rock and soil in an area can influence its susceptibility to erosion.

Human Activities:

- Deforestation: Removing trees reduces the stabilizing effect of roots and increases runoff, leading to soil erosion.
- Overgrazing: Excessive grazing by livestock can strip vegetation cover, leaving soil exposed to erosion.
- Urbanization: Construction activities and the replacement of natural landscapes with impervious surfaces contribute to increased runoff and erosion.
- Effects of Erosion:
- Loss of Soil Fertility: Erosion can deplete the topsoil of essential nutrients, affecting agricultural productivity.

Landform Changes: Erosion plays a key role in shaping landscapes, contributing to the formation of valleys, canyons, and river deltas.

- Sedimentation: Eroded material is often transported by water and deposited in rivers, lakes, or coastal areas, impacting aquatic ecosystems.
- Infrastructure Damage: Erosion can undermine structures and lead to landslides, posing risks to human settlements.

Preventing and Controlling Erosion:

- Vegetative Cover: Planting vegetation helps stabilize soil, reducing the risk of erosion.
- Terracing: Creating stepped or graded landscapes can slow the flow of water and minimize soil displacement.
- Contour Plowing: Plowing along the contour lines of the land helps retain water and prevent erosion.
- Sediment Control Structures: Installing barriers or structures to trap sediment in runoff can mitigate the impacts of erosion.

In conclusion, erosion is a natural geological process driven by various factors, both natural and human-induced. Understanding its mechanisms and implementing effective erosion control measures are crucial for preserving soil fertility, protecting ecosystems, and mitigating the potential adverse effects on human activities and infrastructure.

Real world connections/careers:

A deep understanding of erosion can open up various career paths, particularly in fields related to Earth sciences, environmental science, engineering, and land management. Here's an overview of careers where knowledge of erosion is crucial: geologistm , geomorphologist, civil engineer,bnatural resource manager,

Next Generation Science Standards

- MS-ESS2-2 Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales
- MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem
- MS-ESS2-2 Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales

Students will be able to:

- Students will gain a comprehensive understanding of erosion as a dynamic geological process, connecting theoretical concepts to real-world observations and scenarios

Student Vocabulary:

- Splash Erosion: Results from the bombardment of the soil surface by raindrops
- Wind Erosion: is a natural process that moves soil from one location to another by wind power
- Erosion describes the movement of broken down substances from their origin to be deposited somewhere else.
- Glacier Erosion: includes the loosening of rock, sediment, or soil by glacial processes, and the entrainment and subsequent transportation of this material by ice or meltwater

- River Erosion: the river erodes away the bed and banks of its channel vertically and laterally.

Exploring Erosion (engage)
- Start with a discussion about the landscapes around us.
    - Ask questions like:
        - "Have you ever wondered how mountains, valleys, or rivers are formed?"
        - "What do you think happens to rocks and soil over time?"
            - Show images or short videos depicting various erosion processes (e.g., water cutting through rocks, wind shaping sand dunes, landslide events).
                - "Have you ever noticed changes in the soil after heavy rain?"
                - "Why do some areas have more plants than others?"
    - Begin by showing images or short videos depicting erosion processes, such as water cutting through rocks, wind shaping sand dunes, or landslides.
        - Khan Academy's Video on Weathering and Erosion: This video discusses how water shapes the world through weathering and erosion. It's a comprehensive resource that explains the process in a way that's accessible to a younger audience.
        - National Geographic's "Wind and Water, Meet Rock": This video provides a tour of the world's longest sea cave, carved out by the power of water. It showcases the battle between water and rock and how water shapes the earth's surface over time, creating incredible cave formations through erosion.
        - Generation Genius' Weathering & Erosion Video for Kids: This resource is specifically designed for 3rd to 5th graders. It explains how weathering breaks down the Earth’s surface into smaller pieces, which are then moved in a process called erosion. The video also covers how water, wind, ice, plants, gravity, and temperature changes contribute to these processes.
        - National Geographic's Educational Page on Erosion: This page explains various forms of erosion, including ice erosion by glaciers creating dramatic landforms, and mass wasting processes like landslides and avalanches. It also touches on factors impacting erosion such as climate, topography, vegetation, and tectonic activity.
            - Ask students what they observe and how these processes might affect the environment.
                - What do you see happening in the images or videos of erosion processes?
                    - Encourage students to describe the physical changes they observe, such as the movement of soil, rocks, or water.
                - How do you think water cutting through rocks might affect the landscape over time?
                    - This question encourages students to think about

        - the long-term consequences of erosion on geological features.
    - What impact might wind shaping sand dunes have on the desert ecosystem?
        - This question prompts students to consider the ecological implications of erosion in specific environments.
    - Can you identify any signs of landslides in the images or videos? How might landslides affect the environment?
        - This question focuses on a specific type of erosion and its potential consequences.
    - What happens to the soil when it is carried away by water during erosion? How might this affect plant growth in the area?
        - Encourage students to think about the relationship between erosion, soil loss, and vegetation.
    - How might erosion processes impact human activities and structures in areas prone to erosion?
        - This question prompts students to consider the human aspect of erosion, including its impact on infrastructure and land use.
    - What do you notice about the speed of erosion processes in the videos? Are some processes faster than others?
        - This question encourages students to compare different erosion processes and their rates.
    - Do you think erosion is always a destructive force, or can it have positive effects on the environment too?
        - Encourage students to think critically about whether erosion always has negative consequences.
    - Can you think of any ways that erosion processes might be harnessed or managed to benefit the environment or human activities?
        - This question invites students to explore potential solutions and strategies related to erosion control.
    - How might changes in climate and weather patterns influence erosion processes in different regions?
        - Encourage students to consider the role of climate change in altering erosion patterns.
- Discuss different creative writing techniques, such as personification, vivid descriptions, and emotional expressions. Emphasize the importance of creating a personal connection between the natural element and the reader.
    - In literature, perspective refers to the viewpoint from which a story is told. It's like stepping into the shoes of a character or an object and seeing the world through their eyes. By adopting a unique perspective, we can gain new insights and empathy for the subject matter. Today, we'll be taking on the roles of natural elements involved in erosion, such as rocks, raindrops, or gusts

of wind. This will allow us to connect with erosion on a personal level and tell its story from an entirely different viewpoint. It's like giving a voice to the often overlooked actors in the natural world.

- Provide an overview of erosion processes. Explain that students will need to conduct research on how erosion works, including the causes and effects.
    - Now, let's explore what erosion is and how it works. Erosion is a natural process that shapes and changes the Earth's surface over time. It's like nature's sculptor, slowly but persistently carving and molding the land. There are several key processes involved in erosion that we should understand
        - Weathering: Erosion starts with weathering, which is the breakdown of rocks into smaller particles. Weathering can occur due to physical factors like temperature changes and pressure, as well as chemical factors like exposure to water and acids.
        - Transportation: Once rocks and soil are weathered, they are transported or moved from one place to another. This movement can happen through various agents like water (rivers, streams), wind, ice, or even gravity in the case of landslides.
        - Deposition: As eroded material is transported, it eventually settles or gets deposited in new locations. This deposition can lead to the formation of sedimentary layers over time.
        - Impact on Landscapes: Erosion plays a significant role in shaping landscapes. It can create valleys, canyons, and river deltas, while also wearing down mountain ranges over millions of years.
        - Environmental Impact: Erosion can have both positive and negative effects on the environment. It helps distribute fertile soil, which is beneficial for plant growth, but excessive erosion can lead to problems like soil loss, sedimentation in rivers, and habitat changes.
        - Human Influence: Human activities such as deforestation, construction, and agriculture can accelerate erosion processes. Understanding erosion is crucial for sustainable land management.
- In our creative writing activity, we will step into the shoes of rocks, raindrops, or gusts of wind and tell the story of erosion from their unique perspectives.
    - You won't need to research these processes on your own; I've provided you with an overview. Now, it's your turn to use this knowledge to create engaging and insightful stories or poems that capture the essence of erosion.
        - For added creativity, allow students to create illustrations or drawings that complement their stories or poems. This step is optional but can enhance the visual aspect of their

work.

- Have each student share their erosion story or poem with the class. Encourage them to use expressive language and vivid descriptions.
    - Haiku example inspired by erosion:

      Raindrop on the rock,
      Carving lines through ancient stone,
      Time's patient sculptor.

      Wind whispers secrets,
      Sand dunes shift,
      memories fade,
      Nature's art in motion.

- After each presentation, open the floor for questions and comments.
- Conclude the lesson by discussing how seeing erosion from a unique perspective through creative writing can deepen their understanding of this natural process. Ask students to reflect on what they learned and how it changed their perspective on erosion.

Exploring Erosion (explore)

- Set up exploration stations with rock and soil samples, topographic maps, and erosion experiment materials.
    - For the Exploration Stations focusing on different types of erosion, you'll need the following materials:
        - Wind Erosion Station:
            - Sand
            - Fan
            - Small rocks
            - Barrier objects (to demonstrate windbreaks)
        - Glacier Erosion Station:
            - Clay
            - Ice cubes
            - Sandpaper (to simulate glacial movement)
        - Splash Erosion Station:
            - Soil samples
            - Water spray bottles
            - Tray to catch runoff
        - River Erosion Station:
            - Long, shallow tray (for river model)
            - Sand and small pebbles
            - Water
            - Pitcher or jug for pouring water
        - Common materials for all stations:
            - Topographic maps
            - Notebooks and pencils for observations

        - Magnifying glasses
- Provide students prior to grouping a brief overview of each example
    - Wind erosion—Wind has the ability to move small fine particles of sand and dust across a landscape. When the wind blows the smaller particles, the sand and dust are blown and will make contact with an obstacle. In making contact, a sand dune will begin to form. Generally speaking, wind erosion tends to occur in low rainfall areas. An extreme example is the Dust Bowl of the 1930's
    - Glacier Erosion Glaciers are formed when there is more snow piling up each year than melts away. The snow begins to compress and becomes denser. Many thousands of years ago, ice would have covered northern Missouri. They assist in erosion by picking up materials (plucking) via freezing and as the glacier moves with the materials the ice sheet will act as sandpaper with rocks and sediment rubbing and grinding. Once the glacier recedes, the sediment that is left behind, the glacial till. Although we may not see glaciers, they have had a tremendous impa ple ct on our life as we know it. This glacial till provided humans with geologically speaking new soil that we use today in our farming practices.
    - Splash erosion is one of the first steps in the erosion process. Splash erosion begins when rainfall makes contact with bare soil. This impact will cause soil particles to rise and fall to a new location. Once at this new location, the particles will begin to form a crust like layer that increases water runoff
    - River erosion or runoff erosion is caused by gravity moving water from higher elevations to lower ground. As this occurs, the material that is eroded is carried into larger bodies of water. Erosion by rivers or streams depends of the velocity of the water. Faster water will remove and move more material than slower water
        - Arrange exploration stations with labeled trays containing soil samples, rocks, topographic maps, and materials for the erosion experiment.
            - Ensure that each station has clear instructions and safety guidelines.
        - Divide the class into small groups and assign each group to a specific exploration station. Encourage students to actively explore the materials at each station, making observations and asking questions. Rotate groups through the stations to ensure everyone has an opportunity to investigate each aspect of erosion.
        - Allow students to touch and observe different types of rocks and soils. Have them analyze topographic maps to identify areas susceptible to erosion.
    - The following activities will demonstrate to students various types of erosion and how they form different landforms
        - In small student group settings, rotate among each of the various demonstrations highlighting different types of erosion
            - Each demonstration includes an activity of that particular example and a student reading.
            - Estimated time at each example 25 minutes

- Demonstration activity station 1: Windblown deposits creating sand dunes:
  - Activity station will need the following materials: newspaper, dry colored sand (two colors, one uncolored), plant tray cardboard box, hand held fan
  - Provide enough materials for all groups rotating to the station the ability to demonstrate the erosion
  - It would be helpful to display procedures at table for students to follow with minimal educator direction
  - Explain the following steps, and encourage students to follow visual instructions at the station with minimal educator direction:
    - Place the plant tray cardboard in the center of an unfolded newspaper page.
    - Ensure the box has one short side laying flat and the opposite short side clipped together.
    - Pour uncolored sand in a corner of the box with the lid up.
    - Remove one bag of colored sand and pour its contents in the center of the tray.
    - Remove the second bag of colored sand (smaller particles) and pour its contents around the first colored sand.
    - Place the handheld fan near the sand to slowly blow the sand.
    - Increase the strength of the fan until sand is being blown out of the lid.
    - Once sand is being blown out of the box, continue blowing for 5 seconds at this rate of fan strength.
    - Encourage students to change the direction of the sand to observe if wind direction causes differences.
      - Students can change direction of the sand to observe if wind direction causes a differences
  - Observations and Discussion
    - In their science notebooks, students should note observations detailing how sand dunes are formed during the demonstration.
    - Ask students to consider if they could make the whole pile move if they blew long enough.
      - Examine the materials that were blown out of the box and onto the paper.
      - Discuss if the material out of the box is finer than the material inside the box.
  - Connecting to the Dust Bowl. Encourage students to find video clips and discuss the Dust Bowl's causes, consequences, and impact on farmland.
    - Ask questions like, "How might this affect the availability of farmland?" and "How familiar are students with an event called the Dust Bowl?"

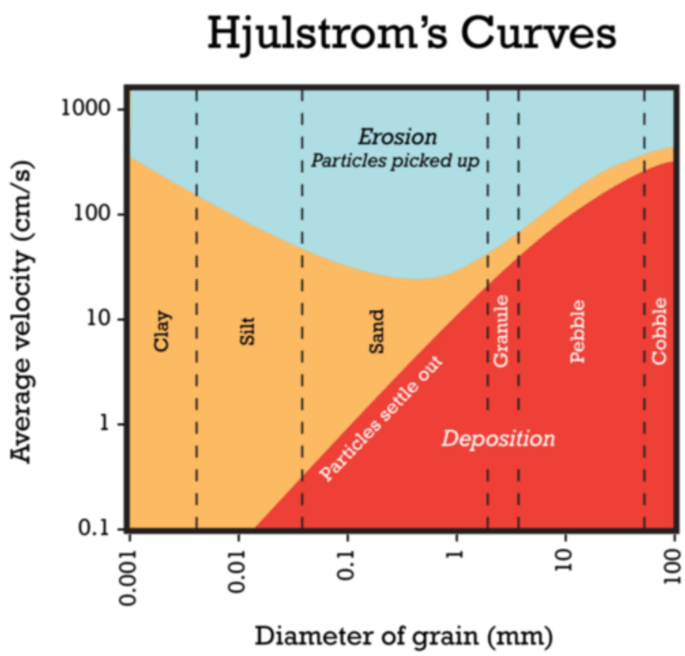
        - Further enhance student exploration on the term "Breadbasket" regions around the world and encourage students to research other regions known for agriculture.
        - Discuss how similar or different the procedures for this activity might be applicable to those regions.
- Demonstration activity station: Glaciers and Erosion
- Activity station will need the following materials: aluminum tray, ice cube, sand (about 1 spoonful), modeling clay, paper towel, pencil, and paper
    - Provide each group with the necessary materials and visual instructions at the station.
    - Explain the following steps and encourage students to follow them with minimal educator direction:
        - Place a two-inch in diameter ball of clay in the center of the aluminum tray.
        - Flatten the ball of clay with the palm of the hand.
        - Press the ice cube lightly on the flat surface of the modeling clay.
        - Allow students to move the ice cube back and forth several times.
        - In their science notebooks, have students note observations of what happened to the clay during this process.
        - Place a small pile of sand on the surface of the clay.
        - Place the ice cube over the sand on the clay.
        - Let it sit for about one minute.
        - Pick up the ice cube and look at the surface that had been on the sand.
        - In their science notebooks, describe what they see.
        - Place the ice cube back in the same position on the clay and move the ice back and forth on the sandy surface of the clay a few times.
        - Remove the ice cube and gently wipe the excess sand off the surface of the clay.
    - Notebook observation prompts that you can provide to students to help guide their observations and class discussion about the erosive effects of ice and sand:
        - Initial Clay Surface (Ice Only):
            - Describe the initial appearance of the clay surface before placing sand on it.
            - Did you notice any changes in the clay when you pressed the ice cube onto it? If so, what changes did you observe?
        - Adding Sand to Clay:
            - Describe the appearance of the clay after adding a small pile of sand.
            - Did the sand sit on the clay's surface or become embedded in it? Explain what you observed.

- Effects of Ice on Sand-Covered Clay:
  - After placing the ice cube over the sand-covered clay, what happened to the sand?
  - Did you notice any changes in the clay's surface after the ice cube was removed? If so, describe those changes.
- Rubbing Sand with Ice:
  - Describe the surface of the clay after moving the ice cube back and forth on the sandy surface.
  - Did you notice any differences in the clay's appearance compared to when the ice cube was simply pressed on it?
- Comparison to Glacier Erosion:
  - Based on your observations, how does the combination of ice and sand affect the clay's surface compared to when only ice is used?
  - What similarities or differences can you identify between this process and the way glaciers erode land?

- Introduce the National Landslide Hazards Program as a real-world example of monitoring and mitigating geological hazards.
  - Provide students with computers or mobile devices and guide them to navigate the National Landslide Hazards Program website.
  - Have students explore the website to learn about United States Geological Survey (USGS) current monitoring protocols and mitigation strategies related to landslides and erosion.
    - Encourage students to take notes on key information they find on the website.

Demonstration activity station: Water erosion Splash and river Activity

- With river and water erosion, erosion can take place in a variety of ways.
  - Hydraulic is when water collides with the river banks. Air is trapped in the cracks of the river bank and causes rock to break apart
  - Abrasion occurs when pebbles grind along the river bank (think the process of sanding wood using sand paper)
  - Solution is the process of water dissolving certain types of rocks, most commonly in our area—limestone
  - Speed of water, past water erodes more material than slower water. As the water slows all the materials the water has picked up is deposited in the slower water\
    - Hjulstroms Curves graphs this below. Image taken from https://flexbooks.ck12.org/cbook/ck-12-middle-school-earth-science-flexbook-2.0/section/14.1/primary/lesson/erosion-by-streams-ms-es



- Provide each group with the necessary materials:
  - 8x8 aluminum pan filled with clean fill dirt
  - Water pitcher
  - Cup of water
  - Pipette (or small funnel for pouring water)
  - Science notebooks
  - Visual instructions at the station
- Explain the following steps and encourage students to follow them with minimal educator direction:
  - Test 1 - Low Water Height:
    - From a low distance (less than a meter), pour a pipette of water over the pan and into the clean fill.
    - Observe and record the time it takes for noticeable changes to occur in the earth's surface.
      - In their science notebooks, have students record observations regarding changes in the "earth" during the first test.
  - Test 2 - High Water Height:
    - Repeat the process on the same location but hold the pipette of water at the highest possible distance (greater than one meter).
    - Again, observe and record the time it takes for noticeable changes to occur.
      - In their science notebooks, have students record observations regarding changes in the "earth" during the second test.
  - Test 3 - Intermediate Water Height:

        - After conducting the low water height test (step 3 of "Test 1"), introduce an intermediate water height.
        - Pour water from a moderate distance (e.g., about half a meter) onto the same spot of clean fill dirt.
        - Observe and record the time it takes for noticeable changes to occur in the earth's surface.
            - In their science notebooks, have students record observations regarding changes in the "earth" during this intermediate test.
            - Compare the results with the low and high water height tests, discussing any differences in erosion patterns and timeframes.
    - Test 4 - Variable Water Flow Rate:
        - Maintain the low and high water height tests as described in "Test 1" and "Test 2."
            - In addition to the high water height test (step 1 of "Test 2"), introduce variations in water flow rate.
            - For example, pour water slowly and steadily for one test and quickly in a sudden rush for another test.
        - Observe and record the differences in erosion patterns and timeframes between the different flow rates.
        - Discuss the impact of water flow rate on erosion and how it may relate to real-world scenarios
- Science Notebook Observation Prompts:
    - Initial Pan Surface (Low Water Height):
    - Describe the appearance of the clean fill dirt on the aluminum pan before adding water.
    - Record any changes you observe when you pour water from a low height onto the dirt.
        - Include details about how the dirt reacts to the water.
    - Initial Pan Surface (High Water Height):
        - Describe the appearance of the clean fill dirt on the aluminum pan before adding water.
        - Record any changes you observe when you pour water from a high height onto the dirt.
        - Include details about how the dirt reacts to the water.
    - Comparing Low and High Water Heights:
        - Compare the effects of pouring water from a low height to pouring it from a high height.
        - Note any differences in the way the earth's surface changes.
        - Consider the force of the water and how it impacts the dirt.
    - Relating to Natural Rainfall:
        - Based on your observations, how do the changes caused by pouring water relate to the effects of rainfall in various places around Earth?
        - Discuss similarities and differences in the erosive processes.
    - Mitigation Strategies for Splash Erosion:

    - Brainstorm possible strategies to slow down or prevent splash erosion based on your observations.
    - Consider materials or methods that could protect the earth's surface.
- Demonstration activity station
  - In this hands-on activity, students will explore how different soil conditions and the presence of vegetation affect wind erosion.
  - Provide each group with the following materials:
    - Tray filled with clay and grass (representing soil with vegetation)
    - Tray filled with gravel, silt, and sand (or topsoil without grass) (representing bare soil)
    - Hand-held fan
    - Science notebooks
    - Visual instructions at the station
  - Instruct each group to gather around their assigned trays and place the trays on a flat, stable surface.
  - Begin by explaining the significance of the trays. Emphasize that they represent varying soil conditions found in nature.
  - Tray 1 contains clay and grass, representing soil with vegetation (natural ground cover).
  - Tray 2 contains gravel, silt, and sand (or topsoil without grass), representing bare soil without vegetation.
  - Ensure that students understand the purpose of the activity: to observe how wind (simulated by a hand-held fan) affects these different soil conditions and how the presence of vegetation can make a difference.
  - Distribute a hand-held fan to each group, making sure they understand how to use it safely.
  - Instruct each group to gently and evenly blow air from the fan over the soils in their assigned trays.
    - Emphasize that the materials in the tray should not blow out onto the floor; they should stay within the confines of the tray.
  - Encourage students to observe and record their findings diligently. Ask them to pay attention to any changes or movements they observe in the clay and grass-filled tray and the sand and silt-filled tray.
  - Science Notebook Observation and Hypothesis Prompts:
    - Observations in Clay and Grass-Filled Tray:
      - Describe the initial appearance of the clay and grass-filled tray before using the fan.
      - Record any changes or movements you observe in the materials as you blow air over the tray.
        - Note the behavior of the grass in response to the airflow.
      - Are there any patterns or patterns in the movement of materials? Document them.
    - Observations in Sand and Silt-Filled Tray

        - Describe the initial appearance of the sand and silt-filled tray before using the fan.
        - Record any changes or movements you observe in the materials as you blow air over the tray.
            - Note any differences in behavior between the materials in this tray and the previous one (clay and grass-filled).
        - Are there any noticeable patterns in the movement of materials in this tray? Document them.
    - Hypotheses and Explanations:
        - Based on your observations in both trays, what hypotheses can you formulate regarding the role of vegetation (grass) in preventing soil erosion by wind?
        - Consider the differences you observed between the two trays.
            - Why do you think one tray experienced more or less movement of materials compared to the other?
        - What do you believe is the impact of soil type (clay, sand, silt, gravel) on the susceptibility to wind erosion?
        - If you were to relate these observations to real-world scenarios, how might the presence of vegetation and soil type influence erosion in natural environments?
        - Are there any additional factors beyond soil type and vegetation that you think might influence wind erosion?
            - Share your thoughts.
- Demonstration activity station
    - the focus on simulating water erosion on a hillside and understanding the impact of incline heights
    - Provide each group with the following materials:
        - Plastic tub
        - Books or objects to create incline
        - Packed sand/soil mixture
        - Small figurines
        - Ruler or straight object
        - Water container
        - Cup of water (100 ml)
        - Collection container
        - Science notebooks
        - Visual instructions at the station
    - Instruct each group to set up their plastic tub with an incline by placing objects under one side to create a stable hillside.
    - Inside the plastic tub, students should create a hillside using the packed sand/soil mixture, ensuring it covers no more than half of the tub.
        - Place small figurines into the surface of the sand mixture to represent objects on the hillside.
        - Lay a ruler or straight object across the tub.

- Instruct students to place the water container atop the ruler or straight edge.
- With the cup of water placed on the ruler, students should slowly pour 100 ml of water atop the hill to simulate a rain event.
- As the water flows down the hill, measure the amount of soil that flows through the hole and into the collection container.
    - Encourage students to make detailed observations regarding erosion patterns, object dispersal, and any observations on the movement of soil particles being deposited elsewhere.
        - Observations on Erosion Patterns:
            - Observe and describe how the water flows down the hillside. What patterns or pathways does it follow?
            - Pay attention to any visible changes in the surface of the hillside as the water flows. Are there areas where the soil seems to be eroding more quickly or slowly?
            - Note any channels or grooves formed by the flowing water. What shapes do they take, and how do they evolve over time?
            - Document any changes in the slope or contour of the hillside caused by erosion.
        - Object Dispersal:
            - Keep an eye on the small figurines placed on the hillside. Describe what happens to them as the water flows. Do they remain in their original positions, or do they move?
            - Record any observations about the distance and direction in which the figurines are carried by the flowing water.
            - If some figurines remain stationary, explain why you think this might be happening while others are displaced.
        - Movement of Soil Particles:
            - Focus on the movement of soil particles carried by the water. Describe how the soil is transported downhill.
            - Record any observations regarding the size of soil particles that are being moved by the water. Are larger or smaller particles more susceptible to erosion?
            - Observe where the soil particles eventually settle or get deposited. Do you notice any patterns in their distribution?
    - Variations and Incline Height

- Allow students to vary the height of the incline by adjusting the number of books or objects under the tub.
- Have them repeat the test with different incline heights, making sure to note the number of books or objects used for each variation.
- As they conduct the test with varying incline heights, instruct students to:
- Measure the angle of incline for each setup using a protractor.
- Document any changes in elevation or steepness.
- Make detailed observations of erosion patterns, object dispersal, and the movement of soil particles for each incline height.

- Science Notebook Prompts for Comparing Incline Heights:
    - Compare the erosion patterns observed at different incline heights. How does the rate and pattern of erosion change as the incline becomes steeper or gentler?
    - Analyze the impact of incline height on the distance objects are carried by the flowing water. Do objects travel farther or shorter distances on steeper inclines?
    - Document the effect of incline height on the size and distribution of soil particles that are transported by the water. Are larger or smaller particles more affected by changes in incline?
    - Formulate hypotheses about why incline height influences erosion patterns. What factors related to the incline itself might contribute to these differences?

- Through a series of engaging activity stations, we gained hands-on experience and deepened our understanding of various erosion types, factors, and their real-world implications.
    - Windblown Deposits and Sand Dunes Activity:
        - At the Windblown Deposits station, we mimicked the formation of sand dunes through wind erosion. We observed how different wind strengths and directions influenced the movement of sand particles.
    - Glaciers and Erosion Activity:
        - The Glaciers and Erosion station allowed us to simulate glacier erosion by observing how ice interacts with clay and sand, leading to changes in the landscape.
    - Water Erosion - Splash and River Activity:
        - At the Water Erosion station, we explored how water erosion occurs on hillside terrain. By adjusting incline

heights, we discovered how slope affects the rate and pattern of erosion.
- As we wrap up our exploration of erosion, it's essential to recognize that erosion plays a significant role in reshaping our world. Understanding the factors influencing erosion is crucial for sustainable land management, environmental conservation, and mitigating the effects of natural disasters.

Exploring the Wonders of Soil—Exploring Erosion Control (explain)

- Loess is considered the most erodible soil, usually by wind or water, in the world. In the Midwest, the loess, a silty soil, was caused by the movement of glacial deposits 11,000 years ago (when very few people lived in the area) that were dry, silty, and wind-blown. Loess continues to be sculpted by erosion
  - Engage students with a brief discussion about the students' experiences with soil, gardening, or outdoor activities.
    - Ask open-ended questions like, "Have you ever noticed changes in the soil after heavy rain?" or "Why do you think some areas have more plants than others?"
  - Define Erosion:
    - Write the term "erosion" on the board and ask students to share their understanding of the word.
      - Refer to the science notebook for effects and types of erosion discussed in the previous lesson
    - Erosion is the process by which soil and rock are worn away by natural forces like water, wind, or ice."
    - Water Erosion —Heavy rains on weaker soil
    - wind Erosion - Drought causes water to dry and moved via wind
    - Glacier Erosion - water transports soil participles downhill
  - Students will apply this knowledge and search for evidence of the erosion taking place in the school yard.
    - Educator may want to pre-determine a general location on the schoolyard for time and access constraints
    - Soil erosion is a slow naturally occurring process throughout the Earth.
      - Although Soil erosion is naturally occurring, the process can be observed in this lesson activity,
    - Display pictures or diagrams illustrating erosion. Discuss visible signs of erosion, such as gullies, exposed roots, or loss of topsoil.
      - National Geographic: Their website provides an in-depth look at erosion, discussing various agents like wind and ice, and the effects they have on different landscapes. The description includes how wind can create sand dunes and polish rocks, and how glaciers shape valleys and transport sediment. The site also explores other forces of erosion and the factors impacting it, such as climate and vegetation.
      - Getty Images: This is an excellent resource for high-resolution images and illustrations of erosion. The collection showcases different forms of erosion and its impact on landscapes. It's a valuable visual aid for understanding the physical signs of erosion in various environments

- Introduction to Erosion Control:
- Define "erosion control" as the practice of preventing or minimizing the effects of erosion. Write the term on the board.
    - Discuss why erosion control is important, linking it to topics like soil conservation, agriculture, and environmental sustainability.
    - Soil Conservation:
        - Preserving Soil Fertility: Erosion can strip away the topsoil, which is rich in nutrients necessary for plant growth. By controlling erosion, we ensure that this fertile layer remains intact, allowing crops to thrive.
        - Preventing Soil Degradation: Erosion can lead to soil degradation, making it less productive over time. Soil conservation through erosion control methods helps maintain the quality and structure of the soil.
    - Agriculture:
        - Safeguarding Crop Yields: Erosion can harm agricultural productivity by washing away seeds, young plants, or even mature crops. Effective erosion control measures protect crops, ensuring a stable food supply.
        - Reducing Input Costs: Farmers spend significant resources on fertilizers and pesticides. Erosion control reduces the need for these inputs, making agriculture more cost-effective and environmentally friendly.
    - Environmental Sustainability:
        - Protecting Water Quality: Erosion can lead to the sedimentation of water bodies like rivers and lakes. This sedimentation negatively impacts water quality, harming aquatic ecosystems and biodiversity. Erosion control helps maintain clean water sources.
        - Mitigating Climate Change: Soil erosion releases carbon stored in the soil into the atmosphere. This contributes to greenhouse gas emissions and exacerbates climate change. Preventing erosion helps sequester carbon in the soil, aiding in climate change mitigation.
        - Preserving Biodiversity: Erosion can disrupt natural habitats and ecosystems. By controlling erosion, we protect the biodiversity of various species, which is essential for a balanced and healthy environment.
    - Economic Benefits:
        - Economic Stability: Erosion can lead to economic losses, both for individual farmers and entire regions. Erosion control measures help ensure economic stability by safeguarding agricultural income and property values.
        - Tourism and Recreation: Erosion control also benefits tourism and recreational activities by maintaining scenic landscapes, which can be vital for local economies.
    - Long-Term Sustainability:

        - Sustainable Land Use: Implementing erosion control practices promotes sustainable land use, ensuring that land remains productive for future generations.
        - Preventing Desertification: In arid regions, erosion control can prevent desertification, the process where fertile land turns into deserts, making it possible to continue utilizing the land for agriculture.
- Planting Vegetation:
    - Stabilizing Soil: Plant roots play a crucial role in stabilizing soil and preventing erosion. They create a network of fibers and roots that bind soil particles together, making it less susceptible to erosion caused by wind or water.
- Erosion Prevention: As vegetation grows, its roots penetrate into the soil, anchoring it in place. This prevents soil from being washed away during heavy rains or blown away by strong winds.
    - Vegetative Cover: A dense cover of plants can shield the soil surface from direct impact by rainfall and wind, reducing erosion significantly. Grasses, trees, shrubs, and groundcovers all contribute to this effect.
    - Mulching:
        - Moisture Retention: Mulch is a protective layer of organic or inorganic material applied to the soil surface. It helps retain moisture in the soil by reducing evaporation. This is particularly important in preventing soil erosion because moist soil is less likely to be eroded by water runoff.
    - Soil Surface Protection: Mulch acts as a barrier between the soil and the elements, shielding the soil from the impact of heavy raindrops. This reduces the dislodging of soil particles, keeping them in place and preventing erosion.
    - Weed Control: Mulch also inhibits weed growth, which can help maintain the stability of the soil. Weeds can contribute to erosion by displacing the native vegetation that holds the soil in place.
- Terracing:
    - Controlling Water Runoff: Terracing involves creating a series of flat platforms or steps on sloping terrain. These terraces slow down the speed of water runoff, preventing it from gaining enough momentum to erode the soil.
    - Increasing Infiltration: By allowing water to infiltrate the soil at each terrace level, terracing helps recharge groundwater and reduces surface water runoff, which can carry away soil particles.
    - Preventing Gully Erosion: On steep slopes, terracing can prevent the formation of deep gullies by redirecting and

dispersing runoff, protecting the landscape from severe erosion.

- Step-by-Step Planting Activity for Erosion Control:
    - Materials Needed:
    - Small plants or seeds (such as grass, wildflowers, or small shrubs)
    - Containers or a designated area with soil
    - Watering cans or hoses
    - Mulch (optional)
- Step 1: Select Your Planting Area
    - Choose an area with bare soil or prepare containers filled with soil. This will be the space where you'll demonstrate erosion control through planting.
- Step 2: Preparing for Planting
    - Explain to students that they will be planting vegetation to prevent soil erosion.
    - Provide each student with a small plant or seeds.
    - Instruct them to clear any debris or rocks from their designated planting area to create a clean and level surface.
- Step 3: Planting
    - Guide students on how to plant:
        - For seeds: Use a small garden tool or their fingers to create shallow furrows in the soil (about 1/4 to 1/2 inch deep).
    - For small plants: Dig holes that are just deep enough to accommodate the plant's root ball, typically around 2 inches deep.
- Step 4: Placing the Vegetation
    - Provide students with the small plants or seeds.
    - Instruct them to place seeds evenly along the furrows or plant small plants in the prepared holes.
    - Encourage proper spacing to allow room for growth. Typically, seeds or small plants should be placed about 2-3 inches apart.
- Step 5: Watering Thoroughly
    - After planting, demonstrate how to water the newly planted area thoroughly but gently.
    - Explain that watering helps the plants establish their root systems and simulate natural growth.
    - Encourage students to ensure that the soil is evenly moist but not waterlogged.
- Step 6: Mulching (Optional)
    - If mulch is available, show how it can be applied around the planted area.
    - Explain that mulch should be spread in a thin layer, about 1-2 inches deep, around the plants.
- Step 7: Observation and Discussion

- Observing Stabilization and Erosion Prevention:
    - Instruct students to regularly visit the planted area and closely observe the soil surface.
    - Encourage them to look for signs of erosion control, such as reduced soil movement, fewer exposed roots, and less evidence of soil washout during rain.
    - Discuss how the planted vegetation, with its root network, holds the soil together, preventing it from being easily washed away.
        - Ask students to take photographs or draw sketches to document changes over time, creating a visual record of the erosion control process.
- Roots as Soil Anchors:
    - Explain the vital role of plant roots in anchoring the soil. Roots penetrate into the soil, creating a web-like structure that binds soil particles together.
    - Discuss how the roots act like "anchors" that help prevent soil from eroding during heavy rains or strong winds.
    - Encourage students to gently dig around a few plants to examine the root systems. Discuss the various types of roots, such as fibrous and taproots, and how they contribute to soil stability.
- Mulch and Moisture Retention:
    - Emphasize the importance of mulch in moisture retention.
    - Encourage students to touch the soil under the mulch layer and compare it to the soil in areas without mulch.
    - Discuss how mulch acts as a protective barrier, reducing moisture loss through evaporation and keeping the soil consistently moist.
    - Explain that the mulch layer also helps regulate soil temperature, which benefits plant growth and soil microorganisms.
- Regular Monitoring:
    - Stress the importance of regular monitoring to assess the effectiveness of erosion control measures.
    - Encourage students to keep a journal or log where they record their observations, noting any changes in the planted area.

- Discuss how long-term monitoring helps us understand how vegetation and mulch continue to protect the soil.
- Emphasize that mulch helps retain moisture and protects the soil surface from erosion.

Exploring the Wonders of Soil—Exploring Erosion Control (elaborate)

- Begin by discussing the concept of soil erosion with the students.
    - Explain that soil erosion is the process by which soil is gradually removed from one place and deposited elsewhere.
    - Emphasize the importance of understanding erosion, as it can have significant environmental impacts.
        - Loss of Fertile Soil: Erosion leads to the loss of the topsoil layer, which is the most fertile and essential for plant growth. As soil erodes, it diminishes our capacity to produce food and sustain agriculture, impacting global food security.
        - Water Pollution: Eroded soil often contains pollutants such as fertilizers, pesticides, and sediment. When this soil is carried into water bodies like rivers and lakes, it can lead to water pollution, harming aquatic life and disrupting ecosystems.
        - Sedimentation: As eroded soil settles in water bodies, it causes sedimentation, which can reduce water quality, clog waterways, and even increase the risk of flooding.
        - Habitat Destruction: Erosion can lead to the destruction of natural habitats, affecting wildlife and biodiversity. Many species depend on stable landscapes for survival, and erosion disrupts these ecosystems.
        - Climate Change: Erosion contributes to climate change by releasing carbon stored in the soil into the atmosphere. This leads to increased greenhouse gas emissions, which contribute to global warming.
        - Loss of Arable Land: Over time, excessive erosion can render land unsuitable for agriculture or development. This loss of arable land exacerbates issues related to land scarcity and urban sprawl.
        - Increased Vulnerability to Natural Disasters: Erosion weakens the integrity of the land, making it more susceptible to natural disasters like landslides, mudslides, and flash floods.
        - Economic Costs: Soil erosion has significant economic implications, including reduced agricultural productivity, increased infrastructure maintenance costs, and property damage due to flooding and landslides.
        - Water Scarcity: Erosion can alter hydrological cycles and reduce water availability. This is particularly critical in regions where water scarcity is already a pressing issue.
        - Long-Term Environmental Degradation: Uncontrolled erosion can lead to the degradation of entire landscapes, turning once-productive land into barren, unproductive areas.

        - Loss of Cultural and Historical Sites: Erosion can threaten cultural heritage and historical sites located near coastlines or rivers, leading to the loss of valuable human history and cultural significance.
- Take the students out to the schoolyard campus and invite them to explore. Instruct them to look for signs of soil erosion, such as:
    - Mud near sidewalks or walkways
    - Exposed tree roots
    - Soil cracks or gullies
    - Bald patches of exposed soil
- Encourage students to use their science notebooks to record their observations.
    - They should document the signs of erosion they find, including descriptions, sketches, and photographs if possible.
    - Analysis and Inference:
        - Once students have explored and documented signs of erosion, gather them together and discuss their findings.
        - Ask students to share their initial impressions about the areas they observed.
            - What did they notice, and how does it make them feel about the schoolyard environment?
        - Have students infer how the areas they observed are currently being used and managed. Are there any human activities contributing to erosion?
    - Detailed Observation and Measurement:
        - Instruct students to select one area with signs of erosion that they find particularly interesting or concerning.
        - Have them describe the type of erosion taking place in detail.
            - Are there any specific patterns or causes they can identify?
                - In their science notebooks, ask students to draw a diagram or take a picture of the landscape and the effects of erosion. Encourage them to label important features.
        - Using rulers or measuring tapes, have students measure the size of the eroded area. This measurement will assist them in creating a scaled-down model.
- Back in the classroom, explain that students will create a scaled-down model of the eroded area to understand erosion dynamics better.
    - Provide materials such as sand, soil, rocks, and containers for the model.
        - Encourage students to refer back to their measurements from the schoolyard exploration to accurately replicate the dimensions of the eroded area in their scaled-down model. Depending on the location, buffer strips, build terraces, gabions, diversions, riprap erosion control blankets
- Encourage them to experiment with different scenarios to understand how erosion can be prevented or mitigated. Describe each type of prototype:
    - Buffer strips - an area of land maintained in permanent vegetation that helps to control soil erosion among other tasks,

        - Terraces - a step-like landform that borders a shoreline or river floodplain
        - Gabions - cage, cylinder or box filled with rocks, concrete, or sometimes sand
        - Diversions temporary ridge or excavated channel or combination ridge and channel constructed to divert water
        - Riprap loose stone used to form a foundation for a breakwater or other structure.
        - Erosion control blankets synthetic or natural fibers to protect soil from the erosive impact of precipitation and overland flow, typically on slopes and in channels.
            - Why would we want to control erosion?
            - After learning about the different erosion controls, move students into groups and recreate the stream erosion tables created during the previous activity In their science notebooks, students should document the setup of their models, the variables they are testing, and their hypotheses.
- Divide the students into small groups or pairs to facilitate collaborative experimentation and idea exchange.
    - Guidelines for Experiments:
        - Provide each group with the following guidelines for their erosion control experiments:
        - Vegetation for Soil Stabilization: Explore how introducing vegetation (such as plants or grass) can stabilize the soil. Investigate different plant types and their root structures. Document how they affect soil erosion.
        - Mulch and Moisture Retention: Test the impact of mulch or ground cover on soil moisture retention. Experiment with various types of mulch (e.g., straw, wood chips) and observe how they affect soil moisture levels.
        - Barriers for Soil Protection: Investigate the effects of barriers, such as small rocks or sticks, in preventing soil movement. Test different barrier materials and arrangements to see which provides the best protection against erosion.
        - Water Management for Erosion Control: Simulate rainfall or runoff control to understand the role of water management in erosion prevention. Experiment with different techniques for diverting or controlling water flow.
        - Additional Erosion Control Methods: Allow students to explore any other erosion control methods they are interested in. Encourage creativity and critical thinking in devising new approaches to erosion prevention.
    - Science Notebook Prompts for Data Collection and Analysis:
        - Setting Up the Experiment:
            - In their science notebooks, have students document the setup of their erosion control experiments. Ask them to describe the materials used, the design of their models, and the variables they plan to test
            - Formulating Hypotheses:

- Encourage students to develop hypotheses for their experiments. For each erosion control method they are testing, ask them to predict the outcomes and explain their reasoning.
- Observation and Recording:
  - Instruct students to carefully observe and record the changes that occur during their experiments. They should document any signs of erosion or soil stabilization over time.
- Effectiveness Analysis:
  - Encourage students to analyze the effectiveness of each erosion control method they tested. Have them compare the results with their initial hypotheses.
  - Prompt them to think critically about what worked and what didn't, and ask them to explain why certain methods were more effective than others.
- Recommendations and Conclusions:
  - Ask students to draw conclusions based on their experiments. Have them provide recommendations for practical applications of the erosion control methods they found to be effective.
  - Encourage critical thinking about real-world scenarios where these methods could be implemented.

Exploring the Botanical Ballet of Plant Reproduction

Investigations and Application
Plant reproduction: Introduction to Plant Reproduction

Plant Reproduction: Educator Background Information
All plants reproduce either by spores or by seeds. For seed reproduction, plants can be classified into two groups angiosperms (flowering plants) and gymnosperms (cycads) where as our spore reproducing plants can be classified into mosses and ferns

The largest group of plants on Earth is the angiosperms, or flowering plants. Angiosperm means " seed in a vessel" and these plants have the ability to create a seed capable or surviving periods of drought or cold. Pollination is the process of sexual reproduction in angiosperms.

During the process of pollination, the male reproductive cells of an angiosperm (pollen) are transferred from the anther (male reproductive organ) of a flower to the stigma (female reproductive organ) of the same or a different flower. The pollen creates a pollen tube, which transports the pollen down into the ovary of the flower. The pollen fertilizes an egg, thus completing the sexual reproductive process. The fertilized embryo is encased within a seed for development and dispersal.

For genetic diversity, it is imperative that flowers from different plants of the same species reproduce (cross-pollination) rather than reproduction with sexual material from the same plant (self-pollination). Cross-pollination is encouraged by the activity of animal pollinators and by the effects of wind and water on flowers. Wind and water pollinated plants generally have small; inconspicuous flowers held high to catch breezes or currents. Animal pollinated flowers use a variety of colors, scents, and structural components to attract visiting pollinators. For example, the red tubular flowers and rich nectar of hibiscus attract hummingbirds. The flat landing platform and pink/purples of asters and lantanas attract butterflies. The sweet scented white moonflowers open at dusk for foraging moths. The sweet, musky roses and marigolds attract bees.

Very likely, all of the honeybees you see sipping nectar are female. The 'stinger' with which each could defend herself if threatened is actually a structure called an 'ovipositor'. In some cases, such as cicadas, female insects must use the ovipositor to insert eggs into bark, decaying wood, or other vegetation. In the case of honeybees, only the queen in a colony lays eggs; the worker bees do not. Their sting is barbed, though, so unlike wasps, bees really do die if they sting. Honeybees are domesticated (farm animals) and rarely sting unless they are defending their nest. Some larger mason and carpenter bees which are seen behaving more aggressively are stinger-less males, however. These species are solitary, so much like birds, the females guard the nest inconspicuously, while males patrol and challenge each other's territories through threats and aerial wrestling matches.

All organisms interact with individuals of other species. They may feed on them, or try to avoid being eaten by them. They may compete with other species for a common resource, or cooperate with them for a common good. In this class we will examine the types of inter-species interactions that can occur between plants and animals. These interactions generally fall under a few categories.

Predation occurs when one organism eats another. For example, herbivores eat plants and carnivores eat animals. There are even carnivorous plants. Carnivorous plants consume insects because the soil in which they grow is very poor in nutrients and the plants need more nitrogen. These plants still obtain their energy from the sun through photosynthesis. Parasitism is similar to predation in that one species benefits at the expense of the other.

The differences are that the host is not usually killed in the process and the parasite is usually smaller than the host. The parasite can be internal (within the body of the host; eg. roundworms) or external (eg. tick, leech). We often call plant sucking insects (like aphids) plant parasites.

Commensalism describes a situation in which one individual benefits and the other is neither hurt nor helped by the interaction. For example, epiphytes on the trunks of rain forest trees are helped by the trees which give them a surface from which to grow. The trees do not seem to be affected by the epiphytes.

Mutualism occurs when organisms of both species benefit from their association. The relationship between pollinators and plants is a great example of mutualism. In this case, plants get their pollen carried from flower to flower and the animal pollinator (bee, butterfly, beetle, hummingbird, etc.) gets food (usually nectar or pollen). Seed dispersal is also often accomplished through a mutualistic relationship between the plant and its animal disperser. Many animals eat the sweet fruit that surrounds the seeds. The seeds are then deposited in a new location some distance away from the parent plant, often in fecal material which adds a little fertilizer as well!

These types of interactions occur between species in every ecosystem. The tropical rain forest, however, seems to have greatest variety of unique and fascinating interactions, especially involving mutualism

For a asexual reproduction, some flowering plants reproduce vegetative, producing offspring that are genetically identical to their single parent. Many trees sprout from the roots of their parent trees to the frustration of homeowners. These sprouts can be cut from the main plant and transplanted. Other plants, produce tiny plantlets on their leaves. These fall off and develop into new plants. Strawberry plants spread and reproduce with special stems called stolons. The cuttings we can take from houseplants are also examples of vegetative reproduction. Plant breeders often graft slips of one desirable plant onto the stem of another plant to reproduce desirable traits. Hybrid roses and special citrus trees have been developed in this manner.

Bulbs, such as tulips and onions which are clusters of food storage leaves surrounding a stem and a bud are both food storage and reproductive structures. One new bulbs is produces around the base each year and can be broken off to form a new plant. This is called a bulbet. Rhizomes are horizontal fleshy underground stems with buds at their end. Food storage roots, such as carrots and sweet potatoes

Real world connections:

- Plant Scientists careers include: Agronomist, Floral designer, Soil Scientists, Greenhouse manager, Propagation scientists, Plant breeder, Landscape Scientists, Environmental scientists, Entomologist, Horticulture, Plant Biologists, botanists, plant geneticist, horticulturist seed technologist

Exploring the Botanical Ballet of Plant Reproduction

Next Generation Science Standards

MS-LS1-4.Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.

Students will be able to:
- Recognize that plant reproduction occurs in two ways, sexual and asexual. During sexual reproduction, plants and pollinators have specialized structures and produce offspring different than parent. During asexual reproduction, plant reproduction comes from vegetative parts that produces offspring identical to parents

Student Vocabulary:

- Anthers - the part of a stamen that contains the pollen.
- Asexual reproduction - is a type of reproduction which does not involve the fusion of gametes or change in the number of chromosomes
- Carpel - One of the leaflike, seed-bearing structures that constitute the innermost whorl of a flower.
- Embryo - an unborn or unhatched offspring in the process of development
- Fertilization - the action or process of fertilizing an egg, female animal, or plant, involving the fusion of male and female gametes to form a zygote
- Gametes - a mature haploid male or female germ cell which is able to unite with another of the opposite sex in sexual reproduction to form a zygote.
- Meristems - a region of plant tissue, found chiefly at the growing tips of roots and shoots and in the cambium, consisting of actively dividing cells forming new tissue.
- Mutualism - the doctrine that mutual dependence is necessary to social well-being.
- Nectar- collects at the base of the flower, enticing pollinators to climb down and brushing against both the pollen containing anthers and the sticky style of the pistil
- nectary - a structure we do not typically discuss because often the glands are too tiny to be seen without a microscope. However, these glands produce a sweet, nutrient-rich liquid that forms the dietary staple of pollinators.
- ovary - where ovules are produced and protected. The ovary may be inside the flower, as shown here, or located below the flower, as in the case with Astroemeria. The ovary is the portion of the flower that eventually grows into a fruit.
- Ovule - a small or immature ovum.
- Pollen - a fine powdery substance, typically yellow, consisting of microscopic grains discharged from the male part of a flower or from a male cone
- Seed - the grains or ripened ovules of plants used for sowing
- Sepals - each of the parts of the calyx of a flower, enclosing the petals and typically green and leaflike.
- Sexual reproduction - the production of new living organisms by combining genetic information from two individuals of different types (sexes)
- Stamen - the male fertilizing organ of a flower, typically consisting of a pollen-containing anther and a filament.
- Stigma - a sticky, bulbous projection at the top of the pistil. The stickiness snags pollen off of visiting pollinators.

- style - long, slender tube that holds the stigma up to the top of the flower, all the better to snag pollen. Pollen granules create a tube that runs down the style from the stigma to the ovary to facilitate fertilization

From Flower to Fruit: Unveiling the Secrets of Plant Reproduction (engage**)**

- Today, we are diving into the incredible world of plant reproduction. Just like humans, plants have their own unique way of bringing new life into the world.
    - Can anyone tell me what part of a plant is responsible for this process?"
        - Pause for student responses.
    - "That's right! Flowers play a crucial role in plant reproduction. They are like nature's matchmakers, helping plants create the next generation.
        - Begin with a brief discussion on the importance of flowers in plant reproduction. Highlight key concepts such as pollination and fertilization.
            - Show a video or use visual aids to introduce the life cycle of a flowering plant, emphasizing the role of flowers in the process.
                - Introduction to Plant Reproduction**:**
                    - "Learn the Plant Life Cycle Steps - Earth Science for Kids" on YouTube: This video is tailored for a younger audience and provides a fun and educational overview of the plant life cycle steps. It's particularly suitable for kids and presents the information in an engaging way.
                    - "Life Cycle of a Flowering Plant (Grade 3, Lesson 1 from the Green Our Planet Curriculum)" on YouTube: This video is part of a curriculum and is designed to be educational and informative, making it a good fit for school-aged children. It offers a clear, step-by-step guide through the plant's life cycle. Khan Academy's "The life of plants - Class 11 | Science": This comprehensive course covers various aspects of plant life, including the morphology of flowering plants, transport in plants, plant growth and development, and sexual reproduction in flowering plants. It's more detailed and suitable for older students or anyone looking for an in-depth understanding. Science Learning Hub's article on "Flowering plant life cycles": This resource provides a detailed written explanation of the life cycle stages of flowering plants, including germination, growth, flowering, pollination, and seed dispersal. It's ideal for those who prefer reading over videos and need a detailed, scientific explanation of the process. The article is available here.
                - Pollination Simulation:
                    - ollination lesson with stop motion science

animation for kids on YouTube: This video uses stop-motion animation to provide a kid-friendly lesson on pollination. It's engaging and visually appealing, making it a great resource for younger students.

        - Pollination Simulation on YouTube: Another educational video that demonstrates how bees cross-pollinate flowers. It's particularly useful for teaching young children about the role of bees in the pollination process. Introduction to Pollination video from National Agriculture in the Classroom: This is a brief, 2-minute animated video that not only illustrates the pollination of a flower but also teaches about flower anatomy to understand the role each part plays in pollination. It's an excellent resource for a quick and comprehensive overview.
        - Pollination for Kids from NeoK12: This platform offers a variety of educational videos and games about pollination, tailored for school kids. The videos cover different aspects of pollination, including the roles of various pollinators like bees and butterflies. These resources are available on their website here.
    - Fruit Formation:
    - "How Fruit Is Formed In Plants | Double Fertilization in Flowering Plants" by Extraclass: This animation video comprehensively explains the fertilization process, including syngamy, double fertilization, and fruit formation. It's an excellent resource for understanding the intricate details of how fruits are formed in plants.
    - "Pollination, Fruit and Seed Formation (Reproduction in Plants - Class VII)": This video is particularly useful for school students, providing a clear explanation of the processes from pollination to fruit and seed formation. It's suitable for a classroom setting or for individual learning.
    - "Seed & Fruit Formation - Seed Structure - Sexual Reproduction in Plants Video 4. Leaving Cert Biology": This video is a part of a series on biology, focusing on seed and fruit formation. It breaks down the complex process of how seeds and fruits develop in flowering plants, making it a great resource for higher-level biology students. Watch it on YouTube here.
- Throughout this unit, we are going to dissect flowers, explore their hidden secrets, and uncover the journey from pollination to fruit formation.
- Pass out flowers, scissors and magnifying glass to student

Exploring the Botanical Ballet of Plant Reproduction

- Discuss with students the four main parts of the flower and what the role of the flower is
    - The flower are the reproductive organs of angiosperms. An angiosperm are seed plants with flowers. This group of plants (angiosperms) are the best adapted seed plants and this success can be attributed to the flower. Nearly all living plants are angiosperms, trees, shrubs, herbs, fruit, vegetables, grains
    - The four main parts of the flower are: Sepals, petals stamens and pistils
        - Sepals: Sepals are the outermost protective structures of a flower. They are typically green and leaf-like, although they can have various colors and shapes in some flowers. The primary function of sepals is to enclose and protect the developing bud before it blooms. Once the flower opens, sepals may remain as a base or fall off, depending on the plant species.
        - Petals: Petals are often the most visually attractive part of the flower and come in a wide range of colors and shapes. They play a crucial role in attracting pollinators, such as bees, butterflies, and birds, by offering them a source of nectar and visual cues. Petals can vary in number and arrangement among different flower species.
        - Stamens: Stamens are the male reproductive organs of a flower. Each stamen typically consists of two parts: the filament and the anther. The filament is a slender stalk that supports the anther. The anther is where pollen grains are produced. Pollen contains the male gametes (sperm cells) necessary for fertilization. When a pollinator lands on the flower and comes into contact with the anther, it picks up pollen, which can then be transported to another flower's pistil.
        - Pistils (Carpels): Pistils are the female reproductive organs of a flower. A pistil consists of three parts: the stigma, the style, and the ovary. The stigma is the receptive surface at the top of the pistil, where pollen grains land. The style is a slender tube that connects the stigma to the ovary. Inside the ovary, one or more ovules are present, each containing an egg cell. Fertilization occurs when pollen grains from a different flower land on the stigma, grow down the style, and reach the ovules, resulting in the formation of seeds.

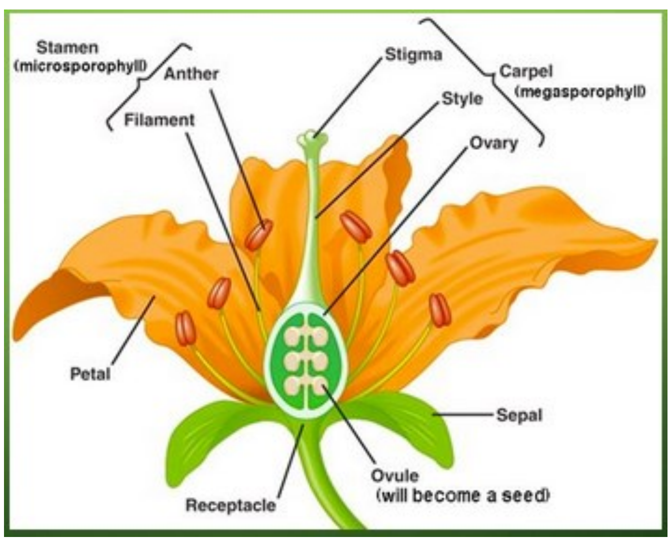
Exploring the Botanical Ballet of Plant Reproduction

- The dissection begins with an external examination of the flower.
    - In student science notebooks, provide time for students to draw and label the external parts of the flower.
        - Observation: Begin by instructing students to carefully observe the flower they have in front of them. Ask them to note down the following:
            - What are the external parts of the flower?
            - What colors do you observe on the petals and sepals?
            - Are there any patterns or unique features on the petals or sepals?
        - Drawing: After observing, have the students draw a detailed and labeled diagram of the flower in their notebooks. Encourage them to include the following parts:
            - Sepals
            - Petals
            - Stamens (with filaments and anthers)
            - Pistil (with stigma, style, and ovary)
        - Labeling: Instruct students to label each part of the flower correctly. They should use clear and legible handwriting or printing for the labels.
        - Colors: Have them indicate the colors they observed for each part of the flower. For example:
            - Sepals: [Color]
            - Petals: [Color]
            - Stamens: [Color]
            - Pistil: [Color]
        - Patterns and Unique Features: Encourage students to describe any patterns, textures, or unique features they noticed on the petals or sepals. For instance:
            - Are there any stripes, spots, or veins on the petals?
            - Do the sepals have a different texture or shape compared to the petals?
            - Are there any variations in color within the same flower or among different flowers of the same species?
        - Comparisons: If you have multiple flowers of the same species or different species available, ask students to compare the external parts, colors, and patterns among them. This can lead to discussions about variation in

flowers within and between species.
        - Questions: Encourage students to ask questions about what they've observed. Are there aspects of the flower that they find intriguing or want to know more about?
- Provide students with a flower called an Alstroemeria.
    - It's a member of the Lily family, and is commonly sold in supermarkets.
    - They are great for dissecting because their blossoms are large and simple, and their features are easy to see.
        - One quirk about this group of flowers, though: the sepals are colored, rather than green.
        - In many flowers, the sepals appear as greenish leaf-like projections below the petals, but in lily-like flowers they comprise half of the 'petals'. Alstroemeria have three sepals, which are usually evenly-colored and have more rounded tips. The three petals are typically longer and more pointed, and may have darts of color or spots running through them.
    - Pull off Sepals – bottom 3 most petal looking thing – helps attracts pollinators
        - The sepals serve to protect the flower as it is forming. In this case, they also aid with attracting pollinating insects.
        - The sepals are leaf like parts that protect the flower from damage with it is a bud. Sepals are located at the outermost circle of a flower
    - Pull off petals – Honey guides to show the insects which way to get nectar
        - The petals enfold the interior parts of the flower and function both as protection for the flower and an attraction to pollinating animals
        - Often vividly colored structures inside the sepals for attraction of pollinator. Wind pollinated flowers have very inconspicuous petals if any
    - Pull off stamen – things with the anthers
        - Stamen is the male part of t e flower. They consists of slender, thread like filaments called anthers
        - anthers are in the ways to get the pollin "stuck" to the insect
        - Carpel – Female parts – pull off rose petals to show the messiness of the carpels inside the rose - in this family tend to remain free instead of becoming fused into a many chambered, single carpe
        - The anther is the production point for pollen. Anther shapes vary from flower to flower, but they tend to look a bit like beans until they mature. Upon maturity, the line down one side splits open and exposes the pollen grains within.
        - The filament holds the anther out so that visiting animals are likely to brush against it.
    - Uncover the Pistils.
        - Pistils are the female part of the flower. The lower part of the pistil is called the ovary and contains the ovules. Rising from

the ovary is the style. At the tip of the style is the a sticky structure called the stigma,

- The stigma is a sticky, bulbous projection at the top of the pistil. The stickiness snags pollen off of visiting pollinators.
- The style is a long, slender tube that holds the stigma up to the top of the flower, all the better to snag pollen. Pollen granules create a tube that runs down the style from the stigma to the ovary to facilitate fertilization
- The ovary is where ovules are produced and protected. The ovary may be inside the flower, as shown here, or located below the flower, as in the case with Astroemeria. The ovary is the portion of the flower that eventually grows into a fruit.
- The nectary is a structure we do not typically discuss because often the glands are too tiny to be seen without a microscope. However, these glands produce a sweet, nutrient-rich liquid that forms the dietary staple of pollinators. This nectar collects at the base of the flower, enticing pollinators to climb down and brushing against both the pollen-containing anthers and the sticky style of the pistil.



- After the dissection, provide students with the following internal flower structure science notebook prompts. These prompts are designed to encourage students to observe, analyze, and reflect on their flower dissection experience, fostering a deeper understanding of plant reproduction
  - Prompt 1: Sketch the Internal Structures
    - Ask students to sketch the internal structures of the dissected flower in their science notebooks. They should include the following parts:
      - Stamen (with filaments and anthers)

        - Pistil (with stigma, style, and ovary)
        - Sepals
        - Petals
            - Instruct them to label each part accurately and note any differences they observe in terms of size, shape, or color among these structures.
- Prompt 2: Observations with Magnifying Glasses
    - If you have provided magnifying glasses during the dissection, encourage students to use them for closer observations. Here are some specific points to guide their observations:
    - Examine the stamen under the magnifying glass. Are there any details or structures that you didn't notice without magnification? Note any unique features.
    - Focus on the anthers of the stamen. Can you see individual pollen grains? How are they arranged within the anther?
    - Move on to the pistil. Observe the stigma, style, and ovary under the magnifying glass. Are there any fine structures or textures on the stigma's surface?
    - Use the magnifying glass to get a closer look at the sepals and petals. Are there any tiny hairs, patterns, or fine details on their surfaces that you didn't notice before?Use a magnifying glass to closely observe the reproductive structures. What details do you notice that you might have missed with the naked eye? How do the textures of different parts vary?
- Comparing Flowers:
    - If students are working in groups and have dissected different flowers, ask them to compare their findings.
    - Prompt them to identify similarities and differences in the structures they observed among the different flowers.
    - Encourage discussions on what might account for these variations. Are the differences due to the species of the flower, environmental factors, or other reasons?
- Questions and Curiosities:
    - Instruct students to write down any questions or curiosities that arose during the dissection. This can include questions about specific structures, their functions, or the broader significance of flower anatomy.
    - Encourage students to share their questions with the group or class, fostering curiosity-driven discussions and potential research opportunities.
- Reflection on Dissection Process:
    - Ask students to reflect on the process of dissecting the flower. Did they encounter any challenges or unexpected difficulties? How did they overcome them?
    - Prompt them to consider what surprised them during the dissection. Were there any unexpected findings or insights?
- Connections to Plant Reproduction:
    - Have students explain how the structures they observed are related to the process of plant reproduction.

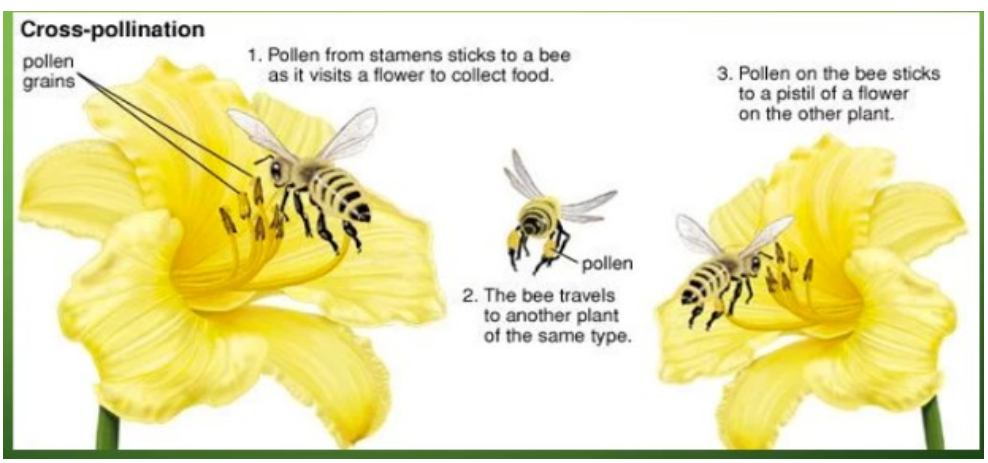
- Guide them to think about how each part, such as stamens, pistils, sepals, and petals, contributes to the overall goal of producing seeds
  - Encourage discussions on the specific roles of each part in pollination, fertilization, and seed development.

From Flower to Fruit: Unveiling the Secrets of Plant Reproduction (explore)

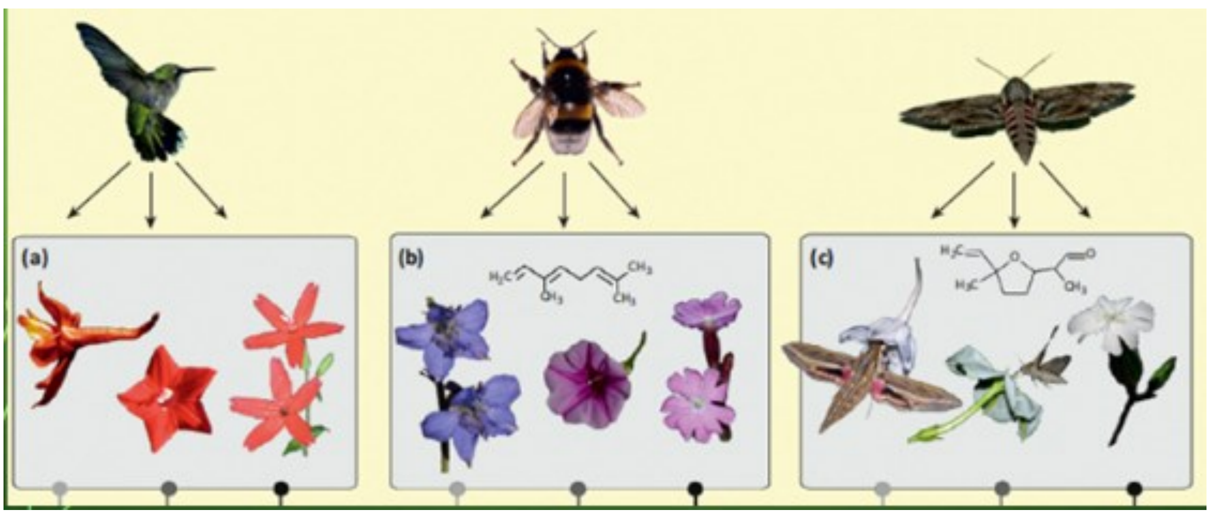
- Now that we've explored the anatomy of the flower, let's dive into the world of pollination. Imagine being a bee or butterfly, buzzing from one flower to another, transferring pollen.
  - We're going to simulate this process, so get ready to be nature's pollinators!"
  - Every organism has genetic information that determine its characteristics, like size, leaf shape, etc.
    - Everyone’s genetics have traits that make it strong against certain kind of threats, but there are also traits that make it weaker against other threats.
      - When all members of a population have the same or very similar genetics, they are all therefore vulnerable to the same threats.
      - Threats might include things like predators or drought or disease.
      - When a threat becomes a reality for a given population of plants, only those whose traits equip them to stand up against the threat can survive.
        - If they’re all weak, as would be the case with asexual reproduction, they all die.
        - Sexual reproduction fixes this problem by mixing the genetics up from one generation to the next.
        - When a population consists of individuals with a wide range of genetic traits, a given threat might kill off some of them, but others survive to reproduce the next generation. Sexual reproduction is the method most higher life forms – including most animals – use for reproduction.
          - In plants, this can take the form of spores, in simple plants like ferns and mosses. More complex plants produce cones – as in the case of conifers – or fruit.
          - Sexual reproduction does require two parent plants most of the time, and the offspring produced have blended genetics from both parents.
            - Because of this, the offspring are not identical to either parent.
            - Sexual reproduction always requires two different reproductive cells, called gametes.
            - Plants gametes include ovules, which are the equivalent of female gametes in

animals. Pollen is the equivalent of male gametes in animals.

- Simply put, ‘fertilization’ describes the reaction that occurs when a pollen grain comes into contact with an ovule.
- The genetic material each contains is combined and a seed develops.
- The seed contains the embryo of a new plant as well as nutrition for that embryo to use as it grows later on.
- Which brings us to the role flowers play in sexual reproduction in those plants that produce them.
- Getting pollen grains to contact ovules can be tricky. After all, plants can’t move, so they have to rely on outside help to transport pollen from one plant to the ovules of another.
- Flowers are produced to help that process – called pollination – along.
    - For pollination to occur, plants and animals have co-evolved to have specialized structures so that both benefit
    - Define mutualism as both species relying upong each other in order to survive. As an example, the plant and bee relationships (see below)



- The bee and the flower. Bees fly from flower to flower gathering nectar, which they make into food, benefiting the bees. When they land in a flower, the bees get some pollen on their hairy bodies, and when they land in the next flower, some of the pollen from the first one rubs off, pollinating* the plant. This benefits the plants. In this mutualistic relationship, the bees get to eat, and the flowering plants get to reproduce.
- However, it is not limited to plants and bees. Plant populations have adapted to create flowers that appeal to their preferred pollinator



- Explain that today's activity involves simulating the pollination process by mimicking the actions of pollinators like bees and butterflies.
    - Distribute small paintbrushes or cotton swabs to each group. Explain that these will act as the "pollinator's tool" to transfer "pollen" from one flower to another.
- Simulation
    - Instruct each group to select one flower from their previous day's dissection to serve as the "source" flower.
    - Provide each group with another flower (of the same or different species) to serve as the "recipient" flower.
    - Explain that their task is to simulate the pollination process by transferring "pollen" from the "source" flower's anther to the "recipient" flower's stigma. They will use cotton balls to mimic the action of pollinators.
        - Provide each group with a small dish containing colored powder or sugar, which represents the

pollen. Explain that they should dip one end of a cotton ball into the dish to collect "pollen" and then transfer it to the stigma of the "recipient" flower.

- Demonstrate the process to the students:
    - Gently touch the cotton ball to the colored powder or sugar to collect "pollen."
        - Carefully place the pollen-coated end of the cotton ball onto the stigma of the "recipient" flower. Encourage them to simulate the gentle touch of a pollinator.
- Encourage students to observe and record the following:
    - Any differences in the structure of the "source" and "recipient" flowers.
    - The amount of "pollen" collected on the cotton ball and transferred to the stigma.
    - Any challenges they encounter during the process, such as reaching the stigma or avoiding damage to the flowers.
- Have each group repeat the simulation a few times to ensure thorough observation and practice.

- After the simulation activity, have each group come together to discuss their findings and observations. Encourage them to answer questions such as:
    - Did they notice any differences in the structure of the "source" and "recipient" flowers?
    - Did they encounter challenges in mimicking pollination? For example, did they find it difficult to reach the stigma with the pollen?
    - Did they observe any differences in the amount of pollen on the "source" flower and the amount transferred to the "recipient" flower?
    - Did they notice any variations in the success of pollination between flowers of the same species and different species?

From Flower to Fruit: Unveiling the Secrets of Plant Reproduction (Explain)

- Start with a discussion about fertilization and its role in plant reproduction.
    - Define fertilization as the crucial step in plant reproduction where male and female reproductive cells come together to form seeds.
        - Explain that this process is similar to the concept of human fertilization, where an egg and sperm fuse to create a new organism.
    - Emphasize the Role of Seeds
        - Stress the significance of seeds in the life cycle of plants. Explain that seeds are vital for the survival and propagation of plants, as they contain the genetic information necessary to grow into new plants.

        - Use relatable examples: Compare seeds to "plant babies" that need to be protected and nourished before they can grow into mature plants.
    - Encourage students to participate in a discussion about fertilization and its role in plant reproduction by asking open-ended questions:
        - Why do you think plants produce seeds? (Prompt students to consider the importance of seeds in the plant life cycle and their role in giving rise to new plants.)
        - How do you think seeds are formed in a flower? (Encourage students to think about the different parts of the flower and how they contribute to seed formation.)
        - What might happen if plants didn't produce seeds? (Discuss the implications of seedless plants and the importance of seeds in plant survival and reproduction.)
        - Can you draw a parallel between fertilization in plants and fertilization in animals (like humans)? (Encourage students to compare the concept of fertilization in plants to the process of creating offspring in animals.)
        - Why do you think it's essential for seeds to be protected within fruits? (Guide the discussion towards the role of fruits in protecting and dispersing seeds.)
        - Provide each student or group with the dissected flowers from the previous activity. Ensure they have magnifying glasses and small containers for seed collection.
  - Instruct students on the task of collecting seeds from the flowers' ovaries. Explain that this hands-on activity will help them observe and examine seeds at various stages of development.
    - Emphasize that not all flowers may have fully developed seeds, and some seeds may be in the early stages of formation, such as tiny embryos. This variation is natural and provides valuable insights into seed development.
    - Encourage students to carefully dissect the ovaries of the flowers to locate any seeds. They should use their magnifying glasses to assist in their observations.
        - As students find seeds, instruct them to gently collect them in their small containers. Remind them to handle the seeds with care and avoid damaging them during the process.
- Exploring the School Yard for Common Seeds
  - Transition the activity to exploring the school yard for common seeds. Explain that this will allow students to see seeds in their natural environment and observe their diversity.
    - Provide guidance on where to look for common seeds in the school yard. Encourage students to search near trees, shrubs, and flowering plants, as these are common sources of seeds.
        - Offer specific examples of common seeds they might find, such as acorns from oak trees, maple seeds (helicopter seeds), dandelion seeds, or seeds from grasses.
  - Exploration

- Allow students to explore the school yard in small groups or individually, depending on your class size.
  - Encourage them to look for seeds on the ground, on plants, or in other natural areas.
- Instruct them to collect any seeds they find and place them in separate containers or bags, labeling each seed type if possible.
- Bring the students back to a designated meeting area, such as an outdoor classroom or the regular classroom, with their collected seeds.
  - Provide each group or student with a clean workspace and small containers for organizing their seeds.
    - Instruct students to share their findings and identify the seeds they collected in their science notebooks
      - Seed Identification:
        - Name and identify each type of seed you collected. Use scientific or common names if known. If you're unsure of the name, provide a descriptive name.
      - Seed Characteristics:
        - Describe the characteristics of each seed, including:
        - Size (measurements in millimeters or centimeters).
        - Shape (e.g., oval, round, elongated).
        - Color (be as specific as possible).
      - Location of Seed Discovery:
        - Explain where you found each of the seeds in the school yard. Be specific about the environment or location. For example:
          - Near a tree in the courtyard.
          - Under a bush near the playground.
          - Along the edges of the soccer field.
      - Additional Observations:
        - Note any additional observations about the seeds, such as unique features, textures, or any signs of adaptations that you observed in the seeds.
      - Reflection (Optional):
        - Reflect on the diversity of seeds you encountered during the collection process. What surprised you the most about the seeds you found? Do you notice any patterns or trends in seed characteristics based on where they were found?
- Engage in a deeper discussion about the diversity of seeds found in the school yard by asking a series of questions and encouraging students to share their observations and insights:
    - What Types of Seeds Did You Find, and Where Did You Find Them?
      - Allow students to describe the various types of seeds they discovered and share where they found each seed. Encourage them to use descriptive language.

- How Do These Seeds Compare to the Ones You Collected from the Dissected Flowers?
    - Prompt students to compare the seeds they found in the school yard to the ones they collected from dissected flowers. Encourage them to note any similarities or differences in size, shape, or other characteristics.
- Why Do You Think Seeds Come in Various Shapes and Sizes?
    - Spark a discussion about the reasons behind the diversity of seed shapes and sizes. Encourage students to think about the advantages different seeds might have in terms of survival and growth.
- Do You Think the Different Shapes and Sizes of Seeds Serve Different Functions or Adaptations?
    - Encourage students to consider whether certain seed shapes and sizes might be adaptations that help seeds disperse, germinate, or survive in specific environments.
- How Might the Diversity of Seeds Benefit Plants and Ecosystems?
    - Foster a discussion about the ecological significance of seed diversity. Encourage students to think about how different seeds contribute to biodiversity and ecosystem ealth.
- Can You Make Any Predictions About Where You Might Find Certain Types of Seeds in Nature?
    - Challenge students to make predictions about where they might find specific types of seeds in their natural habitats based on the seeds they've encountered.

From Flower to Fruit: Unveiling the Secrets of Plant Reproduction (Elaborate)

- Imagine you have a magical plant that can reproduce in a completely different way than most plants you've seen. Instead of relying on seeds, this plant can create new individuals without any involvement from another plant. It's like the plant has a superpower!
    - How do you think this magical plant might reproduce, and what advantages or disadvantages do you think this method of reproduction could have?
- So, what exactly is asexual reproduction?
    - In simple terms, it's a method where a single parent plant can produce offspring that are genetically identical to itself. No need for seeds, no need for pollinators – just the plant's own ingenious mechanisms at work.
    - Explaining Asexual Reproduction Methods:
        - Runners or Stolons: "Imagine a plant sending out long, horizontal stems above the ground. These stems, called runners or stolons, can take root and give rise to a new plant. It's like the original plant saying,

'Hey, I'm going to send a clone of myself over there!'"

- Rhizomes: "Now, picture an underground stem called a rhizome. This underground system allows the plant to spread out and produce new shoots, creating an entire network of genetically identical plants. It's like nature's own underground cloning network!"
- Tubers: "Ever heard of a potato? That's a tuber, and it's another way plants reproduce asexually. The 'eyes' on a potato are actually buds that can grow into new plants. So, when you plant a potato, you're essentially planting a piece of the original plant."
- Bulbs: "Bulbs, like those of onions or tulips, are storage structures that contain everything a new plant needs to grow. These bulbs can sprout into new plants, and just like that, you have a perfect genetic copy of the parent plant.
  - "Now that we've covered a few examples, let's discuss. What advantages might a plant gain from reproducing asexually? Why do you think some plants use both sexual and asexual reproduction methods? How might asexual reproduction be advantageous in certain environments?"

- How does asexual reproduction work?
- The answer lies almost entirely in cell groups known a meristems
  - Meristems are small clusters of cells that are concentrated at the growing points of plants; the root tips and the leaf nodes
    - These groups of cells remain indeterminate in their growth pattern until they are quite advanced
    - Every cell within a plant shares the exact same genetic make up no matter if it forms a part of the leaves or roots
      - What develops is based on its position on the plant may develop into leaves, flowers, roots or stems
      - Just what the meristem will develop into is largely determined by its position within the plant
      - In most plants these meristems that are under the soil will develop into roots, and those above ground into leaves, stems and flowers.
        - However, if we take a section of stem growth which would normally be above ground and insert it into the soil the meristems will tend to behave as if they originally been below ground.
        - They will develop into roots and we get a successful asexual reproduction of the plant
          - Please note that the above is a simplistic explanation of the more complex hormonal

changes that are involved
- Growth hormones known as auxins are also involved in the complex process
- A cutting creates a highly abnormal circumstances and the absence of vital parts which are needed for effective functioning and survival.
- As a result, cells located in appropriate parts of the cuttings are reprogrammed to produce whatever new structures are needed to restore a complete and fully functional plant

- As a contrast to sexual reproduction (pollination), plants can also reproduce via asexual reproduction
    - Asexual reproduction, for example, is a way of life for many plants.
        - the 'offspring' babies are genetic clones of the parent. Genetically, they're the same organism, not a separate one, even if they grow and function independently.
        - As a survival technique, many plants are able to clone themselves fairly easily.
        - Most plants have growth cells throughout an individual that can be coaxed into producing any of a plant's most vital tissues, similar to stem cells in animals.
                - In truth the axillary buds are usually offshoots of the vascular cambium, but in annual plants the cambium only produces buds and vascular tissue in the stem. It doesn't produce consecutive rings.
                - This is also why many plants can be grown from cuttings. meristems in cut stems or branches will create roots under the right conditions, allowing the severed piece to regrow into its own plant.
    - This is why can take cuttings of a plant's stem and coax it to produce roots. This way, even if the plant gets damaged, the cast-off parts have a chance of surviving if they land in moist, nutrient-rich soil.
        - In fact, this method is routinely used by humans who want to clone a given food plant – like an apple tree – because its fruit is especially tasty.
        - Spider plants can reproduce themselves via reproduction and asexual reproduction at the same time
        - Allow students to observe the Spider plant seeds and small plantlets
            - Ask students, how could having both ways of reproduction advantageous?
                - Valuable defense against extinction
                - Especially important that are not favorable to seed growth

        - Too much rain may cause seed rot
        - Fast plant growth may choke out seedlings
        - Not enough moisture may not allow seed germination
        - Small plant that is reproduced vegetative is already partially grown and will have a stronger chance to survive
    - An advantage new plants can be produced quickly
        - Exact copies of parents
        - Seedling stage avoided
        - No need for pollinators
    - A disadvantage would be disease susceptibility will be passed on
        - No new combination of traits to be introduced into the population
- Explain to students that there are various examples of vegetative propagation and certain plant types that can best be reproduced via vegetative propagation
    - Stem cuttings
        - Swedish Ivy
        - Pathos
        - Geranium
        - Philodendron
        - Jade
    - Bulbs
        - Garlic
        - Tulip
    - Leaf Cuttings
        - Begonia
        - Snake plant
        - African violet
        - Winkled leaf peppromia
    - Offsets (new plants send out new plants right from their own bases huddlings close by the larger parent)
        - Spider plant
    - Air layering
        - Rubber plant
        - Dracana
    - Runners (some plants reproduce themselves by sending up complete new young plants at the end of long trailing stems)
        - Strawberry
        - Ajuga
    - Division
        - Bromelia
        - Fern
        - Snake plant

- Allow students to partake in propagation of plants via the above mentioned examples
- The method will depend on the type of plant accessible to the educator but all methods have been described below.
    - Division
        - Simplest way to propagate a plant – the process divides a plant into two or more smaller plants and potting each division separately. Division can occur with any plants sending more than one stem up through the surface of the soil
            - Remove the parent plant from a pot
            - Using a sharp knife “slice” the root ball into smaller pieces
                - Ensure each division has its share of the parent plant roots
            - Put the cur section into a new pot with soil
    - Offsets
        - Remove the parent plant from the pot
        - Cut the offset as close to the parent as possible
        - Plant in new pot
    - Runners
        - Using the parent plant in a pot, place an empty pot filled with soil next to the potted plant
        - Pin a runner with a paper clip tin the pot that does not have the parent plant in it.
        - Water plant
        - When firmly in place by own roots, remove the paper clip and cut the stem from the parent plant
    - Stem Cuttings
        - Common method that involves snipping off a part of a living plant and allowing it to root and develop on its own

        - Best stem cuttings are 3 -6 inches long
            - Important that at least 2 nodes (places where leaves are attached) but no more than 6 nodes

- Remove any leaves that would be below the surface of the rooting medium
- Leaves left below the surface will rot and possibly harm the cutting
- Add moist soil into a pot and make a hole for the stem
    - Do not use the cutting to make the hole

- Set the cutting in place

- Mist leaves
- Seal all in a plastic bag

        - Moisture is needed because the cutting is losing so much water from the fresh cut
    - Remove bag when roots form
- Leaf cuttings (African Violets)
    - Prepare a plant container with propagation media
    - From the parent plant, select a large, healthy leaf that is four inches in length
    - Cut leaf off with a sharp scissors
    - make short (1/2) cuts on the underside of the leaf on the main veins.
    - water and keep in a warm, indirectly lit spo
    - New plants will sprout under good conditions—Roots should appear in 3-4 weeks
    - 6 months for a flowering plant
- Air layering
    - Make a cut 1/3 way through the stem where we want roots to grow

    - Allow the area to dry overnight or at least 12 hours
    - Apply a rooting hormone to the top of the cut to encourage roots to form

- Cover the cut with moist sphagnum moss and tie in place

- Place a sheet of plastic around the moss to hold the moisture in
    - Will take months to see roots coming through the moss
    - At this point take the plastic wrap off, cut off the stem just below the new roots and pot new plant

- Add water as needed. When abundant roots are seen growing through the moss and encircling the plastic the air layered plant is ready to be separated from the parent plant
    - To prepare for transplanting, remove the plastic bag
    - Cut the stem just below the point where the roots have emerged
    - Moisten potting soil and place in a pot to ensure the root ball is about an inch below the pot
    - Gently spread the roots away from the root ball and over the soil
    - Fill in soil around the root ball about one inch below the rim of the to pot
- Discuss with students the current agriculture practice of using cuttings for fruit bearing plants that are used for human consumption
- Here are discussion questions about the pros and cons of plant asexual reproduction:
    - Pros:
        - Efficiency and Rapid Growth:
    - How does asexual reproduction contribute to the efficiency and rapid growth of plant populations?
    - In what ways can the absence of the need for pollinators and seeds be advantageous for a plant in terms of energy and resources?
- Genetic Uniformity:
    - What are the benefits of genetic uniformity in a population of plants produced through asexual reproduction?
    - In what environments or conditions might having genetically identical plants be an advantage?
- Adaptation and Survival:
    - How does asexual reproduction contribute to the adaptation and survival of plants in changing or challenging environments?

- As we wrap up our journey through the captivating world of plant reproduction, it's time to reflect on the remarkable processes, strategies, and adaptations that plants employ to ensure their survival and the continuation of their species. Throughout this unit, we've explored the intricate mechanisms and natural marvels that make plant reproduction a source of wonder and inspiration.
    - Key Insights from Our Plant Reproduction Unit
        - Diversity in Reproductive Strategies: We've discovered that plants employ a wide range of reproductive strategies, including sexual reproduction involving flowers, pollinators, and seeds, as well as asexual reproduction, where new individuals can emerge without the need for seeds.
        - Pollination Partnerships: We've marveled at the intricate relationships between plants and their pollinators, from buzzing

bees to fluttering butterflies, showcasing the vital role of these interactions in fertilization.

- Fruits as Protective Guardians: We've explored the protective and nurturing role of fruits, which shelter and support seeds on their journey to becoming new plants.
- Asexual Reproduction's Efficiency: We've delved into the world of asexual reproduction, where plants can create clones of themselves, highlighting the efficiency and advantages of this method in certain conditions.
- Plant Adaptations: We've witnessed remarkable plant adaptations that help them thrive in diverse environments, from the water-saving strategies of succulents to the specialized adaptations of desert plants

Investigations and Application
Exploring the Botanical Ballet of Plant Reproduction—Pollinators

Pollinator Educator Background Information

Not only is fruit production dependent on pollinating insects, plants can be very particular about which ones. Some fig species only accept a single species of wasp, and some orchids require specific moths for pollination to be successful Fortunately, most of our familiar fruits are not very particular, and honeybees, mason bees, bumblebees, butterflies, skippers and other insects can all contribute to the creation of fruit. During the process of pollination, the male reproductive cells of an angiosperm (pollen) are transferred from the anther (male reproductive organ) of a flower to the stigma (female reproductive organ) of the same or a different flower. The pollen creates a pollen tube, which transports the pollen down into the ovary of the flower. The pollen fertilizes an egg, thus completing the sexual reproductive process. The fertilized embryo is encased within a seed for development and dispersal.
In the realm of botanical exploration, professionals delve into the captivating intricacies of plant pollination, a fundamental process that orchestrates the perpetuation of flowering plants. As stewards of biological knowledge, these experts navigate the labyrinthine world of floral anatomy and the intricate dance between botanical entities.
The stage is set with the central characters: the flowers, adorned with male and female reproductive organs. Stamens, the male components, house the elusive pollen, a fine powder that harbors the male gametes. Meanwhile, pistils, the female counterparts, await the arrival of these tiny messengers on their stigma. Amidst this botanical theater, the actors that play pivotal roles emerge—pollinators. Bees, butterflies, and an array of insects step onto the stage, drawn by the vibrant hues, sweet nectar, and alluring scents emitted by the flowers. Bees, in particular, prove to be skilled protagonists, visiting flowers in their quest for nectar and inadvertently carrying the essence of life – pollen – from one bloom to another. In a separate act, wind takes on the role of an unseen pollinator, especially in the realm of grasses and many trees. Their subtle ballet involves the dispersal of lightweight pollen through the air, reaching its destination with the breeze's gentle guidance. As the narrative unfolds, the plot thickens with different types of pollination mechanisms. Cross-pollination, a grand drama of genetic exchange, occurs when pollen voyages from the anther of one flower to the stigma of another, fostering biodiversity. On the other side of the spectrum, self-pollination unfolds, a more intimate affair where pollen embarks on a shorter journey to the stigma of the same flower or another on the same plant.
The pollination process becomes a symphony of intricate movements. Pollen, once transferred, initiates the growth of a delicate pollen tube, navigating the path from stigma to ovary. It is within this clandestine route that the male gametes find their destination—the ovules, nestled within the ovary, triggering the alchemical process of fertilization. The significance of this botanical ballet extends beyond the petals and stamens; it permeates the ecosystem, contributing to biodiversity and supporting the delicate balance of life. The pollination narrative is interwoven with ecological services, providing sustenance to many crops essential for human consumption.
e thing to point out here is the fact that flowers and flower analogs in plants that make use of wind or water pollination do not look like the structures most of us envision

when we hear the word 'flower'. Because these plants do not need to attract animals, they don't need to bother with showy petals or nectaries. They just need their reproductive structures to be positioned high in the air and open enough that the wind can blow their pollen around. Wind-blown pollen is often microscopic, and you can point out here, too, that wind-blown pollen is what we typically associate with seasonal allergies.

Because abiotic pollination is very imprecise, plants that use wind or water for pollination have to make a LOT of it in order to be successful. So while animal pollinators do have to invest extra energy into the production of nectar and showy plant parts, that effort is rewarded by a much more precise system of pollination. They can get away with producing a fraction of the pollen that their abiotic cohorts must create.

All plants have chlorophyll (permitting photosynthesis) and cell walls. These characteristics separate them from animals, fungi, and bacteria. The major plant groups each have features that have permitted them to survive in the conditions of the sites where they originated. Many of these adaptive features have proven useful in dividing plants into related groups. Students will examine the external characteristics of these plants in light of their habitats. The earliest surviving plant groups are non-vascular (having no xylem or phloem) so they cannot readily transport either water or food from one part of the plant to another. Lacking good circulation and support, they cannot grow very large. These plants are dependent on water for reproduction. As a result, modern non-vascular plants like moss are small and largely restricted to warm, wet environments.
Ferns are one of the oldest vascular (having xylem and phloem) plants. They have conductive tissue, discrete leaves, stems and roots. Although their stems conduct liquids and provide support for upright growth, most ferns live in wet, warm environments because they are dependent upon water for reproduction. The visible reproductive parts on ferns are sori, found on the undersides of leaves.
The two large, dominant groups of vascular plants we see today are seed-bearingplants--angiosperms and gymnosperms. Their seeds allow them to grow in areas that aren't always moist. Vascular systems are highly developed, allowing some woody plants to reach great heights. Examples of these plants are tulips, grasses, and pine trees.
The unique feature of angiosperms is the flower. Flowers have features that attract and reward animal pollinators, or assist in pollination by wind or water. The group is named for the fact that its seeds have an outer seed coat, an adaptation that protects embryos further from the outside environment. Two groups of flowering plants are distinguished at this level: monocots and dicots. The names come from the number of seed leaves (cotyledons) found in members of each group.

Real world connections:

- Plant Scientists careers include: Ecologlist, entomologist, conservation biologist, botanist, agricultural scientist Environmental Policy Analyst (Pollinator Policy)

GIS Specialist (Pollinator Habitat Mapping) Environmental Consultant (Pollinator Impact Assessment) Horticulturist Wildlife Biologist

Exploring the Botanical Ballet of Plant Reproduction

Next Generation Science Standards

- MS-LS1-4.Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.

Students will be able to:

- Recognize that plant reproduction occurs in two ways, sexual and asexual. During sexual reproduction, plants and pollinators have specialized structures and produce offspring different than parent. During asexual reproduction, plant reproduction comes from vegetative parts that produces offspring identical to parents

Student Vocabulary:

Pollination: The process of transferring pollen from the male reproductive organs to the female reproductive organs of a flower.

Pollinators: Animals or insects that move pollen from one flower to another, facilitating pollination.

Nectar: A sweet liquid produced by flowers to attract pollinators.

Stigma: The part of a flower's female reproductive organ that receives pollen.

Anther: The part of a flower's male reproductive organ that produces and releases pollen.

Cross-Pollination: The transfer of pollen from one flower to a different flower on another plant.

Self-Pollination: The transfer of pollen from the anther to the stigma of the same flower or another flower on the same plant

Nature's Dance: The Symphony of Pollinators (engage)

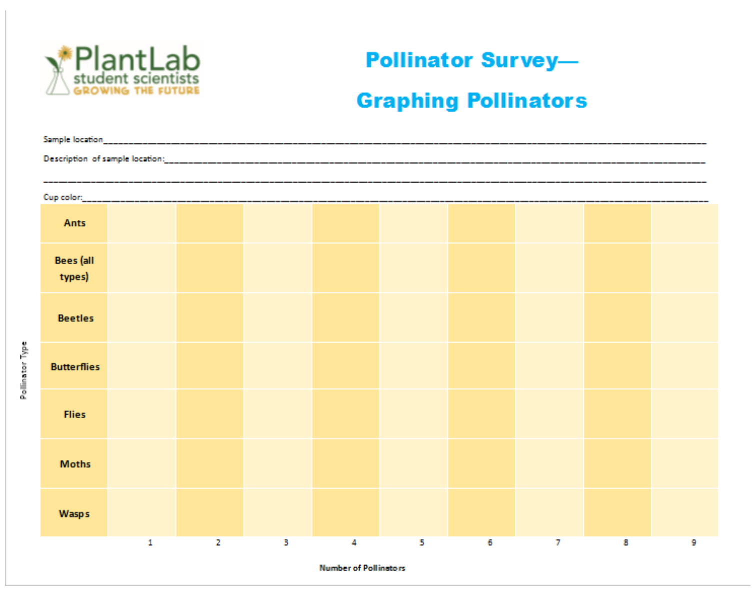
- Today, we embark on an expedition into the captivating realm of partnerships in nature. Get ready to uncover the extraordinary tale of teamwork, where flowers and pollinators join forces in a dance as old as time – welcome to the world of plant-pollinator mutualism!
    - Display an animated graphic of flowers and pollinators interacting
    - Here's a list of resources that educators can explore to find examples and information about mutualism in action:
        - National Geographic Education - Pollination and Mutualism:National Geographic Education offers resources on pollination and mutualism. Explore articles, maps, and activities to engage students in understanding the symbiotic relationships between plants and pollinators.
        - Smithsonian National Museum of Natural History - Ecosystems: The Smithsonian's Ecosystems exhibit provides online resources and information about various ecosystems, including those showcasing mutualistic relationships.
        - PBS LearningMedia - Mutualism in the Rainforest: PBS LearningMedia offers educational videos, lesson plans, and interactive activities. Search

    for resources related to mutualism, such as symbiotic relationships in the rainforest.
  - Explore Learning - Mutualism Gizmo: Explore Learning offers interactive simulations and gizmos for educators. The "Mutualism Gizmo" allows students to explore how species depend on each other for survival.
  - The Concord Consortium - Interactions in Ecosystems: The Concord Consortium provides interactive simulations on various science topics. Their "Interactions in Ecosystems" module allows students to explore the relationships between organisms, including mutualism.
  - Khan Academy - Symbiosis and Mutualism: Khan Academy offers educational videos and lessons on various subjects. Search for resources on symbiosis and mutualism to find engaging content for your students.
  - BIOINTERACTIVE - Mutualism in the Rainforest: BIOINTERACTIVE from the Howard Hughes Medical Institute offers resources on biology. Their interactive module "Mutualism in the Rainforest" explores the relationships between plants and animals.
  - Ecology Project International - Mutualism Lesson Plans: Ecology Project International provides lesson plans and resources for educators. Look for materials related to mutualism and symbiosis to incorporate into your teaching.
- Educator: (with a sense of wonder) Imagine a grand collaboration, a partnership between plants and pollinators that transcends mere chance encounters. This, my dear students, is no ordinary relationship; it's a bond forged through the ages, where both parties play a crucial role in each other's survival.
  - Bees, butterflies, and hummingbirds, the unsung heroes of the floral world. But this isn't a one-sided affair; it's a mutual exchange, a dance of give-and-take.
    - [Animated graphic illustrating the transfer of pollen.]
  - Educator: (with intrigue) So, what's the deal? Picture this – as our pollinator pals collect nectar, they inadvertently become agents of pollination, transferring pollen from one flower to another. It's a win-win scenario: the pollinators get a sweet reward, and the plants secure their future generations.
- Introduction to the activity
  - Start with a brief review of the previous lesson on pollinators and their importance in plant reproduction.
    - Discuss the different types of pollinators students learned about.
    - Introduce the concept of observing pollinators in their natural habitat.
  - Activity 1: Preparing for Observation

        - Discuss the importance of being quiet and observant to not disturb the pollinators.
        - Provide each student with their student science notebook or paper, a pencil or pen, and a magnifying glass.
            - Optionally, distribute clipboards for easier note-taking.
- Pollinator Observation
    - Take students to an outdoor area with a variety of flowering plants (school garden, park, etc.).
        - We want to observe this interaction to be able to see cross pollination in person. What is occurring when the insect visits different flowers is cross pollination
    - Invite students to go into the schoolyard for longest time allowed by classroom time length/ Be sure to encourage the students to spread out among the garden flowers and keep an eye out for visiting pollinators. (Butterflies, bees, ants, or wind are the pollinators most likely to be evident during this activity.).
        - Instruct students to quietly observe the flowers, looking for signs of pollinators.
        - Encourage them to record their observations in their field notebooks, including the type of pollinator, behaviors observed, and any unique characteristics.
            - The chart will help students visualize if a pollinator is a generalists visiting many types of flowers or a specialists only visiting one type of flower
            - Students should pay special attention to the flower color and the type of insect that is visiting that particular flower.
            - Students are to explore if there is a particular plant that is more attractive to a pollinator than others? And if we do find a plant that is more attractive why do the students think that occurs
                - This overview is very general and by no means comprehensive. These characteristics describe the flowers that tend to be most attractive to the pollinators listed.

Drawing of Flower	Name of Flower	Flower Traits	Pollinator	Time on flower

        - While students are outside, students are to observe closely for a minute or two noticing interactions between the pollinator and the flower.
            - Ask the students: What do you think the insects are getting from the plant? Do you think the plant will be hurt or helped by this interaction
                - Example: The coneflower produces nectar attractive to the bee. The bee drinks the nectar and its rear legs are covered with pollen. As it leaves, it takes the pollen and pollinates another coneflower which provides for the plant reproduction
        - Observe flowering plants in the schoolyard and observe the number of pollinator visits to that flower during observation window
    - Remind students to respect the natural environment and not disturb the pollinators.
- Group Discussion and Data Sharing
    - Bring students together for a group discussion.
    - Have each student share their observations and discuss the diversity of pollinators they encountered
        - A simple class graph can be created to capture the class data



- Discuss the importance of different pollinators in the ecosystem and how they contribute to plant reproduction.
    - Discussion Prompts and Science Notebook Entry Suggestions:
    - Pollinator Variety (Reflection):
        - Describe the different pollinators you observed during the activity. Did you see bees, butterflies, birds, or other insects?
        - What variations did you notice in the size, color, and behavior of these pollinators?
    - Pollinator Behavior (Reflection):
        - Share any interesting behaviors you observed in pollinators while they interacted with flowers. Did they visit multiple flowers? How did they collect or transfer pollen?
    - Plant Reproduction (Connection):
        - Reflect on how the behavior of the pollinators directly contributes to plant reproduction. How do these interactions between pollinators and flowers lead to the formation of seeds and fruits?
    - Biodiversity (Importance):
        - Discuss why the presence of diverse pollinators is essential for maintaining biodiversity in ecosystems. How might different pollinators help in the reproduction of various plant species?
    - Extension Activity (Research):
        - If you have chosen specific pollinator species to observe, share your findings about their behavior, habitat, and significance in pollination.
        - In your science notebook, create a section dedicated to this research, including facts, sketches, and diagrams.
    - Fruit Formation (Explanation):
        - Explain how fruit develops from a swelling section of a plant's flower. Emphasize that the primary function of fruit is to provide protection and a means of seed dispersal.
        - Describe how some fruits attract animals that assist in seed dispersal by carrying them away.
    - The Role of Attractiveness (Discussion):
        - Discuss why some fruits are designed to be attractive to animals. How does this attraction benefit both the plant and the animal?
- Extension Activity: Have students research a specific pollinator species they observed during the activity. Ask them to create a poster or presentation highlighting key facts about the pollinator's behavior, habitat, and importance in pollination.
    - Explain that fruit develops from a swelling section of a plant's flower. Technically fruit's only job is to provide protection and a means of

dispersal to the seeds inside, but some fruits deal with the dispersal aspect by being attractive to animals that will carry it off.

Nature's Dance: The Symphony of Pollinators (explore)

- Welcome, young naturalists, to a lesson that unravels the vibrant mysteries hidden within the blooming tapestry of our natural world! Today, we embark on a journey into the enchanting realm of flower color and the intricate dance it orchestrates with our buzzing companions, the pollinators.
    - Picture a world where flowers are not just nature's ornaments but dynamic signals, inviting pollinators to a feast of color and nectar. In this kaleidoscope of hues, each shade is a brushstroke, carefully painted by evolution to attract specific pollinator partners.
    - So, fasten your seatbelts as we explore how flowers use color as their language to beckon pollinators, and how this silent conversation shapes the biodiversity we cherish. Get ready to uncover the secrets behind nature's living masterpiece!
        - Introduce the concepts of phenology (seasonal changes affecting living organisms) and niche partitioning (how species divide resources to avoid competition).
        - Explain the activity: Students will explore how different colored cups attract various pollinator species, showcasing phenological adaptations and niche partitioning.
            - adaptation of biotic systems to match seasonal changes is called phenology.
            - Adapting to split up a resource and avoid competition is Niche Partitioning
        - Inform students that we will begin a pollinator survey of our schoolyard. There are many different methods researchers use to survey insects. The technique we are using is a pan trap technique and is very common practice in the research of pollinators
            - Inform students that to conduct this survey, the survey will span over two class periods
                - During today's lesson are going to place pollinator traps out in the schoolyard
                - Tomorrow we will check the results of our survey
            - By conducting this experiment we hope to learn which pollinators in our schoolyard are attracted to which colors
            - Inform students of the procedure for the survey prior to going outside
                - We now know that different pollinators are attracted to different colors
                - We have different colored cups that we will place out in our schoolyard that will mimic the flower color
                    - Colors include red, blue, yellow, clear, white and green
                        - Clear cup will represent our control in the experiment
                            - Inside each cup, we will fill it with

water and a small amount of unscented liquid dish soap.
        - The dish soap breaks the surface tension of the water and will allow us to capture the pollinator
            - Inform students that the insects we catch will not survive and we will collect them as classroom specimens
    - To set our sample, we are going to place alternate colored cups in three feet intervals near existing vegetation.
        - Once the cups are in place, fill with water and add 5 drops of liquid dish soap
            - Do not stir the soap into the water
        - Prefill a one gallon jug of water prior to going outside
    - After our collection cups have been placed outside for 24 hours, we will graph our results in our science notebook or on the pollinator graph provided

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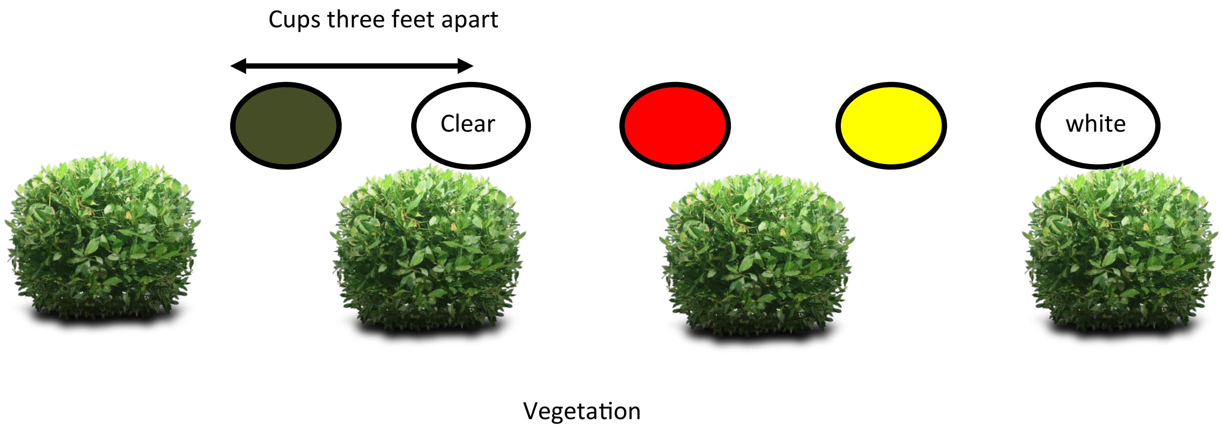
    - By conducting this experiment we hope to learn which pollinators in our schoolyard are attracted to which colors
- Once students understand the sampling method instructions, lead students outside to an area of the schoolyard campus that the sample can take place
    - Area should be as sunny a location as possible
        - If students wish to compare independent variables from a shade location and a sunny location allow this test
        - Divide students into small groups and provide each group with four differently colored cups.
            - Place cups in different environments around the school grounds (e.g., near flowers, in shaded areas, near water sources).
            - Assign each group a specific environment to observe.
                - It may be beneficial to create a "please do not disturb" sign and place it at sampling

area indicating that a science project is taking place

- We have different colored cups that we will place out in our schoolyard that will mimic the flower color
    - Place one cup of each color near vegetation, spacing the cups out no less than 3 feet
        - Location of cups does not need to be next to flowers in bloom. Pollinators will travel as they look for flowers
    - Colors include red, blue, yellow, clear, white and green
    - Clear cup will represent our control in the experiment
- Inside each cup, we will fill it with water and a small amount of unscented liquid dish soap.
    - The dish soap breaks the surface tension of the water and will allow us to capture the pollinator
    - Inform students that the insects we catch will not survive and we will collect them as classroom specimens
    - To set our sample, we are going to place alternate colored cups in three feet intervals near existing vegetation.
    - Once the cups are in place, fill with water and add 5 drops of liquid dish soap
    - Do not stir the soap into the water
        - Prefill a one gallon jug of water prior to going outside

- Remind the students that we conducted this survey to allow us to determine if our schoolyard hosts a healthy population of pollinators and which colors were our schoolyard pollinators' favorite.
    - After our collection cups have been placed outside for 24 hours, we will graph our results in our science notebook or on the pollinator graph provided



- After 24 hours, bring all cups back in the classroom and instruct the groups to Individually strain the water from each individual cup.
    - Using a spoon, remove each pollinator from the strainer and sort the pollinator based upon the type of pollinator they are: ie. Ant, fly, bee etc.
    - Create a graph in the student science notebooks and note the total number of pollinators and how many of each type of pollinator was found in each of the colored cups.
        - It is important to note that the color of the flower (in our experiment the cups) are designed to attract a particular pollinator type.
            - This interaction is vital for the success and survival of both the plant and animal
            - Students are to graph the pollinator count for each cup color.
            - Once all pollinators have been graphed for each cup color type, lead the class in a discussion to interpret the data
    - Gather students back together to discuss their observations.
        - Have each group share their findings, including the types of pollinators captured in each colored cup.
            - Facilitate a discussion on how the color of the cups may influence pollinator attraction, connecting it to phenological adaptations.
            - Introduce the concept of niche partitioning and discuss how different pollinators may have preferences for specific resources, avoiding direct competition.
                - Discuss how the distribution of pollinators among the colored cups reflects niche partitioning strategies and adaptations to seasonal changes.
                - Discussion Question: Across the groups, was there one particular color that was preferred by

pollinators?
- Discussion Question: Did this color have a variety of pollinators or just one type?
- Discussion Question: Could an organism land in our cup by mistake?
- Discussion Question: Did the location of the cups play a role? For example, did the blue cup next to the school building have the same overall number of pollinators as did the blue cup placed in the soccer field?

- Summarize the key concepts of the lesson, emphasizing the connection between phenology, niche partitioning, and pollinator behavior.
    - Discuss the broader implications of these ecological concepts on biodiversity and ecosystem health.
    - Encourage students to reflect on how understanding these adaptations can contribute to conservation efforts.

- Extension Activities If desired, collected specimens can be preserved for classroom study and observation.
    - To preserve specimens, very slowly pour hand sanitizer into a small vile to the top
        - Going slow will assist in the elimination of as many air bubbles as possible
            - Hand sanitizer has a high enough alcohol content in it to preserve the specimen
        - Using forceps or tweezers pick up a dried specimen and slowly place the insect into the vile.
        - The hand sanitizer is thick enough to ensure that the specimen will not sink to the bottom
        - If air bubbles entered the vile, an eye dropper can be used to suck up and remove the bubble
            - Discard in a separate container and repeat as needed
- With the knowledge of which pollinators inhabit our schoolyard habitat, students can create a bee hotel for our native solitary bees.
- In Missouri, there are nearly 450 different species of native bees
    - Show students the Missouri Bee Identification sheet created by the St. Louis Zoo and Missouri Department of Conservation
- ***Most of these Missouri native bees are harmless***
    - Native bees often lack a stinger long enough to penetrate human skin
        - Allow students the opportunity to create a bee hotel out of 10—20 pieces of bamboo that can come in a variety of

diameters

- Pieces of bamboo should be cut to 6″ to 8″ lengths and should have a stem node at one end to ensure one end is capped
    - Once the pieces of the bamboo have been cut, tie them into a bundle.
    - Ensure that all pieces of bamboo are horizontal, then place outdoors.
- Placement should be firm to ensure wind does not disturb the nest
    - Placement should be free of extreme weather, and the entrance hole should face east or southeast. Capturing the morning sun
    - Place near a flower garden as most bees nest yards away from their food source

- Bee hotels should be replaced every year to ensure they remain clean
    - Wasps can also take over a bee hotel, when this happens close the opening with outside materials
    - Students can observe the bee hotels over the course of the school year and document observations into their science notebook

BEE FLOWERS

Color: blue, yellow, white, pink, anthers usually yellow

Features: bowl-shape, tubular shape, horizontal with lip, landing platforms, nectar guides (lines directing bee into flower)

Scent: sweet

Other: open during day

Plants: clovers, columbine, foxglove, violet, legume family, e.g. redbud, golden chain tree, sweet pea, orchids, mint family, poppies, impatiens, snapdragon, larkspurs

Pollinators: Bees are the most numerous of all insect pollinators. Bees first locate sources of nectar by odor, then by the flower's color and shape. Bee-pollinated flowers are usually yellow or blue and frequently have lines or "guides," to indicate the location of the nectar. Some of these markings are visible only to insects. Most bees visit flowers actively seeking the pollen, which is a rich source of protein that they feed to their larvae.
Bumblebees favor foxglove, larkspurs, snapdragons—flowers providing convenient and sturdy landing platforms.

BIRD FLOWERS

Color: red, green, blue, orange
Features: sturdily constructed with wider flower tubes than in butterfly or moth-pollinated flowers
no nectar guide
downward-hanging or downward-facing with no landing platform
(Hummingbirds hover around the flower and drink while flying.)
Scent: none
Other: copious amounts of nectar

Plants: aloes, bird-of-paradise flower, eucalyptus, fuchsia, cardinal flower, trumpet creeper, scarlet salvia, red honeysuckle, mimosa, nasturtium, poinsettia, hibiscus

Pollinators: Most birds have a poor sense of smell, so flowers depending on them for pollination do not need to be fragrant. Red flowers are attractive to hummingbirds. Since some birds can drink large quantities of nectar, certain flowers have evolved to be long and tubular, able to hold much nectar.
In tropics and subtropics, birds are as important as insects, especially in mountains, where there are fewer insects. In the Old World, non-hovering birds are the pollinators so there are sturdier flowers and perches of twigs.

BAT FLOWERS

Color: snow white or drab

Features: large, sturdy, bell-shaped with wide mouth

Scent: strong, unpleasant night odors (mouse- or urine-like), stale, musty or rancid

Other: open at night
copious amounts of nectar

Plants: kapok tree, calabash tree, sausage tree, some bananas, saguaro, century plant (Agave

Pollinators: Bats are important pollinators in tropical areas. Flowers adapted to pollination by ba often large, pale, and strongly odored, particularly at dusk when bats begin to fly.

WIND-POLLINATED FLOWERS

Color: not colorful

Features: many very tiny flowers in clusters often with no petals

Scent: not scented

Other: no nectar
usually separate male and female flowers
feathery stigmas on the pistils to catch pollen, lots of dry, dust-like pollen

Plants: grasses, sedges, rushes, coniferous trees (pine, fir, cedar), and most deciduous trees (walnut, oak, birch, etc.)

Pollinators: Since flowers of wind-pollinated plants have no need to be bright, showy, or fragrant, most have no petals, Instead they have long stamens and long, feathery stigmas and styles exposed to wind currents. They produce large amounts of lightweight pollen that floats randomly on the breeze. Grasses and many trees are wind-pollinated.

FLY FLOWERS

Colors: light, dull colors, prefer yellow, brown to deep red, drab

Features: simple nectar guides, thread-like appendages

Scent: odor of decaying protein, or no odor

Other: early blooming flowers, so they are available to flies year round and in the North

Plants: holly, witch hazel, pawpaw, cacao tree, snowdrop, honeysuckle family, elderberry and vibernums

Pollinators: Many types of flies lay their eggs in decaying flesh. Some flowers have strong, unpleasant odors and maroon colors that attract flies. Flies lay eggs in the flowers, inadvertently pollinating them. Purple trillium is an example.

BEETLE FLOWERS

Colors: brown to deep red, dull whitish

Features: flat to bowl-shaped, no nectar guides

Scent: strong odor, sometimes fragrant, but often carrion- or dung-like

Other: rarely closed

Plants: magnolia, tulip tree, dogwood, skunk cabbage, Dieffenbachia, philodendron, spicebush, Cycad, water lilies

Pollinators: Beetles often eat flower parts. Flowers depending on them for pollination are often large, so some plant parts are left after beetles have dined. Magnolias are an example

CARRION FLOWERS

Unlike the fragrant blossoms that attract bees, moths, and butterflies, carrion flowers simulate the odor of a rotting carcass and attract carrion beetles and a variety of flies including blowflies and flesh flies, Not only do these flowers smell like a dead animal, but their petals are typically flesh colored, often with a dense covering of hair.

During warm weather, egg-laying blowflies can locate a stinking flower within hours. Flies move from one flower to another, looking for a place to deposit their eggs. In the process pollen is transferred from one flower to another.

BUTTERFLY FLOWERS

Color: blue, yellow, white, red, some pastels

Features: bowl-shape, tubular shape, landing platform like an upside-down witch's hat,

Scent: sweet

Other: open during day

Plants: verbena, buddleia, composites including daisies, zinnias, milkweeds

Pollinators: Butterflies often visit the same flowers that bees do. Butterflies have a long tongue called a proboscis and are therefore attracted to tubular-shaped plants.

MOTH FLOWERS

Color: drab or white

Features: no landing platform, often tubular

Scent: intense fragrance at night

Other: open only at night
lots of nectar

Plants: jasmine, gardenia, lilies, sanseviera, Missouri evening primrose, pale honeysuckle, Spanish moss (spring bloom, odor after 6 p.m.), tobacco

Pollinators: Moths are nocturnal, so the flowers they pollinate tend to be pale or white, more visible at night, and very fragrant at dusk. The flowers are often tubular, so that their nectar is accessible to long moth tongues. Many orchids are pollinated by moths.

Nature's Dance: The Symphony of Pollinators (explain)

- Begin by introducing the concept of coevolution and its relevance to the plant and pollinator relationship.
    - Explain that coevolution is a process in which two species influence each other's evolution due to their close interactions over time.
    - Coevolution Defined: Start by defining coevolution as a dynamic process in which two or more species mutually influence each other's evolution through their close interactions over an extended period.
        - Discussion Prompt: Ask students why they think it's important to study coevolution and how it might apply to real-world scenarios.
        - Science Notebook Prompt: In your notebook, write down your initial thoughts about why plants and pollinators might evolve together over time. What benefits could this mutual adaptation offer?
    - Display of Pollinator Images: Show a series of images or illustrations of various pollinators, including bees, butterflies, moths, hummingbirds, and beetles. Briefly explain their different characteristics, behaviors, and adaptations:
        - Bees: Discuss how bees are equipped with specialized body parts like branched hairs for pollen collection and color vision for flower recognition.
        - Butterflies: Explain their long proboscis (tongue) for reaching nectar deep inside flowers and their vibrant colors to attract mates.
        - Hummingbirds: Highlight their unique hovering ability, long bills for accessing nectar, and reliance on high-energy foods like nectar.
        - Moths: Mention their role as nighttime pollinators, often with coiled proboscises for accessing nectar.
        - Beetles: Discuss their strong mouthparts for chewing pollen and flower structures that make it easier for them to crawl.
            - Discussion Prompt: Ask students to consider why different pollinators have evolved different characteristics.
                - What advantages do these characteristics offer to each pollinator in their interactions with flowers?
            - Science Notebook Prompt: Choose one of the pollinators discussed and write a brief description of its unique characteristics, behaviors, and adaptations.
                - How do these features make it an effective pollinator?
    - Connecting Pollinators to Coevolution:
        - Linking Characteristics to Coevolution: Emphasize that the characteristics, behaviors, and adaptations of each pollinator have evolved in response to the specific features of the flowers they interact with. Discuss how these interactions form the basis of coevolution.
            - Discussion Prompt: Encourage students to think about how the features of flowers (e.g., color, scent, shape) might have influenced the evolution of specific pollinator traits.

        - Why is it essential for pollinators to match the flowers they visit?
    - Science Notebook Prompt: Consider the pollinator you wrote about earlier.
        - Reflect on how its characteristics are well-suited for its role as a pollinator and how these traits might have evolved over time.
- Distribute worksheets or notebooks to each student and have them draw a simple flower on the first page. Ask them to label the parts of the flower (petals, stamen, pistil, etc.).
    - Instructions for Drawing a Flower:
        - Distribution of Worksheets or Notebooks: Begin by distributing worksheets or notebooks to each student. Explain that they will be drawing a simple flower as part of their exploration of coevolution between plants and pollinators.
            - Title and Date: Ask students to write the title "My Coevolution Flower" at the top of the page, along with the date.
            - Drawing the Flower: Instruct students to draw a detailed representation of a flower in the space provided on the first page. Encourage them to include as much detail as possible, such as petals, leaves, and stem.
            - Labeling Flower Parts: Below the drawing, ask students to label the essential parts of the flower, including petals, stamen (anther and filament), and pistil (stigma, style, and ovary).
        - Discussion Prompt - Part 1:
            - Before they begin drawing, initiate a brief discussion to connect the flower they are drawing with coevolution.
            - Mention that the features of the flower they draw have evolved to attract specific pollinators.
            - "Think about the flower you're drawing. Imagine it in a real-world setting. What features do you think this flower might have developed over time to attract a particular pollinator?
                - How do you think these features benefit both the flower and the pollinator?"
    - Drawing and Labeling: Now, students can proceed to draw and label the flower while keeping in mind the discussion prompt about the flower's features and potential pollinators.
    - Discussion Prompt
        - After students have drawn their flowers and labeled the parts, initiate a second discussion prompt to encourage them to reflect on their drawings and the concept of coevolution.
            - "Look at your flower drawing and the labels you've added. Consider the specific characteristics and features

of your flower. How might these features have coevolved with a particular pollinator over time? Can you make any connections between the flower's traits and those of a pollinator that might be attracted to it?"

- Science Notebook Prompt:
  - In your science notebook, write a brief paragraph explaining how the features of your flower might have evolved in response to the characteristics of a potential pollinator. Consider how this mutual adaptation benefits both the flower and the pollinator in their coevolutionary relationship.
- After the students have reflected on their drawings and coevolution, facilitate a class discussion based on their responses to the previous prompts.
  - Encourage them to share their thoughts and ideas about the connections between flower features and potential pollinators.
- "Let's discuss the relationships between your flower drawings and the pollinators that might be attracted to them.
  - Are there any common traits or characteristics you've identified?
  - What do you think the benefits are for both the flowers and the pollinators in these interactions?"
    - Science Notebook Prompt
      - Instruct students to write down their insights and conclusions from the discussion in their science notebooks.

- Explain to students that they will now embark on an in-depth study of specific pollinators and the flowers they are attracted to.
  - This activity will allow them to explore the intricacies of coevolution in more detail.
- Assign Pollinator and Flower Pairs: Assign each student or group a particular pollinator species (e.g., honeybees, hummingbirds, butterflies) and a specific flower species that is known to be one of their primary food sources.
  - Bumblebees and Red Clover:
    - Bumblebees are excellent pollinators for red clover (Trifolium pratense).
    - Students can investigate the physical characteristics of bumblebees, such as their furry bodies and long proboscises, and how these traits aid in pollinating red clover. They can also explore how red clover has adapted its flower structure to accommodate bumblebee pollination.
  - Butterflies and Lantana Flowers:
    - Butterflies, including species like the Painted Lady butterfly, are attracted to lantana flowers (Lantana camara).
    - Students can study the colorful and fragrant lantana flowers and how they appeal to butterflies. They can also explore

butterfly characteristics, such as their delicate wings and feeding behavior, in the context of lantana pollination.

- Hummingbirds and Bee Balm (Monarda):
    - Hummingbirds are frequent visitors to bee balm or Monarda flowers.
    - Students can research the unique characteristics of hummingbirds, including their iridescent feathers and hovering abilities, and how these adaptations enable them to pollinate bee balm. They can also examine bee balm's tubular red or pink flowers and how they match hummingbirds' bill shape.
- Flies and Stinking Corpse Lily (Rafflesia arnoldii):
    - Certain flies are attracted to the massive and malodorous blooms of the stinking corpse lily.
    - Students can explore the unusual characteristics of stinking corpse lilies, including their pungent odor and large size, and how these traits mimic rotting flesh to attract flies. They can also investigate the behaviors of flies that pollinate these flowers.
- Birds (e.g., Sunbirds) and Bird-of-Paradise Flowers (Strelitzia):
    - Sunbirds, often found in tropical regions, are known for their pollination of bird-of-paradise flowers (Strelitzia reginae).
    - Students can study the vibrant and complex flowers of the bird-of-paradise plant and how they are adapted to attract sunbirds. They can also explore the feeding habits and physical characteristics of sunbirds that enable them to pollinate these flowers.
- Moths and Night-Blooming Cereus:
    - Moths, such as the hawk moth, are attracted to the fragrant and night-blooming cereus flowers (Epiphyllum oxypetalum).
    - Students can investigate the nocturnal behaviors of moths and how they navigate and pollinate night-blooming cereus flowers. They can also explore the flower's large, white petals and sweet scent, which are tailored for moth pollination.
        - Provide reference materials, books, or online resources for students to research their assigned pollinators and flowers.

- Research and Study: Instruct students to use their resources to gather information about their assigned pollinator and flower. They should focus on:
    - Assign Pollinator and Flower Pairs: Distribute the assigned pollinator and flower pairs to each student or group. Make sure they have clear instructions regarding which pollinator and flower they are responsible for.
    - Access to Resources: Ensure that students have access to various resources for their research. These resources can include textbooks, reference books, websites, articles, and any pre-selected materials you provide.

- Guidelines for Research: Provide clear guidelines for students to follow as they conduct their research. Emphasize that they should focus on specific aspects of their assigned pollinator and flower, including:
- Physical Characteristics of the Pollinator: Students should investigate the physical traits of their pollinator, such as size, shape, coloration, wingspan, feeding apparatus (e.g., proboscis, beak), and any unique features that aid in pollination.
- Unique Features of the Flower: Instruct students to explore the unique features of the flower they are studying. This can include flower shape, color, scent, size, arrangement of reproductive parts, and any specialized adaptations or structures.
- Attractiveness to the Pollinator: Encourage students to research and describe how the flower attracts their assigned pollinator. This can involve discussions of color preferences, scent production, nectar availability, and any coevolutionary adaptations that have occurred between the two species.
- Role of the Pollinator: Have students investigate the role of their assigned pollinator in pollinating the flower. What specific behaviors or actions does the pollinator perform when interacting with the flower? How does this contribute to successful pollination?
- Use of Resources: Students should utilize the provided resources effectively. They can take notes, highlight key information, and bookmark relevant websites or articles for future reference.
- Note-Taking and Documentation: Encourage students to keep organized notes and document their findings. They should record important details about the physical characteristics of both the pollinator and the flower, including measurements, colors, and any notable patterns or features.
- Support and Assistance: Be available to answer any questions or provide guidance as students conduct their research. Ensure they have access to any necessary materials, such as magnifying glasses or internet-connected devices for online research.
- Time Management: Emphasize the importance of time management, as students may need to allocate sufficient time for thorough research. Remind them of deadlines for presentations or reports.
- Collaboration: Encourage students to collaborate within their assigned groups to share and discuss their findings. Collaboration can lead to a more comprehensive understanding of both the pollinator and the flower within their coevolutionary context.

- Discussion on In-Depth Studies:
  - Pollinator Characteristics:
    - What are the most distinctive physical characteristics of your assigned pollinator?
    - How do these physical traits aid your pollinator in its role as a pollinator?

    - Are there any specific adaptations that make your pollinator well-suited for its pollination tasks?
- Flower Features:
    - Describe the unique features of the flower you studied.
    - How have these features evolved to attract and accommodate your assigned pollinator?
    - Were there any surprising or particularly interesting characteristics of the flower that you discovered during your research?
- Attractiveness to Pollinator:
    - What did you learn about how the flower attracts your assigned pollinator? Was it through color, scent, or other means?
    - Did you find any coevolutionary adaptations between the flower and pollinator that enhance their mutual attraction?
    - How does the flower ensure that its pollinator can find it easily?
- Pollinator's Role in Pollination:
    - Discuss the specific role your assigned pollinator plays in pollinating the flower. What actions or behaviors does it exhibit?
    - How does the pollinator contribute to the successful pollination and reproduction of the flower species?
    - Are there any interesting behaviors or strategies your pollinator employs during pollination?
- Mutual Benefits of the Relationship:
    - Reflect on the benefits that both the flower and the pollinator gain from their mutual relationship. How do they rely on each other for survival and reproduction?
    - Can you identify any trade-offs or costs associated with this mutualism, or is it mostly mutually beneficial?
- Comparisons Across Pairs:
    - In what ways do the findings about your assigned pollinator and flower pair align with or differ from those of other groups?
    - Are there common themes or patterns that emerge when considering different pollinators and flowers in the context of coevolution?
- Ecosystem Implications:
    - Discuss the broader implications of the plant-pollinator relationship in the ecosystem. How might the interactions between your assigned species affect the larger environment?
    - Can you think of any ecological consequences if these relationships were disrupted?
- Questions and Further Exploration:
    - Are there any unanswered questions or aspects of the coevolutionary relationship between your pollinator and flower that you'd like to explore further?
    - What additional research could be conducted to gain a deeper understanding of this plant-pollinator partnership?

- Presentation Preparation: Instruct each group to prepare a short presentation to share with the class in the next class period. Their presentations should include information about the pollinator, the flower, and how their characteristics are adapted for mutual benefit.

- Title and Introduction:
    - Ask each group to come up with a catchy title for their presentation that reflects the essence of their assigned plant-pollinator relationship.
    - Instruct them to start their presentation with a brief introduction that captures the audience's attention and outlines the main focus of their talk.
- Pollinator Profile:
    - Encourage each group to provide a detailed profile of their assigned pollinator species, including:
        - The scientific name of the pollinator.
        - Physical characteristics, highlighting any unique features.
        - Behaviors and habits related to pollination.
        - Information about its habitat and distribution.
        - Any interesting facts or anecdotes about the pollinator.
- Flower Features:
    - Have each group thoroughly describe the specific flower species they studied, emphasizing:
        - The scientific name of the flower.
        - Unique features, such as shape, color, scent, and size.
        - Structural adaptations that facilitate pollination.
        - The geographic regions where the flower is commonly found.
        - Any historical or cultural significance of the flower.
- Coevolutionary Adaptations:
    - Ask groups to delve into the coevolutionary adaptations that have occurred between their assigned pollinator and flower. They should explain:
    - How the flower's characteristics have evolved to attract and interact with the pollinator.
    - How the pollinator's traits have adapted to efficiently pollinate the flower.
    - Any specific examples of mutual adaptations or dependencies that highlight the coevolutionary relationship.
- Mechanisms of Attraction:
    - Instruct each group to explore the mechanisms by which the flower attracts its pollinator. They should address:
        - The role of coloration in attracting the pollinator.
        - The importance of scent or fragrance in luring the pollinator.
        - Nectar production and how it entices the pollinator.
        - Any other sensory cues or signals used to guide the pollinator to the flower.
- Visuals and Illustrations:

    - Encourage groups to include visual aids, such as images, diagrams, or videos, in their presentations to help the class better understand the plant-pollinator relationship
    - Emphasize the use of clear and well-labeled visuals to reinforce key points.
- Conclusion and Mutual Benefits:
    - Ask each group to conclude their presentation by summarizing the mutual benefits of the coevolutionary relationship between the pollinator and the flower.
    - Encourage them to highlight how this partnership contributes to the reproductive success and survival of both species.
- Q&A Session:
    - After each presentation, allocate time for a brief question-and-answer session during which the audience can ask clarifying questions or seek further information.

Nature's Dance: The Symphony of Pollinators (elaborate)

- Begin by briefly reviewing the key concepts from the previous lesson, such as coevolution, plant-pollinator relationships, and the adaptations of real pollinators and flowers.
    - Discussion Questions for Review:
    - Coevolution:
        - What is coevolution, and why is it important in the study of plant-pollinator relationships?
            - Can you provide an example of coevolution between a specific pollinator and flower species?
    - Plant-Pollinator Relationships:
        - How would you define a plant-pollinator relationship, and what is the primary goal of this interaction for both parties?
        - What are some common types of pollinators, and how do they differ in terms of their characteristics and behaviors?
    - Adaptations of Pollinators:
        - What physical characteristics or traits do pollinators often possess that make them effective at their pollination tasks?
        - Can you describe one adaptation of a specific pollinator that aids in pollination?
    - Adaptations of Flowers:
        - What are some common adaptations of flowers that enhance their attractiveness to pollinators?
        - How do flowers use color, scent, or other features to entice pollinators?
    - Mutual Benefit:
        - Why is the concept of mutual benefit crucial in understanding plant-pollinator relationships?
        - How do both the plant and the pollinator benefit from their mutual interactions, and what are the consequences if this mutualism is disrupted?

- Examples of Coevolution:
  - Share one example of a well-known plant-pollinator pair that illustrates coevolutionary adaptations. How have they evolved together over time?
- Ecological Significance:
  - Discuss the ecological significance of plant-pollinator relationships. How do these interactions impact ecosystems and biodiversity?
- Human Impact:
  - What are some ways in which human activities can impact plant-pollinator relationships, and what are the potential consequences?
- Knowledge Application:
  - How might the knowledge of coevolution and plant-pollinator relationships be useful in fields like agriculture or conservation?

- Explain that in this activity, students will have the opportunity to create their own imaginary flowers and pollinators using art materials. These creations should be inspired by the principles of coevolution and mutual benefit.
  - Brainstorming Session: Have a brainstorming session where students individually or in small groups generate ideas for their imaginary flowers and pollinators. Encourage them to consider the following:
    - What unique characteristics will their flower possess to attract their pollinator?
      - Encourage students to think creatively about the unique features their imaginary flower could possess to attract their pollinator.
      - Ask them to consider the shape, size, and structure of the flower. Can it have unusual petals, patterns, or arrangements?
      - Suggest thinking about the flower's scent, if any, and whether it emits a fragrance that would appeal to their pollinator.
      - Prompt them to explore how the flower might utilize sensory cues, such as color, to signal its presence to the pollinator.
    - How will their pollinator be adapted to pollinate their flower effectively?
      - Challenge students to brainstorm adaptations for their imaginary pollinator that would make it highly effective at pollinating their unique flower.
      - Discuss how the pollinator's physical traits (e.g., size, shape, appendages) could be specialized to interact with the flower's reproductive structures.
      - Encourage students to think about the behavior of the pollinator and how it might carry out pollination in a way that benefits both the flower and itself.
      - Have them consider any sensory or communication mechanisms that their pollinator might use to locate and engage with the flower.
    - What colors, shapes, and features will make their creations stand out?

        - Prompt students to experiment with colors, shapes, and features that will make their imaginary creations visually striking and memorable.
        - Discuss the significance of color in attracting pollinators and how their chosen colors might influence the pollinator's behavior.
        - Encourage them to think beyond conventional shapes and explore unconventional or fantastical forms.
        - Ask students to consider any unique features or adaptations that could set their imaginary flower and pollinator apart from real-world examples
    - Sketching Phase: Provide studenEcosystem Integration:
        - Encourage students to think about how their imaginary flower and pollinator fit into a broader ecosystem or habitat.
        - Discuss whether their creations have specific roles in the ecosystem, such as providing food for other creatures or contributing to the overall biodiversity.
        - Challenge them to consider how their designs interact with other elements of nature, such as other plants, animals, or environmental conditions.
    - Storytelling and Context:
        - Emphasize the importance of storytelling and context in their creations. Encourage students to think about the backstory of their imaginary flower and pollinator.
        - Prompt them to consider questions like: Where do these creatures live? How do they interact with other species? Are there any unique behaviors or rituals associated with their pollination process?
    - Scientific Accuracy (Optional):
        - Depending on the educational goals, you can encourage students to incorporate elements of scientific accuracy into their designs. Discuss how certain adaptations in the natural world are grounded in biological principles.
- Provide students with art supplies and instruct them to start sketching their imaginary flowers and pollinators. They can use the reference materials from previous lessons as inspiration.
    - Distribute art supplies such as colored paper, markers, colored pencils, glue, scissors, and model clay (or access to computer programming tools if available).
    - Instructions for Sketching:
        - Instruct students to start by sketching their imaginary flowers and pollinators on paper. They should use the reference materials from previous lessons as inspiration.
            - Encourage them to pay attention to details and make their sketches as accurate and visually appealing as possible.

- Model Clay Option:
    - Begin by introducing students to the model clay option. Explain that they have the opportunity to bring their imaginary pollinator to life in 3D form using model clay.
    - Provide each student or group with an appropriate amount of model clay in various colors.
- Materials and Tools:
    - Ensure that students have access to the necessary materials and tools:
    - Model clay in different colors.
    - Sculpting tools (if available), such as clay shaping tools, rolling pins, and small carving instruments.
    - A clean and safe workspace with protective coverings (to prevent clay from sticking to surfaces).
- Planning the Sculpture:
    - Before students start working with the clay, encourage them to review their sketches or design concepts for their pollinators.
    - Instruct them to consider how they will translate their 2D designs into a 3D sculpture. Discuss any adaptations or details they plan to include.
- Step-by-Step Sculpting Process:
    - Provide step-by-step guidance on the sculpting process:
    - Begin with the core structure: Instruct students to create the basic structure of their pollinator using the primary color of clay they have chosen.
    - Adding details: Explain how they can add details, such as wings, antennae, or specific body markings, using different colors of clay. Encourage them to be precise in replicating the characteristics they envisioned.
    - Texture and surface: Discuss techniques for adding texture and surface details to their sculptures. They can use sculpting tools or even household items like toothpicks to create fine details.
    - Assembling parts: If their pollinator has multiple parts (e.g., wings, legs), guide them on how to assemble these parts securely.
    - Balancing and stability: Emphasize the importance of ensuring that their sculptures are balanced and stable so that they can stand or be displayed effectively.
- Sculpting Tips:
    - Share sculpting tips to help students work effectively with the clay:
    - Keep hands and tools clean: Model clay can pick up dirt easily, so it's essential to work with clean hands and clean tools.
        - Working in layers: Encourage students to work in layers, starting with the core structure and adding finer details as they go along.

      - Experimentation: Allow students to experiment with different sculpting techniques and materials to achieve the desired look for their pollinator.
    - Time Management:
      - Advise students on time management, as working with model clay can be time-consuming. Remind them to allocate sufficient time to complete their sculptures within the class period or over multiple sessions if needed.
    - Final Touches:
      - Instruct students to take their time with final touches and refinements to ensure that their pollinators accurately represent their original designs.
    - Drying and Display:
      - Provide information on how long the model clay sculptures need to dry, which can vary depending on the type of clay used. Advise students on how to store their sculptures during the drying process to prevent damage.
        - Once dry, discuss display options, such as creating a miniature habitat or setting that showcases their pollinators and flowers together.
  - Computer Programming Option:
    - If computer programming tools are available, inform students that they can also create a digital representation of their pollinator. This could involve coding a simple animation or simulation.
    - Provide access to relevant programming software or platforms, and offer basic guidance or tutorials if necessary.
- Peer Feedback Session:
  - Schedule a dedicated session for peer feedback once students have completed their sketches, model clay sculptures, or computer programs.
  - Divide the class into pairs or small groups to facilitate the sharing and feedback process.
    - Instruct students to take turns presenting their creations to their peers. Encourage them to discuss the following aspects of their designs:
      - The unique characteristics of their flower and pollinator.
      - How well their creations convey the adaptations and coevolutionary aspects they envisioned.
      - Any specific details or features that stand out in their designs.
      - Challenges they encountered during the creative process and how they addressed them.
  - Constructive Feedback:
    - Emphasize the importance of constructive feedback. Encourage students to provide feedback that is specific, actionable, and supportive.

    - Encourage peers to ask questions about each other's creations to gain a deeper understanding and offer suggestions for improvement.
    - Advise students to highlight aspects of the designs that they find particularly creative or effective in conveying the concept of coevolution and mutual benefit.
- Discussion on Effectiveness:
    - Prompt students to engage in discussions about the effectiveness of conveying their ideas through their chosen medium (sketch, model clay, or computer program).
    - Encourage them to reflect on whether their designs effectively showcase the coevolutionary aspects and mutual benefits of their imaginary plant-pollinator relationships.
- Collaboration and Idea Exchange:
    - Emphasize collaboration and idea exchange during the peer feedback session. Encourage students to share their own thoughts and suggestions for enhancing their peers' designs.
        - Remind them that collaborating and learning from one another's perspectives can lead to creative improvements.
- Revisions and Enhancements:
    - Encourage students to take notes on the feedback they receive from their peers. Suggest that they consider implementing constructive suggestions for revisions and enhancements to their creations.
        - Discuss the idea that the peer feedback process is an opportunity for growth and improvement in their creative work.
- Conclusion:
    - Reflection and Improvement:
        - Conclude the peer feedback session by asking students to reflect individually on the feedback they received from their peers.
        - Encourage them to identify specific ways they can improve their creations based on the feedback provided.
- Revisiting and Refining:
    - Let students know that revisiting and refining their designs based on the feedback is an essential part of the creative process.
    - Highlight that the act of revising and refining their work allows them to further develop their artistic and critical thinking skills.
- Encourage Appreciation:
    - Encourage students to express appreciation to their peers for their valuable feedback and insights. Discuss the importance of fostering a supportive and collaborative learning environment.
- Continued Collaboration:
    - Emphasize that collaboration and constructive feedback are not limited to this activity but are skills that students can apply in various aspects of their academic and creative endeavors.

Investigations and Application
Plant reproduction: Seed Germination

Seed Germination Educator Background Information

In the quiet intimacy of the soil, a profound and intricate dance of life unfolds – the wondrous journey of seed germination. At the heart of this botanical marvel lies a tiny embryonic plant encapsulated within the protective embrace of a seed. This process, seemingly modest in its initiation, carries profound implications for the survival and perpetuation of countless plant species, shaping the verdant landscapes that adorn our world.

The Seed's Dormant Reverie: A seed, in its dormant state, is a repository of potential. Wrapped in layers of protective coatings, it harbors the genetic information and essential resources required for life's awakening. This dormant phase is not a passive slumber but a contemplative interlude, awaiting the cues that will summon it to action. The seed's external shell shields it from harsh environmental conditions, ensuring that its vitality remains intact until the opportune moment arrives.

Initiating the Symphony: The overture to germination commences when environmental conditions align with the seed's intrinsic programming. Essential factors such as moisture, temperature, and light act as catalysts, breaking the seed's dormancy and signaling the start of the botanical symphony. Water infiltrates the seed, penetrating the protective layers and reinvigorating cellular activity. This hydration process activates enzymes within the seed, setting in motion a cascade of biochemical events.

Breaking Ground – Radical Emergence: A pivotal moment in germination occurs with the emergence of the radical, the embryonic root of the plant. Eager to explore its subterranean domain, the radical pierces through the seed coat, delicately navigating the soil in search of nourishment. This emergence is a testament to nature's precision, as the radical unfurls with purpose, propelled by the inherent wisdom encapsulated in the seed's DNA.

Cotyledon Unveiling – Embryonic Leaves Unfurled: Simultaneously, the cotyledons, the embryonic leaves within the seed, break free from their confinement. These tender leaves, often the first to see the light of day, unfurl with a graceful vulnerability. Their emergence signifies the plant's transition from dependency on stored nutrients to the utilization of sunlight for energy through photosynthesis. The cotyledons, like miniature green sails, harness the sun's rays, initiating the plant's journey towards autonomy.

Roots of Anchorage and Absorption: As the radical ventures deeper into the soil, it sprouts lateral roots, anchoring the nascent plant securely in its terrestrial abode. These roots, branching out like delicate fingers, serve dual roles of stability and resource acquisition. By establishing a firm connection with the soil, the roots facilitate the absorption of water and essential nutrients, ensuring the plant's continued growth and development.

Stem and Leaf Elevation – Reaching for the Sky: Concomitant with root development, the shoot – the embryonic stem and leaves – ascends towards the surface. This upward thrust is a testament to the plant's indomitable will to reach the light. The shoot system, cradling the promise of future foliage, emerges from the soil with an almost palpable sense of purpose, guided by an intrinsic awareness of its symbiotic relationship with the sun.

Importance of Germination: The significance of germination extends far beyond the seemingly routine emergence of plants from seeds. It is a poignant narrative of survival, adaptation, and the perpetuation of life on Earth. Several aspects underscore the critical importance of this botanical phenomenon. Firstly, germination serves as a mechanism for the dispersal of plant species. Through diverse strategies such as wind, water, or animal-mediated dispersal, seeds find new niches for growth, contributing to the ecological mosaic of diverse ecosystems. This dispersal not only ensures the survival of individual species but also fosters biodiversity by populating varied habitats. Secondly, germination marks the transition from a state of dormancy to active growth. The awakening of a seed represents the resilience of life in the face of adversity, as it responds to environmental cues and initiates a journey towards maturity. This process is a testament to the adaptability inherent in plant life, a dynamic dialogue with the ever-changing conditions of the natural world. Furthermore, germination plays a crucial role in the carbon cycle and the global balance of atmospheric oxygen. As plants undergo photosynthesis, converting carbon dioxide into oxygen, they contribute to the maintenance of atmospheric composition. This symbiotic relationship between plants and the atmosphere underscores the interconnectedness of all life forms on Earth. Beyond its ecological implications, germination holds profound agricultural significance. It is the foundation of crop production, providing the basis for food security and sustenance for human and animal populations alike. The understanding and manipulation of germination processes have been pivotal in the advancement of agriculture, shaping the course of human civilization. In a broader sense, the narrative of germination echoes the broader themes of life's cyclical nature. It is a story of renewal, regeneration, and the perpetuation of the green tapestry that blankets our planet. It prompts reflection on the intricate dance of life, where each seed embodies the potential for growth, adaptation, and contribution to the ever-evolving narrative of the natural world. In conclusion, the story of seed germination is a captivating saga that unfolds silently beneath the surface, but its implications resonate far and wide. It is a narrative of beginnings, of the delicate balance between dormancy and growth, and of the resilience inherent in the tapestry of life. As seeds awaken and send forth shoots and roots, they carry with them the promise of a greener, more vibrant world – a testament to the enduring beauty and complexity of the botanical realm

Real world connections:

- Plant Scientists careers include: Agronomist, Floral designer, Soil Scientists, Greenhouse manager, Propagation scientists, Plant breeder, Landscape Scientists, Environmental scientists, Entomologist, Horticulture, Plant Biologists,

Next Generation Science Standards

• MS-LS1-4. Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively. • MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.

Exploring the Botanical Ballet of Plant Reproduction

Students will be able to:

- Define seed germination as the process by which a seed begins to grow into a new plant.
- Recognize and describe the key stages of seed germination, including imbibition, radicle emergence, and cotyledon development.
- Discuss the environmental factors that influence seed germination, such as water, temperature, and light.
-

Student Vocabulary:

- Auxin: a plant hormone which causes the elongation of cells in shoots and is involved in regulating plant growth.
- Cotyledon: an embryonic leaf in seed-bearing plants, one or more of which are the first leaves to appear from a germinating seed.
- Geotropism: the growth of the parts of plants with respect to the force of gravity.
- Mutualisms: the doctrine that mutual dependence is necessary to social well-being
- Niche Partitioning: refers to the process by which competing species use the environment differently in a way that helps them to coexist
- Phenology: the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life.
- Plant embryo: A young, developing plant, such as the rudimentary plant inside the seed of higher plants
- Pollinator syndromes: are suites of flower traits that have evolved in response to natural selection imposed by different pollen vectors, which can be abiotic (wind and water) or biotic, such as birds, bees, flies, and so forth
- Seed coat: the protective outer coat of a seed.
- Seed dispersal - Seed dispersal is the movement, spread or transport of seeds away from the parent plant.
- Seed germination: is the process of seeds developing into new plants
- Germination: The process by which a seed begins to sprout and grow into a new plant.
- Imbibition: The absorption of water by a dry seed, leading to the swelling and softening of the seed coat.
- Radicle: The embryonic root of a seedling that emerges first during germination and eventually develops into the main root of the plant.
- Cotyledon: The first leaf or pair of leaves that emerges from the seed during germination, providing nutrients to the growing seedling.
- Embryo: The young, developing plant within a seed.
- Seed Coat: The protective outer layer of a seed that covers and protects the embryo.
- Hydration: The process of adding water to the seed to initiate germination.
- Environmental Factors: External conditions such as temperature, light, and moisture that can influence seed germination.
- Life Cycle: The sequence of growth and development stages that a plant goes through from seed to maturity and reproduction.
- Agriculture: The practice of cultivating plants and raising crops for food, fiber, and other resources.

Seeds Alive! Exploring the Magic of Germination (engage)

- Today, we embark on a journey into the hidden realm of nature's magic – the extraordinary process of germination.
    - Imagine a seed, seemingly dormant, holding within it the incredible potential for life. Our story begins with this unassuming seed, a tiny package of hope and renewal.
        - Provide each student or group with different types of seeds (lima beans or radish seeds work well).
        - Encourage students to examine the seeds closely, noting their size, shape, and any distinguishing features in their student science notebook
            - Ask students to predict what will happen if the seeds are provided with the right conditions for growth.
    - Seeds come in all shapes and sizes, each harboring a unique story waiting to unfold. But how does this quiet dormancy transform into vibrant life?
        - Let's dive into the tale of germination and witness the miracle within.
            - Provide students with an animated graphic of a seed cross-section
                - Within the seed lies a miniature plant, patiently waiting for its cue to emerge.
                - As we provide the right conditions – soil, water, and warmth – a symphony of biochemical reactions is set into motion, awakening the dormant seed from its slumber.
    - Now, picture this seed nestled in the soil, a cozy home ready to nurture new life. We add water, the elixir of life, triggering the seed to absorb moisture and swell. This hydration is the catalyst for change, the initiation of the plant's journey.
        - Provide students with an animated graphic of a germinating seed
        - As the seed absorbs water, the outer shell softens, and the embryonic root, known as the radical, emerges. It ventures into the soil, anchoring the seedling and seeking nourishment. Simultaneously, the shoot, the precursor to leaves and stems, stretches towards the sky, fueled by the energy stored in the seed.
            - Provide students with an animated time-lapse visuals of seed germination
    - Our quiet seed transforms into a seedling, breaking through the surface with delicate leaves and roots exploring the soil. The once dormant seed is now a thriving plant, ready to embrace the world.
    - But why does germination matter beyond our classroom exploration? Picture vast fields of crops, wildflowers carpeting meadows, and forests teeming with life. Germination is the heartbeat of these ecosystems, ensuring the continuity of plant species and the balance of life on our planet.
        - Show images of vibrant ecosystems, fields of crops, and lush forests.
            - Ask students if they've ever wondered how all these plants come to life.
            - Explain that today, they will uncover the magical process of seed germination and its importance.
        - Why is Seed Germination Important.

    - Seed germination sustains life on our planet.
    - It's a reminder of nature's resilience and interconnectedness.
    - It's the starting point of a grand orchestra in nature.Provide each student or group with a plastic cup or small pot filled with potting soil.
  - Explain that the class will now start Activity 1: Planting Seeds.
    - Emphasize that understanding seed germination helps us understand how plants grow, reproduce, and sustain ecosystems.
    - Place the seeds and a small scoop or spoon for planting on a table in the center of the classroom.
    - Instruct students to follow these steps for planting the seeds:
      - Fill their cups or pots with potting soil, leaving about an inch from the top.
      - Select 2-3 seeds from the available options (e.g., beans, peas, sunflower, radish).
      - Plant the seeds in the soil at the recommended depth (varies depending on the seed type; provide guidelines).
        - Beans: Plant bean seeds approximately 1 to 1.5 inches (2.5 to 3.8 centimeters) deep in the soil. Beans are relatively large seeds, so they should be planted deeper than smaller seeds.
        - Peas: Plant pea seeds about 1 to 2 inches (2.5 to 5 centimeters) deep in the soil. Peas are also larger seeds and benefit from being planted somewhat deeper.
        - Sunflower: Sunflower seeds are relatively large, so you can plant them about 1 inch (2.5 centimeters) deep in the soil. Make sure to space sunflower seeds adequately to allow for their growth.
        - Radish: Radish seeds are smaller, and they should be planted relatively shallow. Plant radish seeds about 0.5 to 1 inch (1.3 to 2.5 centimeters) deep in the soil. They germinate more easily when closer to the surface.
      - Cover the seeds with soil,
    - Emphasize the importance of proper spacing between seeds to prevent overcrowding as they grow.
  - Discussion Prompts:
    - Before planting, ask students what they predict will happen to the seeds once they are planted in the soil.
    - During planting, encourage students to discuss why it's essential to plant seeds at the correct depth and not too deep or too shallow.
    - After planting, have students reflect on the different seed types they chose and any expectations they have regarding their growth.
- Explain the concept of a mini greenhouse and its role in providing optimal conditions for seed germination.

- Instruct students to cover each cup or pot with plastic wrap or place them inside clear plastic bags. Ensure they seal the containers to create a greenhouse effect.
- Place all the covered cups or pots in a location with ample natural light or under grow lights.
    - Explain that the mini greenhouse will help retain moisture and create a controlled environment for the seeds to germinate.
- Discussion Prompts:
    - Ask students why it might be necessary to create a mini greenhouse for the seeds. What environmental factors might the plastic covering help with?
    - Encourage students to consider how the greenhouse effect can mimic the natural conditions needed for seed germination.
- Observation and Documentation (Ongoing):
    - Detailed Instructions:
        - Instruct students to make daily observations and record them in their journals or science notebooks.
            - Encourage them to be specific in their observations and use sketches to document changes in the seeds, such as the emergence of shoots, roots, and leaves.
            - Emphasize the importance of consistency in observations and recording data over several days or a week.
    - Discussion Prompts:
        - During the observation period, prompt students to discuss any changes they notice in their seeds. Are all seeds germinating at the same rate, or are there differences among them?
        - Ask students to think about how their observations relate to the factors discussed earlier, such as moisture, light, and temperature.
- Class Discussion
    - Discussion Prompts:
        - During the class discussion, ask students to share their observations and insights.
        - Encourage them to discuss factors that seem essential for seed germination based on their observations.
        - Explore any variations among the seeds planted by different students or groups and why these variations might occur.
        - Discuss how the students' findings align with the broader significance of seed germination in the life cycle of plants and sustaining ecosystems.
- Conclusion
    - Discussion Prompts:
        - Summarize the key points of the lesson and ask students to reflect on what they have learned about seed germination.
        - Encourage students to consider the broader implications of their findings and how the process of seed germination impacts the natural world.

        Conclude by reiterating the importance of understanding and appreciating the silent symphony of renewal, growth, and the perpetual cycle of life that seed germination represents.

Seeds Alive! Exploring the Magic of Germination (explore)

- Begin with a captivating question: "What do you think is inside a seed, and how does it transform into a plant?"
    - Share the lesson's learning objectives and briefly explain the importance of understanding seed structures for plant growth.
        - Facilitate a brief discussion by asking students to share any prior knowledge about seeds.
            - Understanding seed structures is like having the key to unlock the mysteries of plant growth. It helps us become better gardeners, farmers, and stewards of our environment by allowing us to nurture and support plants effectively.
        - Facilitate a brief discussion by asking students to share any prior knowledge about seeds.
            - Discussion Questions:
                - Have you ever planted a seed before? What did you observe when it grew into a plant?
                - Do you know what's inside a seed? Any ideas on how it turns into a plant?
        - Introduce key terms such as seed coat, cotyledon, and embryo, connecting them to their functions.
            - Seed Coat:
                - Let's start by exploring the term "seed coat." Imagine you have a jacket to protect yourself from the cold. Well, a seed has something similar – it's called the seed coat.
                - Definition: The seed coat is the tough, outer covering of a seed. It acts like a protective shield, guarding the delicate embryo inside from harm.
                - Website Reference: Link to Seed Coat Information
                - Website Summary: This website from Britannica provides a detailed explanation of the seed coat and its role in protecting seeds. It includes images and additional information about seed structure.
            - Cotyledon:
                - move on to the term "cotyledon." Think of it as a lunchbox – but not for you! Cotyledons are like the first food storage units for the baby plant inside the seed.
                - Definition: Cotyledons are the thick, fleshy structures inside a seed that store food for the developing plant. They provide nourishment to the young plant as it begins to grow.
                - Website Reference: Link to Cotyledon Information
                - Website Summary: The Spruce offers a clear explanation of cotyledons, their functions, and their importance in seed germination. It's a user-friendly resource with visuals to aid understanding.
            - Embryo:
                - let's talk about the "embryo." Picture it as a tiny plant-to-be, all packed and ready for growth.

        - Definition: The embryo is the miniature, undeveloped plant inside the seed. It contains the essential parts of the future plant, including the shoot (which becomes the stem and leaves) and the root.
        - Website Reference: Link to Embryo Information
        - Website Summary: Science Learning Hub provides an in-depth look at seed structure and the role of the embryo. It includes interactive diagrams and explanations for a comprehensive understanding.
- We will dissect lima beans to explore their internal structures and deepen our understanding of seed anatomy
    - Explain that the lima beans were soaked overnight to soften the seed coat, making it easier for us to dissect and examine the internal structures.
        - Emphasize that planning and preparation are essential in scientific investigations to ensure accurate and successful outcomes.
    - Organize the materials in a way that is easily accessible to students.
        - Lima beans (soaked overnight)
        - Dissecting trays (one for each student or group)
        - Magnifying glasses (one for each student or group)
        - Tweezers or dissecting needles (one for each student or group)
        - Science notebooks or journals
        - Pencils or pens
        - Paper towels or disposable wipes for cleanup
        - Plastic bags or containers for discarding used materials (such as seed coats)
        - Printed or visual reference materials (diagrams or images of lima bean seed structures, if available)
    - Place the following items at each student's station:
        - Dissecting tray: This is where students will perform the dissection.
        - Lima beans: Provide each student with one soaked lima bean.
        - Magnifying glass: Explain that this will help students observe details more closely.
        - Tweezers or dissecting needles: Emphasize the importance of gentle handling to avoid damaging seed structures.
        - Science notebook and pencils: Encourage students to use detailed drawings and labels for recording observations systematically.
    - Demonstrating Proper Technique:
        - Demonstrate the proper technique for lima bean dissection before students begin.
        - Show how to use the tweezers or dissecting needles to carefully remove the softened seed coat.
        - Emphasize the gentle handling of tools to avoid

damaging the seed structures.

- Dissection Process:
- Instruct students to:
    - Place the soaked lima bean in the dissecting tray.
    - Use the tweezers or dissecting needles to gently remove the seed coat.
    - Observe and draw what they see in their science notebooks, paying attention to the seed coat, cotyledon, and embryo.
        - Note any surprises or unexpected findings.

- Collaboration and Discussion:
    - Encourage students to discuss their observations with a partner, promoting collaboration and deeper understanding.
    - Pose open-ended questions to guide the discussion, such as:
    - "How does the seed coat protect the embryo?"
    - "Why might the cotyledon be compared to an egg yolk?"
- Sharing Findings and Seed Dispersal:
    - Allow students to share their findings and discuss any variations observed among different seeds.
    - Relate the observed seed structures to the concept of seed dispersal.
    - Discuss different mechanisms of seed dispersal (e.g., wind, animals, water) and how they contribute to a plant's survival.
- Recap and Reinforcement:
    - Recap the main points about seed structures and their roles in plant growth and survival.
    - Reinforce the idea that each part plays a crucial role in the germination process.

Lab Safety Reminders:

- Reiterate safety precautions, such as using tools responsibly and disposing of materials properly.
- Ensure that students wash their hands after the dissection activity to maintain hygiene.

Seeds Alive! Exploring the Magic of Germination (Explain)

- Begin by discussing the importance of seeds in plant growth.
    - Ask students what they know about how seeds grow into plants.
    - Explain that seed germination is the process by which a seed develops into a young plant.
    - Discuss the factors that influence seed germination, focusing on the role of temperature.
    - Ask students to share any thoughts or prior knowledge about how temperature might affect seed germination.
        - Discussion Point 1: Temperature as a Trigger
            - Temperature serves as a trigger for many biological processes, and seed germination is no exception. Seeds are like little packages of potential life. They contain all the necessary genetic information and resources for a new plant to grow, but they need the right environmental conditions to kickstart this

process.
    - When a seed experiences the right temperature range, it's like a wake-up call that signals the seed to start germinating. Temperature acts as a switch that activates the plant's growth hormones.
- Discussion Point 2: Temperature Ranges
    - Different plant species have different temperature preferences for germination. Some plants prefer cooler temperatures, while others require warmth.
    - Typically, seeds have a minimum, optimum, and maximum temperature range for germination. The minimum temperature is the lowest temperature at which germination can occur, the optimum is the ideal temperature for germination, and the maximum is the highest temperature at which germination can happen.
    - For example, some seeds might require cooler temperatures, like those in the fall or winter, to break their dormancy and start growing. Others might need the warmth of spring or summer.
- Discussion Point 3: Effects of Temperature Extremes
    - If temperatures are too low, the seed may remain dormant, meaning it won't start germinating. Cold temperatures can inhibit or slow down the metabolic processes necessary for growth.
    - On the other hand, if temperatures are too high, they can damage the seed's delicate structures or cause it to dry out. High temperatures can also lead to the loss of moisture, which is essential for germination.
- Discussion Point 4: Seasonal Adaptations
    - Many plants have adapted to specific seasons for germination. For instance, some seeds have evolved to germinate in the spring when temperatures start rising and conditions become favorable.
    - Others, like certain types of bulbs, might have a dormant period during the winter, when it's too cold for growth, and then they germinate when warmer temperatures return in the spring.
- Discussion Point 5: Role in Agriculture
    - Understanding the temperature requirements for seed germination is crucial in agriculture. Farmers need to know when and under what conditions to plant their crops to maximize germination rates and crop yields.
    - Temperature also affects the timing of planting and harvesting in different regions and climate
- Why do you think seeds need to go through a process like germination to grow into plants?
    - What do you think might happen to seeds if they are exposed to extreme temperatures?
- Science Notebook Prompt:
        - Write down your thoughts about how temperature might affect the germination of seeds.
- Provide each student with two clear plastic cups, paper towels, and 8

pinto bean seeds.

- Instruct students to fold one sheet of pre-moistened paper towel around one of the clear plastic cups.
- Have them stuff the remaining paper towels inside the folded towel to ensure the moistened paper towel is in contact with the glass.
- Ask students to evenly space four bean seeds between the folded towel and the plastic cup.
- Label the cups as "Refrigerator" and "Room Temperature."
    - Place one cup in a refrigerator and the other in a non-refrigerated area (room temperature).
- Instruct students to keep the paper towels touching the bean seeds moist and observe them for the next week.
    - Encourage students to document their observations and thoughts on why seeds may not germinate in a refrigerator in their science notebooks.

- Observation and Discussion
    - Begin by asking students to share their observations of the cups and any changes they noticed.
    - Discuss the differences between the two sets of seeds (refrigerator vs. room temperature).
    - Emphasize the importance of careful observation in science experiments.
        - Open your science notebook to a blank page dedicated to tracking the growth of your seeds in the refrigerator and room temperature conditions.
        - At the top of the page, write a clear and descriptive title, such as "Seed Growth Observation Log."
        - Set Up Columns
            - Draw a table with two columns. Label the left column "Refrigerator" and the right column "Room Temperature."
        - Record the Date
        - On the first day of your experiment (Day 1), make your initial observations:
            - In the "Refrigerator" column, write down the date (e.g., "Day 1") and describe the appearance of the seeds in the refrigerator cup. Note any changes you observe.
            - In the "Room Temperature" column, do the same for the seeds in the room temperature cup.
        - Each day, for the next week or however long your experiment lasts, follow these steps:
            - Write down the date in the "Date" row of both columns.
            - Observe and describe the seeds in the refrigerator cup. Note any changes in size, color, or any signs of germination.
            - Do the same for the seeds in the room temperature cup, describing their appearance and

any changes.

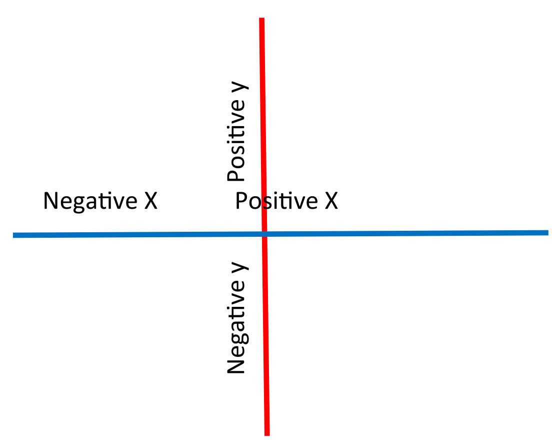
- Be detailed in your descriptions. Use words like "enlarged," "cracks in the seed coat," "roots starting to emerge," and "green shoots" to describe what you see.

- If you're comfortable with it, you can also make simple sketches or diagrams in your notebook to visually represent the changes you observe.
    - For example, you can draw the seeds at different stages of growth.
- As you continue your daily observations, make comparisons between the seeds in the two conditions. Note any significant differences in growth or changes over time.
- At the end of your observation period, summarize your findings in your science notebook. You can draw conclusions about how temperature affected seed germination based on your observations.
- Reflect on what you've learned through this experiment and any insights you gained about the role of temperature in seed germination.
    - Discussion Questions:
        - What differences did you observe between the seeds in the refrigerator and those at room temperature?
        - Based on your observations, what do you think is happening to the seeds in each condition?

- Science Notebook Prompt:
    - Record your observations and any hypotheses you have about the differences in seed germination between the two temperature conditions.
        - Remind students to continue monitoring and documenting the seed growth over the next week.
- Drawing Conclusions
    - Review the observations made by students over the past week.
    - Have students share their findings and discuss the differences in seed germination between the two temperature conditions.
        - Highlight the importance of temperature in seed germination and how it can affect plant growth.
        - Conclude the lesson by emphasizing the significance of understanding environmental factors on plant development.
- Discussion Questions:
    - Based on your observations, what can you conclude about how temperature affects seed germination?
    - How might the findings of this experiment relate to real-life situations in gardening or agriculture?
- Science Notebook Prompt:

        - Summarize your conclusions about the impact of temperature on seed germination based on the experiment.
- At the beginning of a seeds cycle, light and nutrients are not as important factors for seed germination than that of temperature and moisture.
    - In the previous lesson, we looked at how temperature affects the bean seeds germination rate
    - In the upcoming lesson we see how gravity affects seeds quest for moisture
        - The lesson is an example of geotropism or the directional growth of a plant organ in response to the gravitational field where roots grow downwards and shoots grow upwards
    - To begin the lesson we will be creating two separate stations for studying the effects of gravity on seed root growth
        - The first station will attempt to create a simulated field of gravity
        - The second station will harness the field of gravity felt on earth
            - Station 1 – producing a simulated field of gravity
                - Procedures
                    - Place 16 pinto beans in a glass with room temperature water
                    - Place the glass with the beans in a refrigerator and allow to sit overnight
                    - The next day, tear four pieces of aluminum foil about the size of one square foot (30cm)
                    - Tear four pieces of paper towels that are slightly less than one
                    - Place a moisten (not wet) paper towel in the center of each piece of foil
                    - Place four pinto bean seeds on each of the four moist paper towels
                    - With moisten paper towel placed in the center of
                    - This is due to the simulated field of gravity that the rotation of the turntable is creating
                    - This simulated gravity affects the root by pulling the plants auxin away from the center of the turntable
                        - Roots grow towards the auxin – since there is a concentration of auxins occurring on the outside of the of the turntable
                    - Allow students to make observations daily and track root growth

- Simulation 2 – Earth gravity affect on root growth
    - Procedure
        - Place 4 pinto beans in a glass jar with room temperature water
        - Place the glass with the beans in a refrigerator and allow to sit overnight
        - Use a small dark colored towel and wrap with saran wrap
        - This is to ensure the towel does not absorb moisture
        - Wedge the towel into the opening of the root viewing container
        - Using a dark colored paper towel, moisten at least two sheets
        - Place the paper towels inside the root viewing container
        - Place the four bean seeds 2 inches away from the top of the root viewer and on the moist paper towel
        - If needed, add additional towels to the
        - back to ensure the beans are pushed against the front of the root viewing container.
        - Allow students to make observations daily and track root growth
- Students can graph the root growth using an x y axis to chart the root growth of both the plant roots
    - Growth in the root viewers should be graphed on the negative y
    - Growth on the turn table should be graphed on the negative x



Seeds Alive! Exploring the Magic of Germination (elaborate)

- Once a seed does germinate, the seed sprouts struggles are not over
    - If a seed lands amongst a high number of like or unlike individuals it can create a competition for the limited resources
        - The problems for the sprout in a crowded area is that not all can not get the needed nutrients.
            - The sprouts growing the fastest and largest will likely survive as they outcompete the others for the nutrients needed for growth
                - We will be conducting a simulation to highlight this struggle for nutrients in a crowded population
                    - Provide student groups with two pots filled with soil and a packet of radish seeds
    - Procedures
        - In one cup, place a large amount of radish seeds to ensure an exaggerated simulation of an overcrowding scenario.
            - 25 – 30 seeds should suffice
            - Ensure students count the actual number of seeds and record this number in their student science notebook
        - Very lightly, push the seeds into the soil until they have just barely been covered
        - Label the post with the group names and the title: overcrowded population of radish seeds
        - In the second pot, plant a small amount of radish seeds
            - No more than 5 seeds
            - Ensure students count the actual number of seeds and record this number in their student science notebook
        - Very lightly, push the seeds into the soil until they have just barely been covered
        - Label the post with the group names and the title: uncrowded population of radish seeds
        - Measure a predetermined amount of water and give each pot the same amount of water
            - Water each pot so that the soil is damp all the way through, but not a mud consistence
            - ½ cup of water should suffice
        - In science notebook, mark the date in which the seeds were planted
        - Place pots in a location where they will receive the same amount of indirect sunlight

- In science notebook mark the date in which the seeds sprout was first noticed
- Water the pots the one or twice a week, ensuring both pots receive the same amount of water
    - Water at the same time
- Students should check their seeds everyday until seed sprouted.
    - Once sprouting occurs, set aside a few minute once a week for the students to check the plants and to record observations in student science notebooks
    - Students can record number of sprouts emerging, length of sprout, number of leaves on each plant
- If possible, keep plants for 5 weeks, until they grow a radish and flowers.
- After 5 weeks, instruct students to measure the width of their radish
  - Ideally, the students should see that they seeds in the crowded and uncrowded pot germinate around the same time if the conditions of light, water, and temperatures are the same
  - In the crowded cup, the first sprout to emerge with crowd out the others
  - The few that do grow will have a limited radish root growth and fewer leaves than those in the uncrowded cup
    - This is due to the smaller share of resources available for the seedlings

- The development seeded plants has occurred in the last 400+ million years
    - The first plants to successfully make the transition from water to living on land probably had no vascular system fro transporting materials throughout their bodies
    - Vascular plants appeared around 400 million years ago.
        - Vascular plants have tubes of elongated cells that connect end to end like piplines. These tubes transport water and foot to all parts of the plant
        - Rigid cell walls also provide support thus enabling vascular plants to grow much larger than nonvascular plants
    - Following the development of vascular systems the next leap forward for plants was in regards to its seed
        - Seeds appeared around 380 million years ago, gymnosperms were the first seeded plants
        - Gymnosperm comes from the Greek work gymnos, meaning naked and sperma meaning seed

            - Also refers to the fact that gymnosperm seeds do not develop within a fruit
        - Most gymnosperms are conifers
            - Conifers include pine, fir, cedar, juniper
            - Pollen of conifers are carried by wind to seed cones of the same species
                - LOTS of grains of pollen are needed to ensure that at least a few succeed in pollinating species seed cones
            - Gymnosperms make up only 15% of seed plants
    - Flowering plants, also known as angiosperms, evoloved from gymnosperms between 150 and 200 million years ago
        - This is the most recent evolution of plant phyla
        - Angiosperm comes from the Greek words angeion, meaning case and sperma meaning seed
            - References that angiosperm seeds develop within a fruit
        - Angiosperms are the best Adapted seed plants and owe
- Seed germination is the process in which the embryo inside the seed begins to grow.
    - As growth begins, the seed develops a radical (root) a stem followed by leaves
    - Seed germination depends on a variety of factors and each species of plant has a unique process to start germination
        - Ask students what are the things that a plant seed needs in order to germinate?
            - Student answers could include the following
                - Water
                - Oxygen
                - Temperature
                - Smoke
                - Nutrients
                - Soil
                - Space
                - Light
- Seeds are the primary means of reproduction for conifers (gymnosperms) and flowering plants (angiosperms)
    - Conifers produce ‘naked seeds’ (seeds not encased in a fruit of any kind) in cones, while flowering plants produce seeds in a fruit of some kind that helps facilitate dispersal.
    - The seed itself supports everything that the plant needs to begin growth and has three main parts

- The seed has a tough covering called the seed coat
    - Used for protection from disease, insects
    - Seed coat must be broken to develop into a plant
- Embryo plant has the embryonic leaves, epicotyl , hypocotyls and radical
- A food supply that surrounds the embryo
    - This is the only source of nutrients as the early stages of a plants life
    - Once all nutrients are consumed, the plant then begins to produce its own food from the process of photosynthesis

- The process of seed germination can be broken down into the following steps
    - Seed is formed and is dispersed away from the parent plant
    - Seed lands on the ground and at some point water begins to fill the seed. This process is called imbibition
    - The water reacts with enzymes that begin the plants growth cycles
    - Roots begin to form and shoots underground for continued access to water
    - Shoots form and shoot out growing towards the sun
    - Leaves form off of the shoots

Investigations and Application
Exploring the Botanical Ballet of Plant Reproduction: Seed Dispersal

Educator Background Information: Exploring the World of Seed Dispersal

Before they can grow into new plants, seeds need to leave the seed pod. If all the seeds a plant produced landed just underneath the parent plant, they would be too crowded, and the established large plant might not leave them enough light or water for them all to develop properly. When you plant seeds too thickly in a pot, you can see that they grow tall and leggy, and each plant is weak and spindly. The various methods of seed dispersal are designed to ensure that as many seeds as possible have a good chance of growing up to produce seeds of their own.

Sometimes, the pod or fruit containing the seeds is carried away from the parent plant; sometimes, individual seeds are spread to a new location. The size and shape of the seedpod or the seeds influences how they are dispersed. The main methods plants use to disperse their seeds to places with better growing conditions than directly under the parent plant include gravity, animals, force, wind and water. Often, a plant will spread its seeds by a combination of these methods. For instance, a fruit falling to the ground by gravity might then be carried away by animals, or a seed blown by the wind might land in water and be transported somewhere else before germinating.

On some plants native to Australia and South Africa, the seedpods may need the heat of the natural bush fires occurring in these areas to open and release their seeds, which are then dispersed by other means.

Dispersal of Seeds by Gravity

Seed dispersal by gravity is a straightforward mechanism where seeds rely on the force of gravity to move away from the parent plant and settle on the ground. Unlike other methods that involve external agents like wind, water, or animals, gravity dispersal is a passive process in which seeds fall directly to the ground or nearby soil.

- Examples of Seed Dispersal by Gravity:
    - Acorns (Quercus spp.): Oak trees produce acorns, large seeds with a distinctive cup-shaped cap. As acorns mature, they detach from the tree and fall to the ground due to gravity. The cap helps in the dispersal process, allowing the acorn to land some distance away from the parent tree.
    - Maple Seeds (Acer spp.): Maple trees produce seeds contained within wing-like structures known as samaras. These samaras, often called "helicopters" due to their spinning motion as they fall, are dispersed by gravity. The spinning action increases the distance the seeds can travel away from the parent tree.
    - Apples (Malus domestica): Apple trees disperse seeds through gravity when ripe fruits fall to the ground. The seeds are enclosed in the apple's core, and as the fruit decomposes, the seeds are released and settle in the soil beneath the tree.

- Coconuts (Cocos nucifera): Coconuts, though primarily dispersed by water, can also exhibit gravity dispersal. When ripe, coconuts can fall from the tree and roll along the ground, aided by their fibrous husks. This helps them move away from the parent tree.
- Horse Chestnut (Aesculus hippocastanum): The seeds of horse chestnut trees are encased in spiky, thick husks. When the seeds mature, they fall to the ground, and the spiky husk aids in their dispersal by gripping onto passing animals or attaching to their fur, facilitating movement away from the parent tree.

Seed dispersal by gravity is a crucial strategy for plants, especially those in environments where the force of gravity provides a reliable means of moving seeds away from the parent plant. It allows for the colonization of new areas and helps prevent competition among closely related individuals in the same vicinity.

Dispersal of Seeds by Animals

Seed dispersal by animals, also known as zoochory, is a mechanism where plants enlist the help of animals to transport their seeds to new locations. This mutualistic relationship benefits both the plant and the animal involved. Plants offer attractive fruits or seeds as a reward for the services of the animals, which, in turn, aid in the dispersal of seeds to different areas. This method often contributes to the spatial distribution, genetic diversity, and survival of plant species.

- Examples of Seed Dispersal by Animals:
    - Berries (e.g., Blueberries, Raspberries**):** Berry-producing plants, like blueberry and raspberry bushes, entice animals with juicy, colorful fruits. Birds and mammals are attracted to these fruits, consume them, and later disperse the seeds through their droppings in new locations. This aids in the propagation and diversity of these plant species.
    - Acorns (Quercus spp.): Oak trees produce acorns, which are often collected and cached by squirrels. Squirrels bury the acorns in various locations as a food reserve for the winter. Inadvertently, some acorns are forgotten or left behind, leading to new oak tree growth.
    - Burdock (Arctium spp.): The burdock plant produces burrs that stick to the fur of passing animals. As animals move, the burrs hitch a ride, eventually falling off in new locations. Each burr contains seeds, contributing to the dispersal of the plant.
    - Coconuts (Cocos nucifera): Coconuts can be dispersed by animals, especially in coastal areas. Floating coconuts can be carried by ocean currents, and when they reach a new shoreline, animals may feed on them. In the process, the seeds are dispersed, aiding in the plant's colonization of different coastal regions.
    - Cherries (Prunus avium): Cherry trees produce fruits with fleshy coverings attractive to birds. Birds eat the cherries and subsequently disperse the seeds through their droppings. This method helps cherry trees establish new growth away from the parent tree.
    - Dandelion (Taraxacum officinale): Dandelion seeds are attached to fluffy, parachute-like structures that enable them to be carried by the wind. However, small animals, such as rodents, can also inadvertently carry these seeds as they move through the environment, contributing to seed dispersal.

Seed dispersal by animals is a dynamic and intricate process that enhances the chances of a plant species' survival and colonization of diverse habitats. The evolution of attractive fruits, tasty seeds, or specialized structures ensures that animals play a vital role in the dispersal and propagation of various plant species

Seeds with attractive fruit or seeds

Seed dispersal by attractive fruits or seeds is a mechanism where plants produce enticing and often colorful fruits or seeds to attract animals. Animals are drawn to these appealing structures, which serve as a reward for their assistance in transporting the seeds to new locations. As animals consume the fruits or seeds, they inadvertently aid in the dispersal of seeds, contributing to the plant's reproductive success and colonization of diverse environments.

- Examples of Seed Dispersal by Attractive Fruits or Seeds:
    - Apples (Malus domestica): Apple trees produce sweet and succulent fruits that are attractive to animals, particularly mammals like deer and rodents. After consuming the apples, these animals can disperse the seeds in different locations through their droppings, aiding in the propagation of apple trees.
    - Cherries (Prunus avium): Cherry trees produce delicious and brightly colored fruits that attract birds, such as robins. Birds consume the cherries and subsequently disperse the seeds through their droppings, helping the cherry tree colonize new areas.
    - Strawberries (Fragaria × ananassa): Strawberries produce fleshy red fruits that are not only attractive to humans but also to various animals, including birds and small mammals. Animals consume the fruits, and the seeds are dispersed in their droppings or through discarded fruit remains.
    - Mangoes (Mangifera indica): Mango trees bear large, sweet, and aromatic fruits that attract fruit bats, birds, and mammals. As these animals feed on the mangoes, they may disperse the seeds to different locations, contributing to the spread of mango trees.
    - Avocados (Persea americana): Avocado trees produce creamy and nutrient-rich fruits that attract animals such as birds and mammals. Animals that consume avocados may disperse the seeds through their droppings, assisting in the natural propagation of avocado trees.
    - Tomatoes (Solanum lycopersicum): While commonly consumed by humans, tomatoes also attract various animals like birds and rodents. Animals may disperse tomato seeds after feeding on the fruits, facilitating the growth of new tomato plants in different areas.

Seed dispersal by attractive fruits or seeds is a clever strategy employed by plants to utilize animals as agents for their reproduction. The evolution of appealing features ensures that animals are enticed to interact with the fruits, inadvertently participating in the vital process of seed dispersal and contributing to the ecological success of plant species.

Seeds with clinging hooks or spines

Seed dispersal by hooks and spines is a mechanism where plants develop specialized structures that attach to the fur, feathers, or clothing of passing animals. These structures, often hook-like or spiky, enable seeds to hitch a ride on the external surfaces of animals. As animals move through their environment, the seeds are carried to new locations, aiding in the distribution and colonization of the plant species.

- Examples of Seed Dispersal by Hooks and Spines:
    - Burdock (Arctium spp.): Burdock plants produce burrs with hooked bracts that easily attach to the fur of passing animals. As animals brush against the plant, the burrs adhere to their fur. The animals unwittingly carry the burrs to new locations, and as the burrs fall off, the seeds are dispersed.
    - Cocklebur (Xanthium strumarium): Cocklebur plants have spiky burrs with hooked bracts that attach to the fur or feathers of animals. The burrs can also cling to clothing. As animals or humans move, the burrs hitch a ride, facilitating the dispersal of seeds to different areas.
    - Agrimony (Agrimonia spp.): Agrimony plants produce seeds with hooked structures that attach to the fur of animals. The seeds hitchhike on the animals, which can include mammals or even birds, and are dispersed as the animals move through the landscape.
    - Spanish Needles (Bidens spp.): Spanish needles have seeds with barbed awns that easily attach to the fur of animals or clothing. The hooked structures allow the seeds to cling and be carried away by animals, facilitating the dispersal of the plant.
    - Sweetbrier (Rosa rubiginosa): Sweetbrier, also known as eglantine rose, produces rose hips with hooked spines. Animals, especially birds, may eat the fruits, and the seeds inside are dispersed through their droppings. The hooked spines may also catch onto the feathers of birds.
    - Hitchhiker's Plant (Desmodium spp.): Plants in the Desmodium genus have seeds with hooked structures that attach to passing animals. As animals move through the vegetation, the seeds latch onto their fur or feathers, aiding in their dispersal.

Seed dispersal by hooks and spines is an adaptive strategy employed by plants to exploit the movement of animals for their reproductive success. The specialized structures enhance the chances of seeds being carried to new environments, contributing to the plant's ability to colonize diverse habitats.

Dispersal of Seeds by Force

Seed dispersal by force is a mechanism in which plants utilize internal mechanisms to eject or release seeds with significant energy, propelling them away from the parent plant. This active method of dispersal is often triggered by mechanical processes within the plant, leading to the rapid and sometimes forceful expulsion of seeds. The goal is to disperse seeds away from the parent plant, reducing competition and promoting the establishment of new individuals in different locations.

- Examples of Seed Dispersal by Force:
    - Impatiens (Impatiens spp.): Also known as touch-me-not or jewelweed, Impatiens plants have seed pods that undergo explosive dehiscence. When the seed pod matures, a slight touch or disturbance can cause the pod to burst open, forcefully ejecting the seeds. This rapid release ensures that the seeds are scattered in the vicinity of the parent plant.
    - Hura Crepitans (sandbox tree): The sandbox tree is known for its explosive seed pods. As the fruit dries, tension builds up within the seed pod. When the pod reaches maturity, it explosively bursts open, releasing seeds at high

velocities. This forceful dispersal aids in spreading seeds over considerable distances.

- Violets (Viola spp.): Some violet species have seed pods that undergo explosive opening. The seeds are forcibly ejected when the tension in the seed pod is released. This mechanism helps violets disperse their seeds away from the parent plant.
- Touch-me-not Balsam (Impatiens noli-tangere): Similar to other Impatiens species, touch-me-not balsam has seed pods that burst open upon touch. This sudden release scatters the seeds in the surrounding area, promoting the colonization of new habitats.
- Squirting Cucumber (Ecballium elaterium): The squirting cucumber has a unique method of seed dispersal. When the fruit ripens, the internal pressure increases, eventually leading to the explosive ejection of seeds through a small hole in the fruit. This forceful mechanism helps the plant disperse seeds over a distance.
- Geranium (Erodium spp.): Some species of geranium have seed pods that exhibit ballistic dispersal. As the seeds mature, the seed pods split open, and the coiled awns attached to the seeds rapidly unwind, propelling the seeds away from the parent plant.

Seed dispersal by force is a dynamic strategy that allows plants to overcome the limitations of gravity and other passive methods. By actively propelling seeds, these plants increase the likelihood of reaching new areas and optimizing their chances for successful germination and establishment

Dispersal of Seeds by the Wind

Seed dispersal by wind, also known as anemochory, is a method where plants use the air movement to transport their seeds away from the parent plant. This passive dispersal strategy relies on specialized structures that enhance the seed's aerodynamic qualities, allowing it to be carried over varying distances by the wind. Wind dispersal is particularly effective in open environments and is crucial for the colonization of new habitats.

- **Examples of Seed Dispersal by Wind:**
  - **Dandelion (Taraxacum officinale):** Dandelions produce seeds attached to a parachute-like structure called a pappus. When the seeds are mature, the pappus acts as a sail, catching the wind and carrying the seeds away from the parent plant. This aids in the widespread distribution of dandelion seeds.
  - **Maple Trees (Acer spp.):** Maple trees produce seeds encased in wing-like structures called samaras. As the samaras mature, they create a rotating motion that allows them to glide on the wind. This enables maple seeds to travel considerable distances away from the parent tree.
  - **Milkweed (Asclepias spp.):** Milkweed plants produce seeds attached to silky, parachute-like structures known as coma. The coma allows the seeds to be carried by the wind over long distances. Monarch butterflies, in their larval stage, feed on milkweed leaves, and the seeds are dispersed through their migration.
  - **Thistles (Cirsium spp.):** Thistles produce seeds attached to a pappus, similar to dandelions. The pappus aids in wind dispersal, allowing thistle seeds to be carried to new areas. Thistles are often found in open fields and

meadows.

- **Sycamore Trees (Platanus spp.):** Sycamore trees have seeds grouped in spherical clusters attached to a stem. As the clusters dry, they break apart, and the individual seeds, each equipped with a small wing, are carried by the wind. This mechanism ensures widespread dispersal.
- **Willow (Salix spp.):** Willows produce small, lightweight seeds that are equipped with a cottony structure. This cottony material helps the seeds catch the wind, allowing them to be carried to new locations. Willows often grow near water, and wind dispersal aids in the colonization of riverbanks.

Seed dispersal by wind is an efficient method that allows plants to reach areas beyond their immediate surroundings. The adaptation of seeds and fruits to utilize air currents enhances the plant's ability to find suitable conditions for germination and growth.

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Seeds that can fly or glide

Seed dispersal by flying or gliding is a method where plants have evolved structures that allow their seeds to travel through the air for varying distances. Unlike wind dispersal, which relies on the wind to carry seeds, flying or gliding dispersal involves structures that provide the seed with a controlled descent, often resembling flight. This method allows seeds to cover greater distances, facilitating the colonization of new habitats.

- Examples of Seed Dispersal by Flying or Glide:
    - Maple Trees (Acer spp.): Maple trees produce seeds in the form of samaras, which are winged structures. As the seeds mature, the samaras create a spinning motion, allowing them to glide through the air. This controlled descent enhances the distance the seeds can travel away from the parent tree.
    - Ash Trees (Fraxinus spp.): Ash trees produce winged seeds similar to maple samaras. The winged structure allows the seeds to glide through the air. This adaptation aids in the dispersal of ash seeds to new locations.
    - Dipterocarp Trees (Dipterocarpaceae family): Dipterocarp trees, commonly found in tropical rainforests, produce seeds with large, flat wings. The winged seeds can glide for extended distances when released from the tree canopy. This method is crucial for dipterocarps, as it allows them to disperse their seeds in dense forest environments.
    - Tumbleweeds (Salsola spp.): Tumbleweeds are a unique example of plants that disperse their seeds by rolling or tumbling. The dried, spherical structures of tumbleweeds break away from the plant and are propelled by the wind. As they tumble across the landscape, seeds are dispersed.
    - Boxelder (Acer negundo): Boxelder trees produce seeds with wings that enable them to glide through the air. The wings provide a controlled descent, helping the seeds cover distances away from the parent tree.
    - Cottonwood Trees (Populus spp.): Cottonwood trees produce seeds surrounded by cottony fibers. As the seeds are released, the cottony fibers create a parachute-like effect, allowing the seeds to be carried by the wind for substantial distances.

Seed dispersal by flying or gliding is an effective strategy that allows plants to cover greater distances and find suitable environments for germination. The evolution of specialized structures enhances the plant's ability to exploit the air for seed dispersal and colonization of new areas.

Seeds that drift in the wind

Seed dispersal by drifting with the wind is a method in which plants produce lightweight seeds that are easily lifted and carried away by air currents. Unlike active flying or gliding, this passive dispersal strategy relies on the wind's ability to transport seeds over varying distances. Plants with seeds adapted for drifting take advantage of the wind to disperse their seeds to new locations.

- Examples of Seed Dispersal by Drifting with the Wind:
    - Dandelion (Taraxacum officinale): Dandelions are well-known for their fluffy seeds attached to a parachute-like structure called a pappus. When the seeds are mature, the slightest breeze can lift the seeds into the air, and they drift away from the parent plant. This ensures widespread dispersal of dandelion seeds.
    - Salsify (Tragopogon spp.): Salsify, also known as goat's beard, produces seeds with a fluffy, parachute-like structure similar to dandelions. The seeds easily catch the wind, and as they drift, they can travel considerable distances away from the parent plant.
    - Milkweed (Asclepias spp.): Milkweed plants produce seeds attached to silky, parachute-like structures known as coma. The lightweight coma allows the seeds to be carried by the wind over long distances. Monarch butterflies, in their larval stage, feed on milkweed leaves, and the seeds are dispersed through their migration.
    - Fireweed (Chamerion angustifolium): Fireweed produces seeds with a tuft of silky hairs. As the seeds mature, they are lifted by the wind and can drift away from the parent plant. Fireweed is often found in open areas and disturbed soils.
    - Thistles (Cirsium spp.): Thistles produce seeds attached to a pappus, similar to dandelions. The pappus allows thistle seeds to catch the wind and drift away from the parent plant. Thistles are often found in meadows and open fields.
    - Clematis (Clematis spp.): Clematis, also known as traveler's joy or old man's beard, produces seeds with long, feathery tails. The feathery tails enable the seeds to drift with the wind, helping them disperse over a wide area.

Seed dispersal by drifting with the wind is a passive yet effective strategy that enables plants to take advantage of air currents for the widespread distribution of their seeds. The adaptation of seeds to catch the wind ensures that they can reach new locations suitable for germination and growth.

Seeds that are released from their pod by the wind

Seed dispersal by releasing from a pod with the wind is a mechanism where plants use specialized pods or capsules that split open, releasing seeds into the air. The opening of the pod is often triggered by environmental factors such as wind or touch, allowing the seeds to be carried away from the parent plant. This method provides a controlled release, ensuring that seeds are dispersed over a distance.

- Examples of Seed Dispersal by Releasing from a Pod with the Wind:
    - Milkweed (Asclepias spp.): Milkweed plants produce seed pods that split open, releasing seeds attached to silky coma. The pod's splitting is often aided by the wind, and the silky coma allows the seeds to be carried over long distances by air currents.

- Lupine (Lupinus spp.): Lupine plants produce seed pods that burst open when mature, releasing seeds into the air. The forceful release of seeds ensures that they are dispersed away from the parent plant, promoting genetic diversity and reducing competition.
- Touch-me-not Balsam (Impatiens noli-tangere): Also known as jewelweed, touch-me-not balsam produces seed pods that burst open when touched. The explosive opening releases the seeds, and wind dispersal carries them to new locations.
- Hellebore (Helleborus spp.): Hellebore plants produce seed pods that split open when mature, releasing seeds into the surrounding area. The wind can aid in carrying these seeds to new locations, promoting the plant's colonization.
- Poppy (Papaver spp.): Poppies produce distinctive seed pods that open at the top, releasing seeds when the pod is disturbed. The lightweight seeds can be carried by the wind, facilitating their dispersal to different areas.
- Lunaria (Lunaria annua): Also known as silver dollar plant or honesty, Lunaria produces flat, round seed pods that split open, releasing disc-shaped seeds. The wind can carry these seeds away from the parent plant, contributing to the spread of Lunaria.

Seed dispersal by releasing from a pod with the wind is a controlled method that allows plants to respond to environmental cues and ensure the efficient dispersal of seeds. The opening of the pod, often accompanied by wind assistance, helps in the colonization of new habitats and contributes to the plant's reproductive success.

Dispersal of Seeds by Water

Seed dispersal by water, also known as hydrochory, is a method in which plants use bodies of water to transport their seeds to new locations. This method is particularly effective in areas with rivers, streams, lakes, or coastal regions. Plants have adapted various strategies to ensure that their seeds can float and be carried by water currents, facilitating the colonization of different habitats.

- Examples of Seed Dispersal by Water:
    - Coconuts (Cocos nucifera): Coconuts are well-known for their ability to disperse over long distances by floating on water. The buoyant husk allows coconuts to be carried by ocean currents, facilitating the spread of coconut palms along coastlines.
    - Willow (Salix spp.): Willows produce small, lightweight seeds equipped with a cottony structure. The cottony material enables the seeds to float on water, aiding in their dispersal through rivers or streams. Willows often grow near water bodies, and hydrochory helps them colonize new areas.
    - Water Lilies (Nymphaea spp.): Water lilies produce seeds within buoyant fruit pods. As the seeds mature, the pods float on the water surface, and water currents carry them to new locations. This method ensures the spread of water lilies in aquatic environments.
    - Bald Cypress (Taxodium distichum): Bald cypress trees produce seeds with wing-like structures that allow them to float on water. These trees are often found in swampy or waterlogged areas, and hydrochory assists in the

dispersal of their seeds through waterways.

- Duckweed (Lemnaceae family): Duckweed is a small, floating plant that produces tiny seeds. The seeds can be dispersed by water currents, and they remain buoyant on the water's surface, facilitating the colonization of new ponds or water bodies.
- Mangroves (Rhizophoraceae family): Mangrove trees often grow in coastal areas and produce seeds that can float on water. The buoyant seeds are carried by tides and currents, helping mangroves establish in different coastal habitats.

Seed dispersal by water is crucial for plants in riparian or aquatic environments. It allows them to exploit water currents to reach new areas, contributing to the plant's survival, genetic diversity, and adaptation to different ecological niches.

Real world connections:

- Plant Scientists careers include: Agronomist, Floral designer, Soil Scientists, Greenhouse manager, Propagation scientists, Plant breeder, Landscape Scientists, Environmental scientists, Entomologist, Horticulture, Plant Biologists,

Next Generation Science Standards

MS-LS2-2: Ecosystems: Interactions, Energy, and Dynamics
Construct an argument supported by empirical evidence that plants engage in seed dispersal through various mechanisms, and explain how these methods contribute to the survival and diversity of plant populations.

MS-ESS3-3: Earth and Human Activity
Apply scientific principles to design a model that illustrates how environmental factors, such as wind, water, or animals, influence seed dispersal, and explain the ecological significance of these interactions.

MS-LS1-4: From Molecules to Organisms: Structures and Processes
Use models to describe the role of adaptations in seed structures and dispersal mechanisms, demonstrating an understanding of how these adaptations enhance the chances of successful germination and plant growth

Students will be able to:

- Recognize and describe various seed dispersal adaptations, such as wind dispersal, water dispersal, animal dispersal, and more
- Connect the observed features of seeds to the strategies that plants use to disperse their seeds in different environments.

Student Vocabulary:

- Adaptation—Adaptation is a characteristic or trait that enhances an organism's ability to survive and reproduce in its specific environment. In the context of seed dispersal, adaptations refer to features or strategies that plants have evolved to increase the effectiveness of dispersing their seeds.

- Strategy—In the context of seed dispersal, a strategy refers to the specific method or approach that a plant employs to ensure the effective distribution of its seeds. Different plants utilize various strategies based on their environmental context and ecological needs.
- Seed dispersal— Seed dispersal is the movement, spread or transport of seeds away from the parent plant.

Seeds on the move (engage)

- Begin by asking the students a thought-provoking question: "How do you think seeds manage to travel and spread to new places?"
    - Allow students to share their initial thoughts and ideas. Encourage them to think about the diverse environments where seeds might need to disperse.
        - Display a variety of seeds with different dispersal adaptations. Hold each seed up, briefly describe it, and ask students if they can guess how each seed might travel to new locations.
            - Dandelion Seed:
                - Description: Small, fluffy, and attached to a white "parachute."
                - Question: "What do you think happens when the wind blows on these seeds? How might they travel?"
            - Maple Seed (Samara):
                - Description: Flat, winged seeds often called "helicopters."
                - Question: "Have you ever seen these spinning as they fall from a tree? How does that help them disperse?"
            - Coconut:
                - Description: Large, hard-shelled seed with a fibrous husk.
                - Question: "Coconuts are known to float in water. How might this adaptation help them spread to new places?"
            - Burdock Seed:
                - Description: Small seeds with tiny hooks or burrs.
                - Question: "Why do you think these seeds have hooks on them? How might they hitch a ride to new locations?"
            - Acorn:
                - Description: Hard-shelled seed produced by oak trees.
                - Question: "What animals might be interested in eating acorns? How does this help with their dispersal?"
            - Sycamore Seed:
                - Description: Small, round seeds with a tuft of white hairs.
                - Question: "Have you seen these seeds spinning as they fall? What's their strategy for dispersal?"
            - Pea Seed:
                - Description: Round, smooth seeds often used in cooking.
                - Question: "Pea plants rely on animals to disperse their

seeds. Can you guess which animals might help them?"

- Poppy Seed:
    - Description: Tiny, dark-colored seeds found in poppy pods.
    - Question: "How might these small seeds travel to new places? What adaptations do they have?"
- Pine Cone Seed:
    - Description: Seeds found inside pine cones.
    - Question: "Pine cones open up to release their seeds. Can you think of a way that this might help the seeds disperse?"
- Milkweed Seed:
    - Description: Seeds attached to silky, white hairs. -
    - Question: "Why do you think these seeds have fluffy hairs attached to them? How does this aid in dispersal?"

- Discuss the features of each seed and connect them to potential dispersal strategies.
    - Dandelion Seed:
        - Feature: Small, fluffy, and attached to a white "parachute."
        - Dispersal Strategy: The fluffy parachute allows the seed to be carried away by the wind. It acts like a tiny sail, helping the seed travel to new locations when the wind blows.
    - Maple Seed (Samara):
        - Feature: Flat, winged seeds often called "helicopters."
        - Dispersal Strategy: The winged structure of maple seeds enables them to spin and glide as they fall. This allows them to cover more distance and land in new areas, often far from the parent tree.
    - Coconut:
        - Feature: Large, hard-shelled seed with a fibrous husk.
        - Dispersal Strategy: Coconuts can float in water due to their buoyant husk. This adaptation helps them disperse by floating in ocean currents to reach distant shores.
    - Burdock Seed:
        - Feature: Small seeds with tiny hooks or burrs.
        - Dispersal Strategy: The hooks on burdock seeds easily attach to the fur of passing animals. As animals move around, the seeds hitch a ride and are carried to new locations before eventually falling off.
    - Acorn:

        - Feature: Hard-shelled seed produced by oak trees.
        - Dispersal Strategy: Acorns are a valuable food source for many animals like squirrels. These animals bury the acorns for later consumption but often forget some, which eventually sprout into new oak trees.
    - Sycamore Seed:
        - Feature: Small, round seeds with a tuft of white hairs.
        - Dispersal Strategy: Sycamore seeds have a winged structure and are often seen spinning as they fall. This spinning motion helps them travel farther from the parent tree.
    - Pea Seed:
        - Feature: Round, smooth seeds often used in cooking.
        - Dispersal Strategy: Pea plants rely on animals, such as birds, to eat their seeds and then disperse them through their droppings.
    - Poppy Seed:
        - Feature: Tiny, dark-colored seeds found in poppy pods.
        - Dispersal Strategy: Poppy seeds are small and can be carried by the wind. Additionally, they may be spread when the pods burst open, scattering seeds.
    - Pine Cone Seed:
        - Feature: Seeds found inside pine cones.
        - Dispersal Strategy: Pine cones open up when they are exposed to heat, releasing the seeds. This often occurs during forest fires, allowing the seeds to fall onto the freshly cleared forest floor.
    - Milkweed Seed:
        - Feature: Seeds attached to silky, white hairs.
        - Dispersal Strategy: The silky hairs of milkweed seeds act like a parachute. When the wind catches them, the seeds are carried through the air to new locations
    - Use a large poster paper or a whiteboard to create an interactive display. Draw or place pictures of various environments (e.g., a meadow, a forest, near water).
    - Place each seed on the poster in the environment where it might naturally disperse. Discuss with students why each seed is suited to that specific environment.
- Show a short video clip that highlights seed dispersal in nature. Choose a video that showcases different methods of dispersal, including wind, water, and animal dispersal.
    - Seed Dispersal by Wind": Look for videos that illustrate how seeds are

carried away by the wind. These videos often showcase seeds with adaptations like parachutes or wings.

- "Seed Dispersal by Water": Search for videos that demonstrate how seeds use water to travel to new locations, often through rivers, streams, or ocean currents.
- "Animal Seed Dispersal": Explore videos that highlight the role of animals in seed dispersal. This can include animals eating fruits and spreading seeds through their droppings or seeds attaching to fur or feathers.
    - To summarize the content you may find in such videos:
    - Wind dispersal often features seeds with structures that catch the wind, like parachutes or wings. Examples include dandelion seeds and maple seeds.
    - Water dispersal can involve seeds that float or are carried by water. Coconuts are a classic example of seeds adapted for water dispersal.
    - Animal dispersal shows how animals interact with seeds, either by eating fruits and spreading seeds through their digestive systems or by seeds hitching a ride on fur or feathers. Acorns and burdock seeds are good examples.
        - Pause the video at key points to discuss specific examples and engage students in conversation.
            - Discussion Questions:
                - What did you find interesting or surprising about the different ways seeds disperse?
                - Can you identify any patterns in how certain seeds are adapted to specific environments?
                - Why do you think seed dispersal is important for plants?
- Briefly explain the purpose of the activity: to closely observe and categorize different seeds based on their dispersal adaptations.
    - Distribute a variety of seeds and magnifying glasses to each student or group. Ensure that you have a mix of seeds with different dispersal adaptations. Here are some examples of seeds you can include:
        - Maple Seeds (Samara): These seeds have wings that allow them to spin and glide in the wind. Ask students to examine the wings and note how they are shaped.
        - Dandelion Seeds: Dandelion seeds have a parachute-like structure that helps them float in the air. Encourage students to observe the fine hairs on the seeds and how

they are arranged.

- Burdock Seeds: Burdock seeds have tiny hooks that can attach to clothing or animal fur. Have students examine these hooks under the magnifying glass.
- Milkweed Seeds: Milkweed seeds have silky hairs that catch the wind and carry them away. Ask students to closely observe the silky hairs and how they are connected to the seeds.
- Coconut: If available, show a coconut as an example of a seed adapted for water dispersal. Point out its hard shell and fibrous husk, which help it float in water.
    - Instruct students to carefully observe and describe the seeds in their student science notebooks. Encourage them to use the magnifying glasses to examine the seeds closely.
    - Ask students to note any features that suggest a particular dispersal method. For example:
        - Are there wings or structures that could catch the wind?
        - Do the seeds have hooks or burrs that might attach to animals or clothing?
        - Are there hairs or structures that could help the seeds float in water?

- Allow time for individual observations
- In small groups. provide each group with a large sheet of poster paper and markers.
- Instruct students to categorize the seeds into groups based on their observations. For example, they might have categories like "Wind Dispersal," "Animal Dispersal," "Water Dispersal," etc.
    - Students can draw or paste the seeds onto the poster paper in their respective categories.
        - Invite each group to share their categorization and reasoning with the class.
        - Encourage students to discuss any similarities or differences they observed among the seeds in each category

- Discussion Questions:
    - What features did you observe that suggest a seed's dispersal method?
    - Were there any seeds that seemed to have adaptations for multiple dispersal methods?
    - How might the environment influence a plant's choice of seed dispersal method?

        - Emphasize that students will have the opportunity to observe, create, and experiment with seeds to deepen their understanding of this fascinating aspect of plant life.
            - For added creativity, allow students to use craft materials to create a visual representation of a plant that corresponds to one of the seed dispersal categories.
                - This extension can serve as a fun and artistic way for students to express their understanding of seed dispersal.

Seeds on the move (explore)

- Today, we're diving into the captivating world of seed dispersal, where plants have ingenious strategies for sending their seeds on incredible journeys. I
    - Imagine being a seed—how would you travel to find a new home and grow into a flourishing plant? To uncover the secrets of seed dispersal, we have four exciting stations awaiting your exploration. Each station represents a different adventure in understanding how plants ensure the survival of their offspring. Are you ready for this botanical expedition? Let's embark on our Seed Dispersal Adventures!
    - Wind Dispersal Station:
        - At this station, you'll become wind detectives! Investigate how seeds use the power of the breeze to travel and find the perfect spot to grow. Release seeds into the wind, watch them dance, and discover the unique adaptations that allow them to catch a ride on the air currents.
    - Water Dispersal Station:
        - Get ready to make a splash! Here, you'll explore how seeds navigate waterways to find new homes. Watch as seeds interact with water and observe the clever adaptations that help them float or sink. Discover why some plants have chosen the aquatic route for dispersing their seeds.
    - Animal Dispersal Station:
        - Calling all wildlife enthusiasts! Join us at the Animal Dispersal Station, where you'll investigate how seeds hitch a ride with our model animals. Explore the strategies that plants employ to entice animals to carry their seeds. You might even encounter some surprise passengers on this animal-friendly adventure!
    - Craft and Model Making Station:
        - Let your creativity bloom at our Craft and Model Making Station! Here, you'll express your newfound knowledge by creating visual representations of plants with specific seed dispersal methods. Choose wind, water, or animal dispersal, and craft a masterpiece that showcases the unique adaptations plants have developed for successful seed journeys.
    - Activity station instructions
    - Wind Dispersal Station:
        - Procedure with Science Notebook Data Collection:
            - Set up the wind fan in the classroom and position it at one end.
            - Place water trays at different distances from the fan, creating a gradient of wind intensity.

        - Provide various types of seeds with wind-dispersal adaptations, magnifying glasses, student science notebooks, measuring tools, and a list of guiding questions.
        - Instruct students to follow these steps and record their observations in their science notebooks:
            - Choose a seed type.
            - Stand in front of the fan.
            - Release the seed into the air in front of the fan.
            - Observe how far the seed travels under the influence of the wind.
            - Measure the distance from where you released the seed to where it landed in the water tray.
            - Record your observations and measurements in your science notebook.
            - Answer the guiding questions in your science notebook.
                - How did the wind affect the seeds?
                - Did certain seeds travel farther than others?
                - What features did seeds adapted for wind dispersal have?
- Water Dispersal Station:
    - Procedure with Science Notebook Data Collection:
        - Set up water trays in the classroom.
        - Provide various types of seeds with water-dispersal adaptations, magnifying glasses, student science notebooks, containers of water, and a list of guiding questions.
        - Instruct students to follow these steps and record their observations in their science notebooks:
            - Select a seed type.
            - Place the seed gently in the water tray.
            - Observe how the seed interacts with the water. Does it float, sink, or behave in other ways?
            - Record your observations in your science notebook.
            - Answer the guiding questions in your science notebook.
                - How did the seeds behave in water?
                - What adaptations did you notice that aid in water dispersal?
                - In what environments might water dispersal be an advantage for plants?
- Animal Dispersal Station:
    - Procedure with Science Notebook Data Collection:
        - Provide small model animals or figures (optional), various types of seeds with adaptations for animal dispersal, magnifying glasses, student science notebooks, and a list of guiding questions.
        - Instruct students to follow these steps and record their observations in their science notebooks:
        - If using model animals, place the seeds and models on a table.
        - Explore how seeds might attach to or be carried by the animals.
        - Observe the interactions between seeds and model animals or figures.

        - Record your observations in your science notebook.
        - Answer the guiding questions in your science notebook.
            - How did the seeds interact with the model animals or figures?
            - What features of seeds make them attractive to animals?
            - In what ways might animal dispersal benefit plants?
- Craft and Model Making Station:
    - Procedure with Science Notebook Data Collection:
        - Provide craft materials, large sheets of poster paper, various types of seeds with adaptations for wind, water, or animal dispersal, magnifying glasses, student science notebooks, and a list of guiding questions.
        - Instruct students to follow these steps, create a visual model of a plant that utilizes the chosen dispersal method using craft materials, and record their design process in their science notebooks:
            - Choose a seed dispersal method (wind, water, animal).
            - Pay attention to detail and incorporate features that represent the chosen method.
            - Observe how the model reflects the adaptations necessary for effective seed dispersal.
            - Answer the guiding questions in your science notebook.
                - What features did you include in your model to represent the chosen dispersal method?
                - How do the models reflect the adaptations necessary for effective seed dispersal?
    - Encourage creativity and craftsmanship in the models.
    - Optional: Each group presents their model to the class, explaining the chosen seed dispersal strategy and the features they incorporated
        - Encourage them to note the characteristics of seeds that seem Conclusion and Reflection
- Wrap up the lesson by summarizing key points and insights gained from each station.
- Discuss the diversity of seed dispersal methods and their importance in plant survival.
    - Wind Dispersal:
        - Seeds adapted for wind dispersal often have structures like wings, parachutes, or hairs that allow them to be carried by the wind.
        - Importance: Wind dispersal enables plants to colonize new areas, escape overcrowded conditions, and find optimal growth conditions. It promotes genetic diversity by dispersing seeds over long distances.
    - Water Dispersal:
        - Some seeds are adapted for water dispersal, with features that allow them to float and be transported by water currents.
        - Importance: Water dispersal is crucial for plants in riparian habitats or near bodies of water. It helps plants colonize riverbanks, lakeshores, and wetlands, expanding their range.
    - Animal Dispersal:

    - Many plants have evolved adaptations to attract animals that eat their fruits or seeds. These animals then disperse the seeds through their droppings.
    - Importance: Animal dispersal not only helps plants reach new areas but also offers a mutual benefit. Plants provide animals with food, while animals assist plants in seed dispersal. This method also allows plants to reach distant or inaccessible places.
- Explosive Dispersal:
    - Some plants have seed capsules that burst open when mature, forcefully expelling seeds.
    - Importance: Explosive dispersal helps plants colonize nearby areas by scattering seeds over a short distance. This method is ften observed in plants like peas and violets.
- Gravity Dispersal:
    - Seeds with adaptations for gravity dispersal fall directly to the ground when they mature.
    - Importance: Gravity dispersal is suitable for plants that thrive in the same environment as their parent plants. It allows seeds to settle in close proximity to the parent plant, where they are already adapted to grow.
- Ant Dispersal:
    - Some plants have seeds with specialized structures that attract ants. Ants carry these seeds back to their nests, where they consume the seed appendages and discard the seeds in nutrient-rich environments.
    - Importance: Ant dispersal is advantageous for plants in nutrient -poor soils. It also protects seeds from being eaten by other seed predators.

Seeds on the move (explain)

- Explain to students that seeds nearly always travel, but they may do it in different ways.
- Explain to students the various methods of seed dispersal
    - Seeds grow better when they germinate a distance away from their parent plant.
    - Emphasize that plants are somewhat limited in terms of what they can seek out, given that they are rooted to one spot. Given that, seeds benefit from traveling away from their parent plant.
        - The Seedy Side of Plants created as an episode of Nature by PBS explores the methods that seeds are dispersed in nature. If accesses to this documentary can not be viewed, explain the following seed dispersal mechanisms deployed by various plants
        - <u>Seeds that Fall</u>
            - Explain that many seeds rely on gravity to move them along.
            - Seeds that travel this way are typically round.
                - Why would being round help if gravity is your mode of transport?
                - Explain that most plants produce a LOT of seeds.

        - Since seeds sprout wherever they land (or try to), producing a large number of seeds ensures that at least some seeds will germinate, even if not all of them do.
    - If a tree wants at least some of its seeds to survive and grow into new trees, what strategy could it use to ensure that at least some seeds land in a good place?
    - You may also want to point out that most conifer seeds are produced inside the cone and fall out when the seed opens. The scales of the cone make a ramp that sends the seeds scattering outward as they fall out.
- <u>Seeds that Fly</u>
  - Explain that some seeds have structures that allow them to be carried by wind.
    - How is travelling through the air different for seeds and birds
      - birds, bats and insects; they use their muscles to pull them up into the air and to move through it.
      - Seeds do not have muscles or machinery, so they can only drift.
        - In order to travel a long distance, they must therefore start out high up and then make use of wind currents to carry them away.
    - Point out the fact that apple trees, which rely on animals to eat their fruit and carry the seeds away, remain relatively low to the ground where animals can more readily reach them. Elm trees, by comparison, grow very tall. Trees that produce wind-blown seeds often grow tall to give their seeds a good height from which to start drifting.
      - Once a seed falls off of a tree, what could it do to stay in the air?
      - Discuss with students the mechanics of flying machines, including a hang glider, a helicopter, and a parachute. Explain that seeds use each of these strategies to stay aloft even as gravity pulls them down.
        - Air pushes up on the fruit of the seed, keeping it up above the ground for a longer period of time.
        - Parachute seeds include dandelions, goatsbeard/salsify and milkweed. These seeds form with a structure that catches the wind and carries them the way the wind catches a kite.
        - Gliders are seeds that form with papery wings that can keep the seeds aloft. Examples of this sort include elm seeds, javan cucumber seeds, and, to a

lesser extent, basswood/linden seeds. The seeds of the latter form below a large bract that can function rather like a hang glider.
- Samaras are seeds that form with a vane. The vane causes the seed to spin through the air similar to a helicopter's propeller or a pinwheel. Examples of these seeds include maple seeds, ash seeds, etc.
- Finally, you might point out that Sweetgum seeds also make use of the wind for dispersal, but they do not have special structures. They are simply so small that they can drift on the wind like dust.

- Seeds that Float
  - Seeds are surrounded by material that allows them to float.
  - Do all seeds float?
    - Why might it be bad if seeds usually floated on the water?
    - Remind students that seeds need water to germinate.
      - If seeds typically floated, they would not be able to absorb the water they need to grow.
    - When might it be important for seeds to float?
      - Many plants living near or in bodies of water produce a fruit around that acts like a life preserver, allowing the seeds to float on the water for at least a period of time.
      - Some seeds, like a coconut, can potentially float for months due to their thick husk. The husk
- Seeds and Fur
  - seeds are designed to snag on animal fur to be carried away and dropped later.
    - Show students a sample of hook-and-loop 'Velcro' tape and ask if they have ever seen it used. Ask them to provide examples (shoes, purses, backpacks, etc.)
    - Explain that Velcro™ was developed in 1948 by an engineer in Switzerland named George de Mestral. George took his dog hiking in the Alps and returned to find that both the dog's fur and his clothing were covered with burdock seeds. Upon closer inspection, he noticed that the seeds were covered with tiny hooks that snagged and held to anything with loops, including fur.
    - Invite students to examine the clingy seeds at this station with the magnifiers and to practice sticking them to the animal toys.
    - How are the seeds here similar to Velcro™?
      - What is it about a hook-and-loop design that makes it ideal both for what Velcro™ does and what seeds need to do?

                - Point out to students that when you close something with Velcro™, you usually plan to open it again. This makes hook-and-loop closures ideal for shoes and handbags and other items that we like to open and close a lot.
            - Seeds also want to stick to fur temporarily. The hooks hold the seed to the animal for a short time while the animal walks along, but eventually the seed falls out or is brushed out by the animal. The temporary nature of the hook-and-loop design makes it ideal for both situations.
    - Seeds in Fruit
        - develop to protect seeds and entice animals to carry them away.
        - Botanically speaking, any structure that contains seeds is called a 'fruit', even though we might think of it as a 'vegetable' when we cook.
            - What vegetables can you think of that have seeds inside? (Tomatoes, cucumbers, pumpkins, squash, peppers, eggplant…)
        - How does having an edible fruit help the seed to travel?
            - Explain that most animals either eat the fruit whole (in which case the seeds pass through them and are defecated) or they eat the flesh of the fruit like we do and drop the seeds on the ground. Either way, the seed lands away from the parent plant and can grow without competing.
- With students having the background knowledge on how seeds are dispersed in nature, challenge the students to think how they could create a mechanism for a seed to travel away from its parent plant
    - Students are challenged to create a new method for a lima bean to be dispersed.
        - In nature, the seeds become hard and the pods will become dry and fall or become expelled from the pod
        - Students can design a structure for the lima bean seed to be dispersed via wind, float, or attach to animal (hitchhike)
            - To create the seed dispersal structure, provide students with the opportunity to utilize the following materials
                - Scrap paper,
                - Cardboard boxes
                - Straws
                - String
                - Rubber bands
                - Masking tape
                - Scissors
                - Other materials as provided by the educator
        - All student techniques will be tested and measured to discover with method of dispersal would provide the seed the longest traveling distance and what type of dispersal method works best in the environmental conditions of the schoolyard

- Seed structures do not have to conform to particular size constraints
- Allow students a predetermined amount of time to shift through the materials and sketch a diagram of how they will transfer a lima bean seed the farthest
    - Ensure students understand that the problem is to move the lima bean seed—the seed must remain attached to the designed structure in order to be moved a distance
- Once the design time is complete, provide students an additional amount of time to create and test their design
- Once the design has been completed and classroom tested, instruct students to take their built structures with lima bean attached outside to the schoolyard
- Once outside, allow all student designs to be tested three times
    - For those groups that created a floating structure, provide some sort of tub of water to test the design
    - For those groups that created a flying structure, a large fan may be needed to propel the seed if wind conditions are not favorable during the testing time
    - For seeds that attach, invite a student volunteer to be the "animal" and attach the seed structure to that individual
- Students are to record in their student science notebook the distances that the seed has traveled
    - Each student structures travel distance should be averaged and then graphed on a class chart
        - Once all groups have indicated their average, begin a classroom discussion on why they believe a particular seed structure created traveled the farthest or did not travel at all
            - Was a design mimicked by things a student has seen in nature
            - What changes could be made to your structures that could make the seed travel farther than it did
            - Could any of the methods travel via more than one way?
                - Would a plant be advantageous to have a seed capable to traveling in more than one way?
            - If we conducted this lesson inside the classroom, do you believe the results would have been the same?

Seeds on the move (elaborate)

- Begin by reviewing the concepts of seed germination and seed dispersal mechanisms covered in previous lessons.
    - Key Factors Influencing Seed Germination:
        - Temperature: Temperature plays a critical role in seed germination. Different plant species have specific temperature ranges at which their seeds germinate most effectively. Some seeds require warmer

temperatures, while others prefer cooler conditions. Extreme temperatures can inhibit or even damage the germination process.
    - Water: Adequate moisture is essential for seed germination. Water initiates the imbibition process, where seeds absorb water and activate enzymes responsible for germination. Without sufficient water, seeds remain dormant and cannot germinate.
    - Light: Light is a variable factor in seed germination. Some seeds require light to trigger germination (light-sensitive), while others germinate in darkness (light-insensitive). This adaptation allows seeds to germinate under suitable conditions for their growth.
- Various Methods of Seed Dispersal in Nature:
    - Wind Dispersal: Seeds adapted for wind dispersal often have structures like wings, parachutes, or hairs that allow them to be carried by the wind. Examples include dandelion seeds and maple seeds (helicopters).
    - Water Dispersal: Some seeds are adapted for water dispersal and can float on water surfaces. These seeds can be transported by water currents, enabling them to reach new areas. Examples include coconuts and water lilies.
    - Animal Dispersal: Many plants have evolved adaptations to attract animals that eat their fruits or seeds. These animals then disperse the seeds through their droppings. Examples include berries eaten by birds and acorns eaten by squirrels.
    - Explosive Dispersal: Some plants have seed capsules that burst open when mature, forcefully expelling seeds. This mechanism helps seeds scatter over short distances. Examples include peas and violets.
    - Gravity Dispersal: Seeds with adaptations for gravity dispersal fall directly to the ground when they mature. They rely on gravity to place them in proximity to their parent plants. Examples include chestnuts and acorns.
    - Ant Dispersal: Certain seeds have specialized structures that attract ants. Ants carry these seeds back to their nests, where they consume the seed appendages and discard the seeds in nutrient-rich environments. Examples include trillium seeds.
- Explain that in this lesson, students will conduct more in-depth experiments and investigations related to seed dispersal and germination.
- Emphasize the importance of critical thinking, hypothesis testing, and careful documentation.
    - Activity 1: Investigating Seed Dispersal Mechanisms (Day 1) (60 minutes):
        - Distribute assorted seeds to each student or group. Clearly label each type of seed and explain the dispersal mechanism associated with it.
            - Encourage students to carefully observe and compare the physical characteristics of these seeds, noting any adaptations related to their dispersal methods.
        - In their science notebooks, have students formulate hypotheses about how each type of seed might disperse most effectively based on their observations.

    - Prompt them to consider factors such as seed shape, size, and any additional structures that aid in dispersal.
- Instruct students to engineer experiments to investigate the efficiency and effectiveness of the dispersal mechanisms of the provided seeds.
    - Provide materials such as clear plastic cups, cotton balls, and water to help students create controlled environments.
- Have students design and set up experiments for each type of seed, ensuring they maintain consistent conditions for comparison. For example:
    - For Wind Dispersal Seeds:
        - Wind Tunnel Setup: Create a mini wind tunnel using cardboard or clear tubing. Place the seeds at one end and use a fan to generate wind at a controlled speed. Measure how far the seeds are carried by the wind.
        - Parachute Drop Test: Attach wind-dispersed seeds to small paper parachutes. Drop them from a height and observe their descent. This simulates the way seeds with parachutes or wings travel.
    - For Animal Dispersal Seeds:
        - Model Animal Interaction: Use a model animal (toy) with Velcro strips or adhesive material on its fur or body. Attach seeds to the model animal, representing how seeds might attach to real animals. Move the model animal around to simulate dispersal.
        - Bird Beak Simulation: If studying bird dispersal, provide students with different types of beak models (e.g., tweezers, pliers). Attach seeds to the beaks, and have students mimic how different bird species might consume and disperse seeds.
    - For Water Dispersal Seeds:
        - Water Flow Experiment: Set up a mini watercourse using trays, soil, and a gentle water source (e.g., a water hose). Place seeds on the soil near the water source and observe how they are moved by water flow.
        - Float Test: Fill containers with water and place seeds known for water dispersal in them. Observe which seeds float and which ones sink, and discuss the implications for water dispersal.
    - For Gravity Dispersal Seeds:
        - Vertical Drop Experiment: Create a platform with holes or slits through which seeds can fall. Attach seeds to strings and release them from different heights to observe their fall patterns.
        - Slope Slide: Set up inclined surfaces (e.g., ramps or boards). Place seeds on the surface and tilt it to simulate the effects of gravity. Observe how seeds roll or slide downhill.
- Document their experimental setups, including temperature and light conditions in their science notebooks.

- Instruct students to observe and record the results of their experiments carefully. They should measure and record distances traveled, attachment methods, or any other relevant data.
- Encourage students to record any unexpected outcomes or challenges they encountered during the experiments.
- After conducting experiments, initiate a class discussion:
  - Encourage students to share their observations and data from the experiments.
  - Discuss which seeds demonstrated efficient dispersal mechanisms and why.
    - Explore the adaptations of seeds that contributed to their effectiveness in dispersal.
      - Prompt students to consider real-world scenarios where these dispersal mechanisms might be advantageous for plants.
- Have students complete their science notebooks with the following entries:
  - Record their initial observations of seed characteristics and adaptations.
  - Document their formulated hypotheses about each seed's dispersal efficiency.
  - Describe the experimental setups they designed, including variables controlled.
  - Document their daily observations and measurements during the experiments.
  - Reflect on the results of their experiments and how they align with their hypotheses.
- Summarize the understanding discussion points and any new insights gained during the class discussion.
  - Observations and Data Sharing:
    - What were your observations from the experiments, and which seeds seemed to have the most effective dispersal mechanisms?
    - Can you provide specific data or measurements from your experiments to support your observations?
      - For example, how far did dandelion seeds travel in the wind dispersal experiment, and how did this compare to other seeds?
  - Seed Adaptations:
    - What physical adaptations did you notice in the seeds that contributed to their effectiveness in dispersal?
    - Can you provide examples of specific seed adaptations that you observed during the experiments?
      - For instance, how did the wing-like structures of certain seeds aid in their wind dispersal?
  - Real-World Applications:
    - In what natural environments or scenarios do you think the dispersal mechanisms you studied would be advantageous for plants?

        - Can you provide examples of plants in the wild that rely on the same dispersal mechanisms you investigated?
            - For instance, how do water-dispersed seeds contribute to the growth of plants in wetland ecosystems?
    - Interdependence of Factors:
        - How do environmental factors like wind speed, water flow, or animal behavior influence seed dispersal?
        - Can you share examples of how changes in these factors might affect the effectiveness of dispersal mechanisms?
            - For example, how does wind speed impact the dispersal of wind-adapted seeds like dandelion seeds?
    - Diversity in Dispersal Strategies:
        - What did you learn about the diversity of seed dispersal strategies employed by different plant species?
        - Can you provide examples of plants that use multiple dispersal methods, and why might they do so?
            - For instance, how might a plant benefit from producing both wind-dispersed and animal-dispersed seeds?
    - Human Impact:
        - How do human activities, such as deforestation or urbanization, impact natural seed dispersal mechanisms?
        - Can you think of examples where human actions disrupt or alter these mechanisms?
            - For example, how might urban development affect the dispersal of seeds in a local ecosystem?
    - Conservation Implications:
        - How can understanding seed dispersal mechanisms inform conservation efforts?
        - Can you provide examples of conservation strategies that take into account the importance of seed dispersal?
            - For instance, how might protecting habitats crucial for animal-dispersed seeds contribute to ecosystem conservation?
    - Role in Ecosystems:
        - What is the broader ecological significance of seed dispersal mechanisms in ecosystems?
        - Can you discuss how diverse dispersal methods contribute to ecosystem resilience and biodiversity?
            - For example, how do different dispersal mechanisms impact the composition and dynamics of plant communities in an ecosystem?
- Activity 2: Advanced Germination Experiments
    - Begin by revisiting the concept of seed germination and the factors influencing it, such as temperature, light, and water.
        - Explain that students will conduct experiments to explore how different seeds respond to varying germination conditions.
    - Seed Selection

- Distribute assorted seeds to each student or group. Clearly label each type of seed and explain its specific germination response.
    - Encourage students to carefully observe and note any differences in seed characteristics and adaptations related to germination.
- Hypothesis Formulation
    - In their science notebooks, have students formulate hypotheses about how each type of seed will respond to different germination conditions.
    - Prompt them to consider factors like temperature, light exposure, and water availability in their hypotheses.
- Experimental Setup
    - Instruct students to engineer experiments for each type of seed to investigate their germination responses.
    - Provide materials such as clear plastic cups, potting soil, thermometers, and light sources (if necessary) to help students create controlled environments.
    - Have students design and set up experiments, documenting their setups and variables controlled in their science notebooks.
- Observation and Data Collection
    - Instruct students to observe and record daily observations, including seedling growth, changes in temperature and light exposure, and soil moisture.
    - Encourage precise control of variables to ensure accurate data collection.
- Science Notebook Data Entry Points:
    - Have students complete their science notebooks with the following entries:
    - Record their initial observations of seed characteristics and adaptations related to germination.
    - Document their formulated hypotheses about how each type of seed will respond to varying germination conditions.
    - Describe the experimental setups they designed, including temperature, light, and watering conditions.
    - Daily record observations of seedling growth, noting any differences between seed types and conditions.
    - Reflect on the results of their experiments and compare them to their hypotheses.
    - Summarize the key findings and any patterns observed in their science notebooks.
- Activity 3: Combining Seed Dispersal and Germination (Day 3) (60 minutes):
    - Objective: To investigate how the combination of seed dispersal mechanisms and germination conditions affects seedling establishment.
    - Note: For this activity, students will select one seed type from the previous activities (either wind-dispersed, animal-dispersed, or others) and one germination condition (e.g., light-sensitive seeds).
        - Remind students of the seed dispersal mechanisms and germination conditions they explored in previous activities.

- Explain that in this activity, they will combine their knowledge to investigate how these factors interact to affect plant survival.
- Seed and Condition Selection
    - Instruct students to select one seed type from the previous activities and one germination condition (e.g., light-sensitive seeds).
    - Encourage them to consider how the chosen dispersal mechanism and germination condition may interact.
- Hypothesis Formulation
    - In their science notebooks, have students formulate hypotheses about how the chosen seed type will respond when subjected to the selected germination condition.
    - Prompt them to consider how the seed's dispersal mechanism might influence its success in germination.
- Experimental Setup
    - Instruct students to engineer experiments that combine their chosen seed type, germination condition, and a controlled environment.
    - Provide materials as needed for the experiments and have students document their setups in their science notebooks.
- Observation and Data Collection
    - Instruct students to observe and record daily observations, including seedling growth, any specific interactions between the chosen seed type and germination condition, and environmental variables.
    - Emphasize precise control of variables for accurate data collection.
- Have students complete their science notebooks with the following entries:
    - Record their choice of seed type and germination condition, explaining their rationale.
    - Document their formulated hypotheses about how the chosen seed type will respond to the selected germination condition, considering the dispersal mechanism.
    - Describe the experimental setups they designed, including specific conditions and variables controlled.
    - Daily record observations of seedling growth, interactions, and any unique responses that result from the combination of seed type and germination condition.
    - Reflect on the results of their experiments, considering how the chosen factors interacted to influence plant survival.
    - Summarize their findings and discuss any new insights gained from this combined experiment.

- Begin by summarizing the key concepts covered in the activities, including seed dispersal mechanisms, germination conditions, and the interconnectedness of these factors in plant survival.

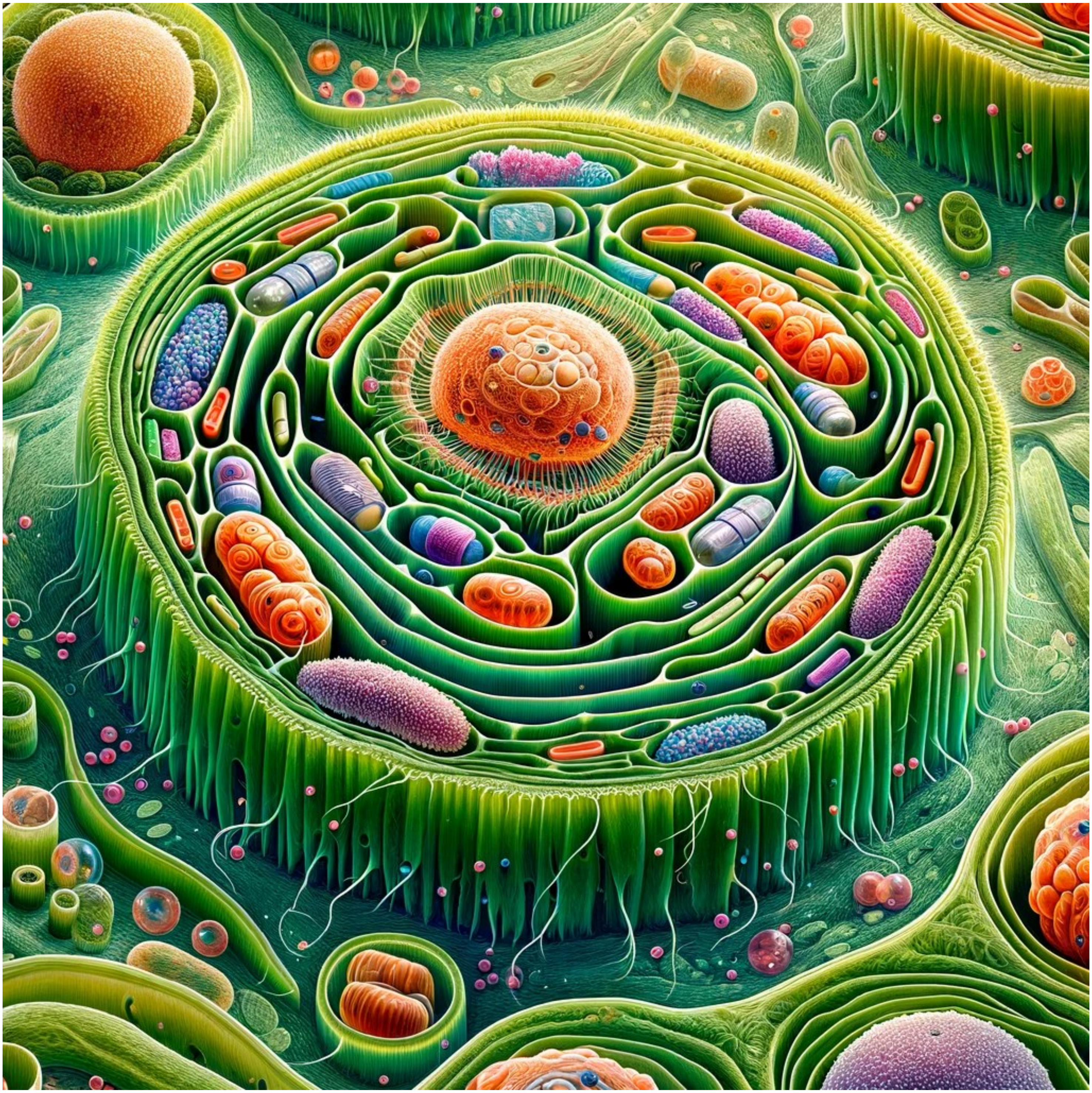
- Seed Dispersal Mechanisms: In the activities, we explored various ways in which plants disperse their seeds to new locations. These mechanisms include wind dispersal (seeds carried by the wind), animal dispersal (seeds carried by animals), water dispersal (seeds transported by water), and gravity dispersal (seeds that simply fall to the ground). We observed different adaptations that seeds have developed to aid in these dispersal methods.
- Germination Conditions: We investigated the conditions necessary for seeds to germinate and grow into plants. This included factors such as temperature, light, and water availability. Some seeds require specific conditions, like darkness or light, to trigger germination. Understanding these conditions is crucial for successful plant growth.
- Interconnectedness of Factors: The activities highlighted how seed dispersal mechanisms and germination conditions are interconnected in determining a plant's success. Different seeds have evolved to disperse in specific ways that align with their germination requirements. For example, seeds dispersed by animals might have adaptations that allow them to thrive in the conditions typically found in animal dung.
    - Discuss how the experiments demonstrated the interconnectedness of seed dispersal mechanisms and germination conditions.
        - Emphasize that different seeds have evolved specific adaptations to thrive in their natural environments.

- Sharing Observations and Findings:
    - Encourage students to share their observations, hypotheses, and findings from the experiments conducted over the past days.
    - Ask students to highlight any patterns, surprises, or challenges they encountered during their investigations.
- Real-World Applications:
    - Prompt students to consider the real-world applications of the knowledge they gained.
    - Discuss how an understanding of seed dispersal and germination can be applied in conservation efforts, agriculture, and ecosystem management.
- Critical Thinking and Scientific Inquiry:
    - Reinforce the importance of critical thinking, hypothesis testing, controlled experimentation, and careful documentation in scientific inquiry.
    - Discuss how students applied these skills to explore complex biological concepts.
- Discussion Questions:
    - Here are discussion questions to guide the conversation:
    - What were the most interesting or surprising findings from your experiments?
    - Can you identify any commonalities or differences in how different seeds responded to germination conditions?
    - How did the combination of seed dispersal mechanisms and germination conditions affect plant survival in Activity 3? Were there any unexpected outcomes?

- Can you think of practical scenarios where understanding seed dispersal and germination would be crucial, such as in ecological restoration or crop farming?
- How might scientists use the data collected in these experiments to better understand plant ecology and make informed conservation decisions?

- Closing Remarks:
    - Conclude the discussion by summarizing the key takeaways and thanking students for their active participation and scientific curiosity.
    - Reiterate the value of hands-on exploration in deepening their understanding of the natural world.

Physiology and Photosynthesis



Investigations and Application
Exploring Plant Physiology and Photosynthesis: Understanding Plant Growth and Movement

Educator Background Information—Plant growth and movement

In the fascinating world of biology, understanding the intricate processes governing plant growth and movement unlocks the secrets to the remarkable resilience and diversity of the plant kingdom. From the microscopic realm of plant cells to the observable phenomena of phototropism and nastic movements, students embark on a journey to uncover the underlying principles that govern the life of plants. As we delve into the science of plant physiology, we explore how factors such as water, soil, light, and temperature influence the growth of these living organisms. Beyond the classroom, the implications of this knowledge extend into various fields, from agriculture and environmental science to biotechnology and pharmaceutical research. Through hands-on experiments, captivating demonstrations, and real-world applications, students not only grasp the intricacies of plant biology but also cultivate an appreciation for the vital role plants play in sustaining life on Earth

Plant Cells:

- Plants are composed of specialized cells with distinct functions.
- The cell wall provides structural support, while the chloroplasts facilitate photosynthesis.

Tissues and Organs:

- Plants have different tissues (epidermal, vascular, ground) and organs (roots, stems, leaves) that contribute to their growth and function.

Meristems:

- Meristematic tissues at the tips of roots and shoots are responsible for primary growth, allowing plants to increase in height.

Factors Affecting Plant Growth:

Water:

- Adequate water is essential for nutrient transport, photosynthesis, and cell expansion.
- Lack of water can lead to wilting and hinder plant growth.

Soil and Nutrients:

- Plants extract essential nutrients from the soil, promoting healthy growth.
- Soil composition and fertility influence plant development.

Light:

- Light is crucial for photosynthesis, the process by which plants convert light energy into chemical energy.
- Phototropism is the movement of plants in response to light, ensuring optimal light absorption.

Temperature:

- Plants have temperature preferences for optimal growth.
- Extreme temperatures can affect enzyme activity and overall plant health.

Growth Hormones:

- Plant hormones, such as auxins and gibberellins, regulate growth processes.
- They influence cell elongation, flowering, and responses to environmental stimuli.

Physiology and Photosynthesis

Photosynthesis and Energy Conversion:

Photosynthesis Process:

- Photosynthesis occurs in chloroplasts, where light energy is converted into chemical energy (glucose).
- The overall equation: $6\ CO_2 + 6\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$.

Chlorophyll:

- Chlorophyll is the pigment responsible for capturing light energy during photosynthesis.
- It gives plants their green color.

Factors Affecting Photosynthesis:

- Light intensity, carbon dioxide levels, and temperature influence the rate of photosynthesis.

Plant Movement:

Tropism:

- Tropisms are plant movements in response to external stimuli.
- Phototropism (response to light), geotropism (response to gravity), and thigmotropism (response to touch) are common examples.

Nastic Movements:

- Nastic movements are reversible, non-directional responses to stimuli.
- Examples include the opening and closing of flowers in response to light or temperature changes.

Circadian Rhythms:

- Plants exhibit daily rhythmic movements, known as circadian rhythms.
- These movements are influenced by internal biological clocks.

Applications and Implications:

Agriculture:

- Understanding plant growth is crucial for optimizing crop yield and quality.
- Farmers consider factors like soil health, water availability, and light exposure.

Environmental Impact:

- Plants play a vital role in carbon sequestration, affecting climate change.
- Conservation efforts depend on understanding plant physiology and movement.

Biotechnology:

- Plant geneticists use knowledge of plant growth for crop improvement.
- Genetic engineering may enhance resistance to pests or environmental stress.

Medical and Pharmaceutical Applications:

- Some plants are sources of medicinal compounds.
- Research on plant growth contributes to pharmaceutical advancements.
- Websites, videos, and interactive simulations can supplement classroom learning.
- Explore reputable educational platforms and botanical gardens.

Understanding plant growth and movement is fundamental for appreciating the vital role plants play in ecosystems, agriculture, and human well-being. The interplay of environmental factors, physiological processes, and adaptive responses forms the basis of plant biology, offering endless opportunities for exploration and discovery.

Physiology and Photosynthesis

Real world connections:
The plant physiology and photosynthesis unit has several real-world connections and potential job applications. Understanding these concepts is crucial in various fields, and individuals with a background in plant biology can pursue careers related to agriculture, environmental science, research, education, and more. Here are some real-world connections and potential jobs: Conservation Scientists, Urban planner, plant geneticist, naturalist, agricultural scientist, botanist, environmental scientist

Next Generation Science Standards

- LS1.A: Structure and Function
    - Students will understand the structure and function of plant cells and their organelles.
- LS1.B: Growth and Development of Organisms
    - Students will explore factors affecting plant growth, including water, soil, nutrients, and temperature.
- LS1.C: Organization for Matter and Energy Flow in Organisms
    - Students will grasp the concept of photosynthesis as the process by which plants convert light energy into chemical energy.

Students will be able to:

- Students should comprehend the process of photosynthesis, including the role of chlorophyll and the conversion of light energy into chemical energy.
- Students should understand different types of plant movements, including tropism and nastic movements, and how plants respond to external stimuli

Student Vocabulary:

- Apical dominance - is the phenomenon whereby the main, central stem of the plant is dominant over (i.e., grows more strongly than) other side stems
- auxin and gibberellin - Auxin and gibberellin are two classes of growth regulators/ hormones found basically in plants and we can identify some similarities as well as differences between them. Plant growth regulators are mainly responsible for the growth and differentiation of cells, tissues and act as chemical messengers in intercellular communication.
- Axillary bud - a bud that grows from the axil of a leaf and may develop into a branch or flower cluster. Also called lateral bud.
- Cork cambium - tissue in the stem of a plant that gives rise to cork on its outer surface and a layer of cells containing chlorophyll on its inner surface
- Lateral - of, at, toward, or from the side or sides. “the plant takes up water through its lateral roots”
- Meristematic tissues - are pluripotent, meaning they divide quickly and can form any kind of tissue found in the
- Nastic - caused by an external stimulus but unaffected in direction by it.
- Nyctinasty - caused by nightly changes in light intensity or temperature
- Phloem - tissues in plants that conduct foods made in the leaves to all other parts of the plant
- Phototropism - is the growth of an organism in response to a light stimulus plant (essentially they are analogous to stem cells).
- Positive Thigmotropism- is a response towards the touch stimulus
    - ~~secondary tropism~~

- Tropisms - the turning of all or part of an organism in a particular direction in response to an external stimulus
- vascular cambium - This is the main growth tissue in the stems and roots of many plants, specifically in dicots such as buttercups and oak trees, gymnosperms such as pine trees, as well as in certain vascular plants
- Xylem - plant vascular tissue that conveys water and dissolved minerals from the roots to the rest of the plant and also provides physical support

Unveiling the Secrets of Plants (engage)

- Begin the lesson with an attention-grabbing statement: Did you know that plants can move? Imagine the stories they have to tell!
    - **"**What do you think plants need to grow and move?"
    - "Have you ever witnessed a plant making its stealthy moves? Share your tales!"
    - "Why might knowing how plants grow and move be as exciting as a thrilling adventure?"
        - Today, you're explorers on a thrilling quest to unveil the hidden lives of plants, like intrepid adventurers on a treasure hunt. What secrets do these mysterious organisms hold? Get ready to dive into the heart of the botanical world with your tools for this grand journey: the enigmatic mystery boxes."
        - "Each of these boxes is a Pandora's box of plant wonders, carefully curated to spark your scientific imaginations. Inside, you'll find a world of botanical treasures waiting to be explored."
            - The teacher thoughtfully pairs students into exploration groups, ensuring diversity within each group to foster collaboration.
            - Describe the contents of the exploration boxes:
                - "Inside these boxes, you'll find treasures beyond your wildest botanical dreams. Explore the wonders of colorful leaves, seeds of various shapes and sizes, rich and fertile soil, carefully preserved plant roots, and captivating images and videos of plant growth."
                - Colorful Leaves:
                    - Types of Leaves: Include leaves from a variety of plants such as maple, oak, palm, and ferns. Each leaf exhibits unique features like shape, texture, and coloration.
                    - Leaf Characteristics: Some leaves may have serrated edges, while others are smooth. Some might be broad and flat, while others are slender and needle-like. This diversity showcases the adaptability of plants.
                - Seeds:
                    - Assortment of Seeds: Include seeds from various plant species, such as sunflowers, beans, pinecones, and dandelions. These seeds vary in shape, size, and color.
                    - Seed Adaptations: Discuss how specific seeds are adapted for different methods of dispersal, like wind, animals, or water.

- Soil Sample:
    - Rich and Fertile Soil: Provide a small container of nutrient-rich soil that supports plant growth. You can mix in organic matter like compost for added complexity.
    - Visible Organisms: Add a magnifying glass to allow students to observe any visible soil organisms, such as earthworms, ants, or tiny microorganisms. Discuss the role of these organisms in soil health.
- Plant Roots:
    - Sample Roots: Include a sample of plant roots, either preserved or dried. Choose roots from different types of plants, such as fibrous, taproot, or adventitious roots.
    - Root Structures: Highlight the structures of roots, including root hairs, branching patterns, and the relationship between roots and soil.
- Images and Videos:
    - Captivating Images: Provide printed images showcasing plant growth stages, including germination, flowering, and fruit production.
    - Video Clips: Share video clips demonstrating intriguing plant behaviors, such as the sensitive plant's leaf folding when touched or time-lapse videos of plant growth.

- To make the most of our exploration into plant growth and movement, here are the rules and procedures to follow:"
    - Equip Your Squad: "Ensure each member of your squad has a magnifying glass. This tool will enable you to closely examine the plant-related items and reveal details related to plant growth and movement."
    - Collaborate Actively: "Active collaboration within your group is essential. Share your observations, questions, and speculations, focusing on how each item might relate to plant growth and movement."
    - Science Notebooks: "Use your vibrant science notebooks to record observations and hypotheses specifically related to plant growth and movement. Use colorful pens and pencils to enhance your notes."
    - Hypotheses: "While exploring the items, jot down hypotheses that specifically address how each item might be linked to the growth or movement of plants. Think critically and creatively, as every idea could unveil insights into plant life."
- Guided Exploration and Discussion:
    - I'll guide you through discussions that center on plant growth and movement.
        - Leaf Exploration: "Examine the leaves closely, focusing on features that might relate to plant growth and movement. How do these features support or influence a plant's

growth or its ability to move or respond to its environment?
        - Seed Analysis: "As you explore the seeds, consider their role in plant growth and potential movement. How might the characteristics of these seeds impact the way plants grow or disperse?
        - Video and Image Insights: "While watching the videos and viewing the images, pay particular attention to any aspects related to plant growth and movement. What behaviors, adaptations, or changes in position can you observe that are connected to plant life?"
    - In your science notebooks, respond to these prompts with a focus on plant growth and movement
        - Leaf Observation: "Describe the leaf features that you believe influence plant growth or movement. How do these characteristics contribute to a plant's overall success?"
        - Seed Analysis: "Document your observations regarding how the seeds may play a role in plant growth or movement. Consider the potential advantages these seed characteristics offer."
        - Video and Image Insights: "Record your observations and speculations about plant growth and movement based on the videos and images. What do these visual cues reveal about how plants adapt and respond to their surroundings?"
- Now, gather your groups for an engaging discussion of your findings. Share your insights and thoughts on the plant-related items you explored."
    - Discussion Questions:
        - "What fascinating discoveries have you made within your groups?"
        - "Have you come up with any surprising hypotheses about the plant-related items?"
        - "Did you observe any connections between different items that contribute to our understanding of plant growth and movement?"
- Additional Information Sharing
    - As you discuss your findings, I'll share additional information about the items in the mystery boxes to reinforce their connection to plant growth."

Unveiling the Secrets of Plants (explore)
- Begin by revisiting the mystery box activity.
    - Ask students to share any lingering questions or thoughts about the items they explored.
    - Today, we'll conduct hands-on experiments to dive deeper into plant growth and movement. Get ready to get your hands dirty and discover more about the amazing world of plants!"

- Organize students into groups. Each group receives a potted plant, additional soil, and a watering can.
- Explain the experiment: "You will investigate the impact of water and sunlight on plant growth. Each group will modify one factor – either water or sunlight – and observe the plant's response over the next week."
    - Encourage groups to discuss and form hypotheses about how altering water or sunlight might affect their plants.
        - Allow groups to modify their plants by adjusting water levels or sunlight exposure.
        - Emphasize the importance of controlled experimentation.
- Instruct students to record daily observations, including plant height, leaf color, and any changes they observe in their student science notebook
    - Facilitate a group discussion at the end of the week. Have groups share their observations and discuss how water and sunlight influenced plant growth.

- Briefly explain phototropism and its significance in plant growth.
    - Phototropism is a plant's natural response to light. Specifically, it's the tendency of plants to grow towards a light source. This growth occurs because the plant's cells on the side exposed to light elongate more rapidly than the cells on the shaded side. This bending towards light helps the plant maximize its exposure to sunlight for photosynthesis, which is essential for producing energy and nutrients. Phototropism is significant in plant growth as it ensures that plants can efficiently capture sunlight, a crucial factor for their survival and overall development.
- Provide each group with a small potted plant and materials (cardboard, pins). Instruct them to set up an experiment to observe phototropism.
    - For the first activity students will observe patterns of growth in a common climbing bean running through a plant maze.
        - To prepare this maze, acquire a large shoebox, extra cardboard that can be cut to shape, and a roll of heavy duty tape to secure the pieces and block out light from extraneous holes.
            - As a precursor to the lesson, educator needs to begin germination of a climbing bean seed

- With the box stood upright, two shelves should be set equally apart into the inside.

- Cut a hole in each shelf at a different point as well as a hole at the top of the box so that the holes cannot directly line up.

- After Germinating a climbing bean in a small pot of soil, place the sprout in its pot at the bottom of the box.

- Have students observe and record its growth over the following week(s) until the plant finds its way through the maze or perishes.
    - Observation and Growth Tracking:
        - Initial Measurements: Measure the height and any notable characteristics of the plant when you start the experiment. Record this in your science notebook.
        - Daily Growth: Document the daily growth of the plant as it navigates through the maze. Note any changes in height, direction, or any visible adaptations.
        - Phototropism Observations: Describe how the plant responds to the light and the maze. Do you notice any bending or directional changes in response to the maze's layout?
        - Time-Lapse Drawings: Create time-lapse drawings or diagrams of the plant's growth progression. Include annotations to highlight changes.
        - Environmental Conditions: Note any changes in environmental conditions that might affect the plant's growth, such as temperature, humidity, or exposure to light.
    - Maze Interactions:
        - Describe how the plant interacts with the maze. Does it encounter dead ends or obstacles? How does it respond when it encounters the maze walls?
        - Decision Points: Document the plant's decision points within the maze. Did it make choices in its growth direction, and if so, what factors influenced those choices?
        - Rate of Progress: Track the rate at which the plant progresses through the maze. Does it move faster in certain directions or phases of growth?
    - Watering Frequency: Record how often you open the box to water the plant. Note any changes in soil moisture or plant health.
        - Light Exposure: Describe the light conditions in the box when you open it for watering. Did the plant exhibit any immediate phototropic responses during these moments?
    - Plant Health:
        - Assess the overall health of the plant throughout the experiment. Document any signs of stress, disease, or mold, if applicable.
        - Survival and Outcome: Keep a record of the plant's overall progress in the maze. Does it successfully navigate through, or does it face challenges that might affect its survival?

        - You will have to open the box periodically to water the plant but try to avoid moldy conditions and subjecting the plant to substantial periods of light when doing so.
- The students should note that there are two types of growth occurring
    - New cells and tissues such as branches and leaves occur only at the top and bottom tips of the plant and at nodes.
        - Nodes are points along the stem at which there are Axillary buds or meristems.
        - Meristematic tissues are pluripotent, meaning they divide quickly and can form any kind of tissue found in the plant (essentially they are analogous to stem cells).
        - Axillary buds become branches and leaves. Root and shoot apical meristems are the center of new growth at the bottom and top of the plant respectively.
- Ask students to observe and record in student science notebook whether the height of the axillary buds and branches increases as the plant grows.
    - Does the stem continue to grow longer between nodes after they form, or does it only grow longer at the top, lengthening from the tip while dropping off leaves and branching points behind?
        - Some combination of the two?
            - If you drove a nail into a tree and came back years later would the nail be higher or at the same level?
            - If the shoot apical bud at the top were cut off what do students believe might happen? Would the stalk stop growing vertically or would side branches take over? How might this affect the pattern of growth and branching.
- As a side activity, teachers may choose to actually do this experiment with a different bean plant or, for greater effect, with basil, repeating the treatment over time. Direct students to research the concept of "Apical dominance" as a follow up.
    - Compare the branching pattern of the beanstalk to other plants. Do the lateral buds emerge in opposite pairs or alternate from side to side as you go up the stem?
        - Some other pattern?
        - What do conifers do?
        - How might the emergence of these buds affect the overall shape of the mature plant?
- Some axillary buds form leaves and others branches, those which form branches are usually found in the crook between a leaf and its branch with the initial leaf falling off before or as the new branch grows.
    - How do students think this pattern might repeat on trees that lose their leaves each year?
- Plants also possess a different kind of lateral meristem tissue, known as vascular cambium, which trails behind the apical meristem as it rises forming an inner layer of the stem.

- The cambium allows some perennial plants to grow thicker by adding dense layers of vascular tissue each year along the length of the stem creating woody growth in the form of tree rings towards the inside (xylem), while filling in gaps in the living outer layers as they stretch thinner around the heartwood (phloem).
- Cork cambium, another lateral meristem, appears in some plants but is only a meristem in as much as it produces protective layers of bark that erupt from underneath the skin of the plant.
    - In truth the axillary buds are usually offshoots of the vascular cambium, but in annual plants the cambium only produces buds and vascular tissue in the stem. It doesn't produce consecutive rings.
    - As seen in the asexual reproduction lesson this also why many plants can be grown from cuttings
        - meristems in cut stems or branches will create roots under the right conditions, allowing the severed piece to regrow into its own plant.
        - Elongation takes place at internodes. Cells along these sections of stem do not multiply to produce growth but rather partially dissolve, shift, and reform their cell walls to grow longer (the cell wall structure can be thought of like a spring or stacked rings that stay intact while the crosslinks that connect vertically are removed and reset). In order to spread the cell itself takes up a great amount of water and nutrients. Sophisticated hormone signaling tells internode cells when to elongate and may be applied more to one side than the other causing directional growth we will explore later in this section.
        - Cells which elongate in young plant tissue often mature into the vascular tissues xylem and phloem. Xylem cells actually die, leaving behind their hollow cell walls to act as structural support and plumbing (recall when cambium lays it down over several years we call xylem wood).
            - How would this affect elongation in mature sections of stem? Do you expect sections of stem that have gone woody to elongate or should it be limited to young green shoots?
        - Knowing about elongation and meristems, what do you predict would be the best way to prune woody bushes and hedges if you don't want to completely stop the plant from growing but rather train it into shape?

            - Teachers may choose to highlight the way horticulturalists utilize this knowledge by google image searching the term "arborsculpture", "Topiary", and "Bonzai"
    - The bean plant in the maze is an annual plant, meaning it will only grow for one season before producing seeds and dying, however bean plants are known to grow exceptionally fast.
        - Do students expect this growth to be more a result of new cells produced at the meristems or elongation of cells in the internode?
        - Knowing that elongation can be applied unevenly to sections and sides of the stem, how is the bean plant likely steering itself through the maze?

Unveiling the Secrets of Plants (explain)

- In the plant maze we saw the most direct way in which plants orient and direct their growth towards the resource of sunlight.
    - The behavioral adaptations/methods by which plants orient their growth are referred to as tropisms.
        - Phototropism, or orienting according to the direction of light is most common and probably most famous due to such clear examples as sunflowers; however there is also hydrotropism, geotropism, thermotropism, chemotropism, and others since certain situations make it advantageous to direct growth towards other resources.
        - Roots should actually direct themselves down while runner type plants may direct themselves towards better soil or moisture; plants exposed to extreme sun might actually seek shade.
            - Additionally orienting towards factors associated with sun (ie just finding a way up) might yield the same result as seeking the sun itself, particularly in cases of heavy shade when the immediately brightest way may not be the ultimately brightest way. To underscore the need of meeting requirements for photosynthesis we will explore two tropisms which indirectly work the plant towards the sun
                - The climbing bean utilized in the plant maze has a secondary tropism alluded to in its name.
                    - in order to climb, these beans must have something to climb on and demonstrate an ability to grow in a way that allows it to grasp its support.
                    - Outside of the previously mentioned plant maze prepare two or more additional pots with sprouted beans, provide one or more with an improvised "beanpole".
                        - You may choose to experiment with variations such as whether the pole is branched, has steps and landings, or is straight, experiment with unconventional supports such as umbrella frames or coat

racks, whether it has different surface textures etc. but keep one pot without any provided supports to act as a control (note the plant may climb suspended anchors as well as supported ones so watch the window blinds).

- Positive Thigmotropism or growth toward to touch and pressure conditions plants to lean into and even curl around surrounding structures. While this behavior counterintuitively puts the plant into the shade of the object it is touching, it also allows it to trade off putting energy and resources into strengthening its stem in favor of growing longer.
    - This ultimately means it will grow over its support. In cases where plants are competing for light this also allows the climbing plant to deny its competitor just as much light in turn, smothering it.
    - Positive tropisms are growth towards a stimulus while negative tropism are growth away from it. Can students think of cases in which negative thigmotropism might happen? When might plants back off from each other rather than jostle for light?
- Show students a google image of “crown shyness”.

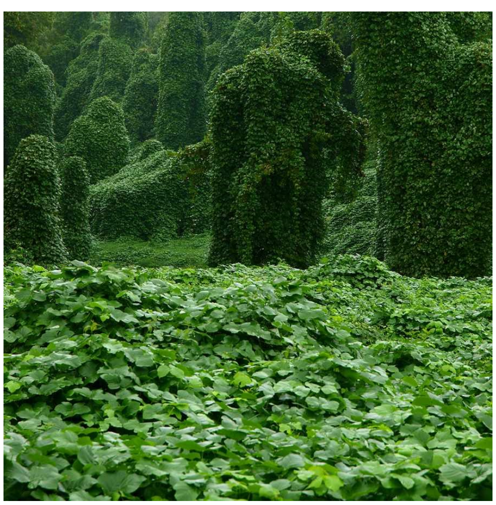
- Crown shyness is a fascinating phenomenon observed in certain tree canopies. It occurs when the upper branches of trees avoid touching or overlapping with the branches of neighboring trees, creating visible gaps or channels in the canopy. This results in a striking pattern where the tops of the trees seem to shy away from each other, leaving open spaces or "aisles" between them.

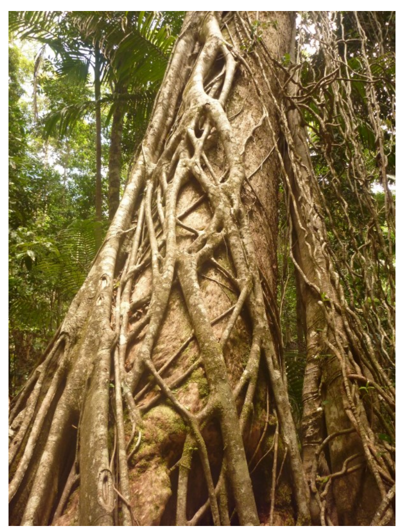
- The exact reasons for crown shyness are not fully understood, but scientists believe it might be influenced by a combination of environmental factors such as wind, light, and competition for resources. Some theories suggest that trees engage in this behavior to reduce the risk of disease transmission, prevent physical damage from rubbing branches, or optimize light exposure for photosynthesis.
- This natural phenomenon can be observed in various types of forests around the world, and it often captivates those who encounter it. Crown shyness showcases the intricate ways in which trees interact with their surroundings and adapt to environmental conditions.
    - Questions for Students after Seeing a Picture of Crown Shyness:
        - What do you notice in the picture of the trees? Describe the patterns or shapes that you see.
        - How would you explain the term "crown shyness" based on the image?
        - How might environmental factors such as wind, sunlight, and competition for resources contribute to the development of crown shyness?\
        - What advantages or disadvantages could crown shyness provide for the trees in terms of their growth and survival?
        - Consider how human activities, like logging or urban development, might affect crown shyness in tree populations. What could be the consequences of these activities on the phenomenon?
        - Do you think crown shyness is more common in natural, undisturbed forests or in areas where humans have had an impact?

- Compare the crown-shy canopy to a regular, dense canopy. What differences do you see in the arrangement of branches and the overall structure?
    - Why do you think some trees exhibit crown shyness while others do not?I
    - f you were a scientist studying crown shyness, what questions would you want to investigate? What experiments or observations could help you better understand this phenomenon?
        - In some cultures, crown shyness is considered a unique and awe-inspiring aspect of nature. How do

you think people from different cultures might perceive and appreciate crown shyness?
- Are there any stories or beliefs in your culture related to trees or forests that might be connected to crown shyness?
    - Encourage students to express their thoughts and hypotheses based on the image, fostering curiosity and critical thinking about the natural world. This activity can serve as a gateway to exploring broader ecological concepts and the interconnectedness of living organisms in their environments

- Show students images of two plants, kudzu, and strangler fig.
    - Thigmotropism is a plant's response to touch or physical contact with objects in its environment. It can result in the plant either growing towards the source of touch (positive thigmotropism) or moving away from it (negative thigmotropism).
        - Positive thigmotropism refers to the plant's tendency to grow towards the touch stimulus. It allows plants to seek support or climb surfaces by growing in the direction of contact.
        - Negative thigmotropism, on the other hand, involves the plant growing away from the touch stimulus. This response is often observed when plants are subjected to mechanical stress or disturbance, and they move away to avoid damage.
    - Two notable examples of plants showcasing different responses to their surroundings are kudzu and the strangler fig:
    - do they appear to demonstrate positive or negative thigmotropism?





- Briefly describe kudzu and strangler fig, mentioning that they showcase different responses to their surroundings.
    - Kudzu
        - Kudzu is an invasive vine known for its rapid growth and ability to cover large areas. It showcases positive thigmotropism, which means it grows towards touch stimuli. This response allows kudzu to sense and climb over surfaces, such as trees, poles, and buildings, as it seeks support for its growth.
        - Kudzu's Rapid Growth:
            - Question: "Kudzu is often known for its rapid growth and ability to cover large areas. How might positive thigmotropism play a role in kudzu's ability to spread and climb over surfaces?"
            - Follow-up: "Do you think positive thigmotropism helps or hinders kudzu's interaction with other plants and structures?"
    - Strangler Fig:
        - Strangler figs are known for their unique growth strategy, where they wrap around host trees. They exhibit negative thigmotropism, meaning they grow away from touch stimuli. This response contributes to the strangler fig's growth pattern, allowing it to encircle and eventually engulf its host tree.
        - Strangler Fig's Growth Strategy:
            - Question: "Strangler figs, on the other hand, are known for their unique growth strategy, wrapping around host trees. How does negative thigmotropism contribute to the strangler fig's growth pattern?"
            - Follow-up: "What advantages might negative thigmotropism provide to strangler figs in terms of obtaining sunlight and nutrients?"
- Interaction with Surroundings:
    - Consider how kudzu's positive thigmotropism and strangler fig's negative thigmotropism influence their interaction with other plants. How might these behaviors impact the ecosystem they are part of?"

- Follow-up: "Can you think of any potential consequences or ecological effects of these thigmotropic behaviors on the surrounding plant life and ecosystem?"
  - Encourage students to think critically about the ecological implications of kudzu's rapid growth towards other plants and structures and how it might compete for resources.
  - Prompt students to explore how the strangler fig's growth away from touch stimuli, coupled with its unique strategy of enveloping host trees, affects the host trees and the overall forest ecosystem.
  - Discuss the potential consequences, both positive and negative, of these thigmotropic behaviors on biodiversity, resource availability, and the balance of ecosystems where these plants are found.

- Impact on Host Trees:
  - Strangler figs can eventually harm or even kill host trees by depriving them of sunlight and nutrients. How does negative thigmotropism contribute to this process, and what might be the consequences for the host tree?"
    - Follow-up: "Do you think there are situations where positive thigmotropism, as seen in kudzu, could also have negative consequences for other plants?"
      - When discussing the impact on host trees, encourage students to think about the long-term consequences of strangler figs' growth patterns on the health and survival of host trees, as well as the ecological implications.
      - Explore the potential scenarios where positive thigmotropism, as seen in kudzu, could lead to negative consequences, such as competition for resources or overgrowth that affects other plant species.
- Human Perspectives:
  - From a human perspective, how do kudzu and strangler figs impact the environments they inhabit? What challenges or benefits might they pose to ecosystems or to human activities?"

        - Follow-up: "Can you think of any human interventions or management strategies related to kudzu or strangler figs based on their growth patterns?"
            - Prompt students to consider the challenges and benefits of kudzu and strangler figs from both ecological and human perspectives. Discuss potential strategies that humans might employ to manage or mitigate the impact of these plants on ecosystems and human activities.
- What sort of environment do these plants seem to come from and why might there be competition for light there?
    - Kudzu (Pueraria montana) is native to East Asia, particularly regions of China and Japan. It thrives in warm, humid climates with fertile soils. Kudzu's native environment features a subtropical or temperate climate with abundant rainfall.
        - Competition for light in the native environment of kudzu arises due to the dense vegetation typical of these regions. In such environments, various plant species vie for access to sunlight, a vital resource for photosynthesis and growth. Kudzu's rapid growth and positive thigmotropism allow it to climb over other vegetation, including trees, as it competes for light. This competitive behavior is an adaptation to maximize its chances of survival and growth in its natural habitat.
    - Strangler figs, including species like Ficus aurea, are commonly found in tropical rainforests and other tropical regions. They prefer humid and warm climates.
        - The competition for light in tropical rainforests is intense due to the exceptionally dense canopy formed by tall trees. In such environments, sunlight penetration to the forest floor is limited. Strangler figs' negative thigmotropism, combined with their growth strategy of wrapping around host trees, allows them to compete for access to sunlight by reaching the upper canopy where light is more abundant. This behavior is crucial for their successful growth and reproduction.
            - In both cases, competition for light is a fundamental aspect of the native environments these plants come from. It reflects the evolutionary adaptations of kudzu and strangler figs to secure the sunlight needed for their growth and

survival amidst the dense vegetation of their respective habitats.

- As we explore the fascinating world of thigmotropism and how plants respond to touch, let's draw a connection to our earlier discussion about kudzu and strangler figs. Just like the tendrils in our experiment, these plants showcase unique responses to their surroundings, which involve touch and support-seeking behaviors."
    - Thigmotropism in Kudzu:
        - "Remember how kudzu, known for its rapid growth, uses positive thigmotropism to climb and spread over surfaces, actively seeking support structures like trees and buildings? Our experiment today will help us understand this behavior better by observing how plants respond to touch."
    - Thigmotropism in Strangler Figs:
        - "Similarly, strangler figs, such as Ficus aurea, employ negative thigmotropism as part of their growth strategy. They wrap around host trees in response to touch, eventually encircling and often overpowering them. Today's exploration will shed light on how thigmotropism contributes to these unique growth patterns."
            - By connecting the thigmotropism experiment to the previous discussion about kudzu and strangler figs, students can better grasp the concept of touch-induced plant responses and see how these behaviors are exhibited in different plant species.
- Provide each student or group with a potted plant, string, stakes, and labels.
    - Instruct students to set up an experiment by gently tying a tendril to a stake with the string. They can create different conditions by varying the angle or height of the string.
    - Science Notebook Entry Points:
        - Before the experiment: Have students make predictions about tendril behavior and record them in their science notebooks.
        - During the experiment: Encourage students to document their daily observations, sketches, and any changes they notice in tendril movement.
        - After the experiment: Have students summarize their findings and reflect on what they learned about thigmotropism and its importance for plants
    - A tendril is a specialized stem, leaf, or petiole with a threadlike shape used by climbing plants for support, attachment, and, in some cases, parasitism. Tendrils play a crucial role in enabling certain plants to climb, find support, and access sunlight and nutrients in their environments. Thank you for pointing out the error, and I appreciate your understanding.
        - Several plants that can be grown from seeds and have tendrils include:
            - Sweet Peas (Lathyrus odoratus): Sweet peas are popular garden flowers that produce delicate, fragrant blossoms. They have long, curling tendrils that help them climb and attach to trellises or other support structures.

- Climbing Beans (Phaseolus vulgaris): Climbing beans, including varieties like pole beans and runner beans, have tendrils that assist them in climbing upward. They are both ornamental and edible plants.
- Morning Glories (Ipomoea): Morning glories are known for their stunning, trumpet-shaped flowers and vining growth habit. They have twining tendrils that allow them to climb and cover fences, walls, or arbors.
- Cucumbers (Cucumis sativus): Many cucumber varieties have tendrils that help them climb vertically. Cucumbers are a common vegetable crop grown in gardens.
- Peas (Pisum sativum): Peas, both garden peas and snow peas, develop tendrils that assist them in climbing. They are commonly grown for their edible pods and peas.

- Encourage students to carefully observe the behavior of the tendrils over the next few days. They should record their observations in notebooks or on observation sheets.
    - Encourage students to closely observe the behavior of the tendrils over the next few days. Use magnifying glasses if available to examine the details.
    - Record their observations in notebooks or on observation sheets.
    - Note the following aspects of tendril behavior:
        - Direction of Movement: What direction do the tendrils move in response to touch? Are they moving upwards, sideways, or in a different direction?
        - Speed of Movement: How quickly do the tendrils respond to touch? Does the movement occur rapidly, or is it slow and gradual?
        - Changes in Plant Orientation: Does the plant change its orientation as the tendrils respond to touch? Is it leaning or moving in a particular direction?
        - Overall Response to Touch: Describe the overall behavior of the plant and tendrils in response to touch. Are there patterns or variations in response?
    - Additional Questions:
        - "What do you think causes the tendrils to move towards or away from the support structure?"
        - "Do you notice any differences in tendril behavior when they encounter different angles or heights of the string?"
        - "Can you identify any specific cues or triggers that initiate tendril movement?"
        - "How might the plant 'know' where to direct its tendrils in response to touch?"
    - Measurement Directions:
        - For tracking the speed of tendril movement, students can measure the distance the tendril travels in a set time period (e.g., centimeters per hour).

- To note changes in plant orientation, students can use a compass or directional terms (e.g., north, south, east, west) to describe any shifts in the plant's position.
- Discussion During Experiment:
  - Circulate among the students, facilitating discussions and addressing questions.
  - Encourage students to compare observations, discuss any unexpected findings, and revise their predictions.
- Group Discussion:
- Bring the class together for a group discussion.
  - Ask students to share their observations and discuss the patterns they noticed in tendril behavior.
  - Create a large chart on the board or chart paper to collectively record the class's observations.
  - Categorize the observations into common patterns and behaviors exhibited by the tendrils.
- Conclusion and Reflection:
  - Engage students in a reflection on what they have learned:
  - "What did you observe about the behavior of tendrils?"
  - "How does thigmotropism contribute to a plant's ability to climb or find support?"
  - "Why do you think plants have evolved to exhibit thigmotropism?"
- Discuss real-world applications of thigmotropism in plants, such as in agriculture or horticulture practices.
  - Ask students to brainstorm ways in which understanding thigmotropism could be beneficial for farmers or gardeners.
  - For an extended project, students can design and conduct their own experiments to explore different factors influencing thigmotropism, such as light or temperature.

Unveiling the Secrets of Plants (elaborate)

- Begin by reviewing the concept of plant movement, emphasizing tropisms such as phototropism, geotropism, and thigmotropism.
  - Facilitate a brief class discussion to refresh students' knowledge.
    - Phototropism: "First up, we have phototropism. Remember, 'photo' refers to light. Phototropism is when plants grow towards a light source. Think about how sunflowers turn their faces to follow the sun throughout the day. They do this to maximize their exposure to sunlight for photosynthesis."
    - Geotropism: "Next, we have geotropism, sometimes called gravitropism. 'Geo' means earth, and this is all about how plants respond to gravity. Roots, for instance, show positive geotropism, meaning they grow downwards into the soil, while stems exhibit negative geotropism as they grow upwards towards the sky."
    - Thigmotropism: "Now, let's talk about thigmotropism. 'Thigmo' relates to touch, and this is what we'll focus on today. It's when plants respond to touch or physical contact. Some plants use tendrils or specialized structures to climb, while others avoid touch or pressure. It's like their way of feeling their environment."

- Introduce the student-led project as an opportunity for them to explore plant movement in-depth.
    - Divide the class into small groups, and let each group choose a specific tropism to focus on. You can provide a list of tropisms or let them come up with their own ideas. Examples include phototropism, geotropism, thigmotropism, hydrotropism (response to water), or chemotropism (response to chemicals). Set up research stations with materials on different tropisms.
    - Students explore and gather information about their chosen tropism, considering factors like how it works, its importance for the plant, and real-world examples.
    - Prepare research stations for each tropism you've selected. These stations should include materials, resources, and guidance specific to the chosen tropism. For example:
        - Phototropism (Response to Light):
            - Information: Explain that phototropism is the plant's response to light. Provide resources such as articles or diagrams that describe how plants detect light using photoreceptors called phototropins. Explain how the plant hormone auxin plays a role in bending towards the light source.
            - Hands-On Demonstration: Use a simple hands-on experiment where students can observe how a plant grows towards a light source. Place a potted plant near a window or under a grow light and have students track its growth direction over a few days. You can also provide a link to NASA's "Growing Plants in Space" website for real-world examples: NASA Growing Plants in Space
        - Geotropism (Response to Gravity):
            - Information: Describe geotropism, also known as gravitropism, as the plant's response to gravity. Provide resources explaining how roots exhibit positive geotropism by growing towards gravity (downward), while stems show negative geotropism by growing against gravity (upward).
            - Hands-On Demonstration: Set up an experiment with seeds planted in a clear container, allowing students to observe root and stem growth in response to gravity. You can also provide a link to a resource like the University of Illinois Extension's "Plant Growth" guide: UI Extension - Plant Growth
        - Thigmotropism (Response to Touch):
            - Information: Explain thigmotropism as a plant's response to touch or mechanical stimuli. Provide articles or diagrams illustrating how plants sense touch through specialized cells and how they adapt their growth in response.
            - Hands-On Demonstration: Offer various materials for students to touch and observe how certain plants react.

For example, you can provide sensitive plants (Mimosa pudica) for students to gently touch and observe leaf folding as a response to touch.
- Online Resource: Share a link to the Botanical Society of America's article on "Thigmotropism in Plants" for further reading: BSA - Thigmotropism in Plants

- Allow students to form small groups based on their interest in a specific tropism
- In their small groups, students brainstorm project ideas that effectively demonstrate their chosen tropism. Encourage creativity and innovation.
    - Provide a project planning worksheet or document where students outline their project goals, materials needed, and steps for implementation.

Plant Tropism Project Planning Worksheet

Group Name:
Tropism Chosen:

Project Goals:
What is the main objective of your project related to the chosen tropism?
What do you aim to demonstrate or prove through your project?
What specific questions or hypotheses will your project address?

Materials Needed:
List all the materials you will require to carry out your project. Be specific.
Include any plants, tools, equipment, or supplies needed.
Consider safety precautions if applicable.

Steps for Implementation:

Introduction: Describe how you will introduce your project to the class or audience. How will you capture their attention and explain the significance of your chosen tropism?

Hypothesis: Clearly state your hypothesis or the expected outcome of your project. How does it relate to the chosen tropism?

Experimental Setup: Outline the setup or design of your experiment or project. Include details such as the type of plant, light sources, containers, and any support structures.

Data Collection: Explain how you will collect data during your project. Specify the measurements or observations you will record. Include the frequency and duration of data collection.

Variables: Identify the variables you will manipulate (independent variables) and measure (dependent variables). Explain how you will control other factors to ensure a fair test.

Data Recording: Describe the methods and tools you will use to record data. Be specific about how you will measure and document your observations.

Analysis: Explain how you will analyze the data collected. Will you create graphs, tables, or visual representations to display your findings?

Results: Discuss the expected results based on your hypothesis. What do you anticipate the data will show?

Conclusions: Summarize the conclusions you expect to draw from your project. How will your findings relate to the chosen tropism, and what broader insights can be gained?

Presentation: Outline your presentation format. What visuals, diagrams, or models will you use to enhance your presentation? How will you engage the audience?

Reflection: Reflect on the project planning process. What challenges or obstacles do you anticipate, and how do you plan to overcome them?

Timeline: Create a timeline indicating when each step of your project will be completed. Include milestones and deadlines.

    - Emphasize the importance of aligning their project with the scientific principles behind the chosen tropism.
    - Allocate time for students to gather materials needed for their projects. These materials may include craft supplies, plants, light sources, and other relevant items.
    - Encourage sustainability by considering the reuse of materials when possible.
- Experiment Design:
    - Instruct students to design their experiments or projects with a clear hypothesis in mind. They should outline the variables they will manipulate and measure to demonstrate the chosen tropism.
    - Provide guidance on experimental controls to ensure valid results.
    - Specify the measurements they need to take, such as the distance of plant movement or the time it takes for a response to occur.
    - Students should also record the conditions they maintain during the experiment, such as light intensity, temperature, or humidity.
- Observation and Data Recording:
    - As students implement their projects, emphasize the importance of careful observation and data recording.
    - Provide guidance on maintaining consistency in data collection, such as using standardized tools for measurements.
    - Encourage students to record their observations at regular intervals or time points, depending on the tropism they are investigating.
        - For phototropism, measurements can include the angle of plant bending towards the light source and the rate of bending.

        - For geotropism, students can measure the angle at which roots or stems are growing in relation to gravity.
        - For thigmotropism, they can record the time it takes for a plant to respond to touch and the extent of the response.
    - Troubleshooting and Adjustments:
        - If students encounter challenges or unexpected results, guide them through troubleshooting and making adjustments to their projects.
        - Reinforce the iterative nature of scientific inquiry, where adjustments are part of the learning process.
  - Project Presentations:
    - During presentations, encourage students to include data tables or graphs that illustrate their measurements.
    - Ask groups to explain how they measured and recorded data throughout their projects.
    - Emphasize the importance of accurate and detailed data in supporting their conclusions.
- Encourage students to take a moment to reflect on what they've learned today. Ask open-ended questions like:
  - "What was the most interesting or surprising thing you discovered about plant tropisms today?"
  - "How do plant tropisms contribute to the overall success of plants in their ecosystems?"

Investigations and Application
Physiology and Photosynthesis—Vascular Systems

Educator Background Information—Vascular systems

Plants, though seemingly static, harbor a remarkable internal network that allows them to thrive, grow, and adapt to their environments. This intricate system is known as the plant vascular system, a complex arrangement of tissues responsible for the transportation of water, nutrients, and other essential substances throughout the plant. Much like the circulatory system in animals, the plant vascular system plays a critical role in sustaining life.

Two Key Components: Xylem and Phloem

The plant vascular system consists of two primary types of tissues: xylem and phloem. These tissues form a continuous network that extends from the roots to the leaves, ensuring the efficient transport of fluids and nutrients. Let's explore the unique functions of each component:

1. Xylem: The Upward Journey

The xylem is the conduit responsible for the upward movement of water and minerals from the roots to the other parts of the plant. This upward journey, often against the force of gravity, is a remarkable feat facilitated by specialized cells within the xylem known as tracheary elements. These elements include vessels and tracheids, which form hollow tubes allowing the unimpeded flow of water.

One key force driving water upward through the xylem is transpiration, a process where water evaporates from the stomata on the leaf surface. This creates a negative pressure, or tension, pulling water up the plant's stem. The cohesion and adhesion properties of water molecules also contribute to this upward movement, creating a continuous column of water within the xylem.

2. Phloem: The Downward Journey

In contrast, the phloem is responsible for the downward movement of sap, a mixture of water, sugars, and other organic compounds produced during photosynthesis. This nutrient-rich sap flows from the leaves, where it is synthesized, to various parts of the plant for growth, energy storage, and metabolism.

The main cells in the phloem are sieve tube elements, which form tube-like structures with perforated end walls known as sieve plates. These sieve plates allow for the efficient flow of sap between adjacent cells. Companion cells, closely associated with sieve tube elements, provide metabolic support and help maintain the integrity of the phloem.

Vascular Bundles: Unity in Diversity

In plant stems, the xylem and phloem are organized into structures called vascular bundles. These bundles vary in arrangement and distribution among different plant species, showcasing the diversity of plant vascular systems. In dicot stems, for instance, vascular bundles are arranged in a ring, while in monocot stems, they are scattered throughout the stem.

Real world connections:

The study and understanding of plant vascular systems are not only essential for scientists and researchers but also play a crucial role in various careers where a deep knowledge of plants is required. These careers involve harnessing the power of plant vascular systems for diverse purposes: botanist, agricultural scientist, arborist, environmental consultant, plant pathologist, landscaper and conservation scientist

Next Generation Science Standards

MS-LS1-1: Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.
MS-LS1-2:Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.
MS-LS1-3:*Standard:* Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
MS-LS2-4:: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Students will be able to:

- Students will engage in scientific practices such as observation, experimentation, data analysis, and constructing explanations to deepen their understanding of plant vascular systems.
- Students will analyze the relationship between plant vascular systems and overall plant growth, recognizing how efficient transport influences factors like size, structure, and health.

Student Vocabulary:

- Xylem: A type of plant tissue that transports water and dissolved minerals from the roots to the rest of the plant. It consists of specialized cells called vessel elements and tracheids.
- Phloem: A plant tissue responsible for transporting sugars (sucrose) produced during photosynthesis from the leaves to other parts of the plant, such as the roots and fruits.
- Vascular Bundle: A structure in plants that contains both xylem and phloem tissues, typically found in the stem. It provides support and facilitates the transport of water, nutrients, and sugars.
- Transpiration: The process by which water vapor escapes from tiny openings called stomata in plant leaves, creating a vacuum that pulls water upward through the xylem.
- Stomata: Small pores on the surface of plant leaves and stems that allow for gas exchange (carbon dioxide in and oxygen out) and water vapor release during transpiration.
- Root Pressure: The force generated by the active transport of minerals into the root xylem, pushing water and nutrients upward through the plant.
- Sieve Tube Elements: Specialized cells in the phloem responsible for transporting sugars. They are connected end-to-end, forming long pipelines.

- Companion Cells: Cells adjacent to sieve tube elements that assist in loading and unlading sugars into the phloem for transport.
- Cambium: A layer of actively dividing cells found in the vascular bundles of stems and roots. It contributes to the growth of plant vascular tissues.
- Vascular Plants: Plants that possess a well-developed vascular system, including xylem and phloem, allowing them to transport water, nutrients, and sugars over long distances.
- Non-Vascular Plants: Plants that lack a true vascular system and rely on diffusion and osmosis for water and nutrient transport. Examples include mosses and liverworts.
- Sap: The sugary fluid produced by the plant and transported through the phloem. It contains essential nutrients and energy for growth and development.
- Root Hair: Tiny hair-like extensions on the surface of plant roots that increase the surface area for water and nutrient absorption.
- Adhesion: The property of water molecules to stick to the walls of the xylem vessels, aiding in water transport against gravity.
- Cohesion-Tension Theory: A theory explaining the movement of water in plants, where cohesion (water molecules sticking together) and tension (pulling force) work together to pull water up through the xylem.
- Casparian strip - The inner vascular section
- Cortex - is an outer layer of a stem or root in a plant, lying below the epidermis but outside the vascular bundles
- Epidermis - is a single layer of cells that covers the leaves, flowers, roots and stems of plants
- Plasmodesmota - a narrow thread of cytoplasm that passes through the cell walls of adjacent plant cells and allows communication between them
- vascular bundles - a strand of conducting vessels in the stem or leaves of a plant, typically with phloem on the outside and xylem on the inside

Unveiling the Secret Pathways of Plants (engage)

- Today, we're embarking on an exciting journey into the hidden world of plants.
    - Have you ever wondered how water, nutrients, and food move within a plant?
    - "Today, we'll unveil the secret pathways that make it all happen."
        - Show different plant specimens with leaves, stems, and roots.
        - Here are some common plant specimens with leaves, stems, and roots that can be easily obtained or prepared for classroom use:
            - Bean Plant:
                - Leaves: Bean plant leaves are easily recognizable with their large, green, and typically serrated edges.
                - Stems: The stem of a young bean plant is usually green, slender, and flexible.
                - Roots: Bean plants have a well-defined taproot system with a primary root and smaller lateral roots.
            - Dandelion:
                - Leaves: Dandelion leaves have a distinct toothed shape and are often lobed.
                - Stems: Dandelion stems are smooth and hollow, with a milky sap.
                - Roots: Dandelions have a long, deep taproot that can be easily observed.

- Carrot:
    - Leaves: Carrot leaves have feathery, fern-like structures and are often green or purple.
    - Stems: The part of the carrot we eat is actually a modified stem, known as a taproot.
    - Roots: Carrots have thick, fleshy taproots that are orange or purple in color.
- Fern:
    - Leaves: Fern leaves are typically divided into multiple smaller leaflets, giving them a delicate appearance.
    - Stems: Fern stems are often slender and covered with scales.
    - Roots: Ferns have fibrous roots that are not as easily observed but can be discussed.
- Sunflower:
    - Leaves: Sunflower leaves are large, broad, and usually green with a rough texture.
    - Stems: Sunflower stems are thick and sturdy, with a prominent central stem.
    - Roots: Sunflowers have a fibrous root system with many lateral roots.
- Radish:
    - Leaves: Radish leaves are typically green and lobed or pinnately divided.
    - Stems: The part of the radish we eat is a modified stem, and it can be observed when cut.
    - Roots: Radishes have a fleshy taproot that is often white or red.

- Show various plant specimens, including bean plants, dandelions, carrots, ferns, sunflowers, and radishes, with leaves, stems, and roots.
- Encourage students to observe them closely and discuss what they notice about their structures.
    - How do you think they're connected internally
    - "What do you think happens inside the plant to move water from the roots to the leaves?"
    - "Are there any specific structures you can identify that might play a role in transporting water or nutrients?"
    - "Do you notice any patterns or differences in the internal structures of leaves, stems, and roots among the different plant specimens?"
    - "How might the internal connections in plants help them survive and thrive in their respective environments?"
    - "Could you make any predictions about how the internal structure of a plant relates to its function?"
    - "Consider the color and texture of the plant parts. How might these characteristics be related to their internal functions?"
- Allow students to form small groups.
    - Assign each group a different plant specimen from the selection.
- Provide magnifying glasses or microscopes for closer examination.

- Distribute science notebooks to each group.
    - Plant Structures Observation:
        - Observe and label the different parts of your assigned plant specimen (leaves, stems, roots).
        - Describe the textures, colors, and shapes you observe.
    - Microscopic Exploration:
        - Use magnifying tools to examine a small section of your assigned plant specimen.
        - Draw what you see at a microscopic level.
        - Discuss how the microscopic structures contribute to the overall function of the plant.
    - Comparing Plant Varieties:
        - Compare the structures of your assigned plant specimen to those of other specimens in the selection.
        - Note similarities and differences in leaves, stems, or roots.
        - Consider how these differences relate to the environments where these plants thrive.
    - Identifying Vascular Elements:
        - Look specifically at the stems of your assigned plant specimen.
        - Can you identify any structures that might be part of the plant's vascular system?
        - Draw and label these structures.
- Hands-On Plant Observation
    - Observe and label different plant parts, including leaves, stems, and roots.
    - Describe their textures, colors, and shapes.
    - Microscopic Exploration:
        - Use magnifying tools to examine a small plant section and draw what you see at a microscopic level.
            - Pay special attention to structures that may be related to water and nutrient transport, such as xylem and phloem.
    - Comparing Plant Varieties:
        - Compare the structures of two different plant specimens, focusing on leaves, stems, and roots.
        - Note similarities and differences that could be related to their internal systems.
    - Identifying Vascular Elements:
        - Look at stems specifically and identify structures related to the plant's vascular system.
        - Can you recognize any components that may be part of the xylem and phloem?
- Bring the class back together and facilitate a discussion
    - Have each group share their observations and findings, especially regarding the structures related to water and nutrient transport.
    - Encourage questions and discussions about the structures observed, including the potential role of xylem and phloem.

- Connect their observations to prior knowledge about plant anatomy and the importance of vascular systems.
- Display images and diagrams showcasing plant vascular systems, emphasizing xylem and phloem:
  - Show images and diagrams of plant cross-sections that clearly illustrate xylem and phloem.
  - Discuss the key features and components of xylem (water transport) and phloem (nutrient transport).
  - Facilitate a discussion with questions like:
    - "What did you observe in the images/diagrams related to xylem and phloem?"
    - "Can you identify different structures within the plant vascular system that may correspond to xylem and phloem?"
    - Have students generate questions about how plant vascular systems work and write them on chart paper.
    - Encourage questions related to the roles of xylem and phloem in water and nutrient transport.

Unveiling the Secret Pathways of Plants (explore)

- Begin by reviewing the key concepts from the previous lesson about plant vascular systems.
  - Ask students what they remember about xylem and phloem. Encourage them to share their prior knowledge.
  - Show diagrams or images of xylem and phloem from the previous lesson.
    - Briefly explain that xylem is responsible for transporting water from the roots to the rest of the plant, while phloem carries nutrients, such as sugars, throughout the plant.
    - Ask students to discuss in pairs or small groups:
      - "Why do you think it's important for plants to have these systems for water and nutrient transport?"
      - "How might xylem and phloem help plants survive and grow
  - Begin by discussing the concept of plant absorption and its importance.
      - Explain the objective of the experiment: to observe how plants absorb different substances.
    - Emphasize the role of the plant's vascular system (xylem and phloem) in this process.
  - Provide each group with an overview of the three experiment stations. Explain that they will rotate through these stations to observe the effects of different substances on plant absorption'
    - Highlighter Fluid Station:
      - Observing changes in the color of the carnation's petals, stems, and other parts.
      - Noting any patterns in color changes over time.
    - Vitamin B Station:
      - Examining the carnation for changes in color compared to plain water.
      - Paying attention to any variations in the plant's structure.

- Tonic Water Station:
    - Close examination of the carnation for changes in color and structure.
    - Noting any patterns in changes observed over time.
- Materials Needed:
    - White carnations (1 per student or group)
    - Three clear cups or vases filled with water (about 300 ml per cup)
    - Highlighter fluid (different colors)
    - Crushed vitamin B complex tablets (1 tablet per cup)
    - Tonic water (enough to fill a cup)

- Station 1 - Highlighter Fluid: Procedure:
    - Add 5-7 drops of different-colored highlighter fluid to the water in your cup.
    - Gently stir the water to ensure the highlighter fluid mixes in.
    - Observations:
        - Use your magnifying glass to closely observe the carnation's petals, stems, and any changes in color.
        - Record your observations in your science notebook, noting the time of each observation.
    - Science Notebook Prompts for Station 1:
        - Describe the color changes you observe in the carnation.
        - How do you think the highlighter fluid is moving through the plant?
        - Can you identify any patterns in the color changes over the 30-minute observation period?
- Station 2 - Vitamin B: Procedure:
    - Crush one vitamin B complex tablet and add it to the water in your cup.
    - Stir the water gently to aid in the dissolution of the crushed tablet.
    - Observations:
        - Use your magnifying glass to closely examine the carnation for any changes.
        - Record your observations in your science notebook, paying attention to color variations.
    - Science Notebook Prompts for Station 2:

    - Compare the appearance of the carnation in this solution to the one in plain water. What differences do you observe?
    - How might the vitamin B be affecting the plant's color?
    - Do you notice any changes in the plant's structure or stems?
- Station 3 - Quinine from Tonic Water: Procedure:
  - Pour tonic water into your cup, filling it to about two-thirds full.
  - Gently stir the tonic water to prepare it for the carnation.
  - Observations:
    - Use your magnifying glass to closely examine the carnation for any changes.
    - Record your observations in your science notebook, paying attention to color variations.
  - Science Notebook Prompts for Station 3:
    - Describe the differences you observe in the carnation submerged in tonic water compared to the one in plain water.
    - How might the quinine from tonic water be affecting the plant?
    - Can you identify any patterns in the changes over the 30-minute observation period?
- Encourage students to use their magnifying glasses to closely observe any changes in the carnation's petals, stems, and overall appearance.
- Bring the class together to discuss their findings at each station.
  - Encourage students to share their observations and any patterns they noticed during the experiments.
  - Facilitate a discussion on how different substances may affect plant absorption.
  - Discuss which parts of the vascular system might be involved in these processes.
- Conclude by summarizing key findings and connecting them to the plant's ability to absorb and transport substances.
  - At the Highlighter Fluid Station, we observed that the carnation absorbed the colored fluid, resulting in changes in the plant's color. This indicates that plants can draw up liquids through their vascular system, just like a straw.
  - In the Vitamin B Station, we noticed that the carnation's color changed when exposed to crushed vitamin B tablets. This demonstrates how plants can absorb nutrients from their surroundings to support their growth.
  - Lastly, at the Tonic Water Station, we saw the carnation undergo changes in both color and structure. This suggests that plants can absorb substances like quinine from tonic water, affecting their appearance and potentially their health.

Unveiling the Secret Pathways of Plants (explain)

- Now that we've taken a peek into the fascinating world of plant vascular systems and discovered the incredible roles of xylem and phloem, it's time for the next part of our adventure – the Explore phase! In Explore, we'll become hands-on scientists, conducting experiments and digging deeper into how these systems work.
  - Remember those questions you wrote down in your science notebooks during

our Engage lesson? Well, get ready to find some answers! We'll be investigating water transport in plants, exploring the microscopic details, and getting our hands into some exciting experiments.

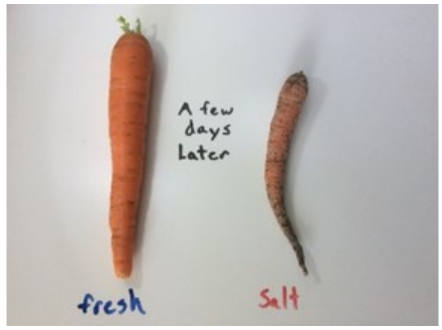
- So, scientists, put on your exploration hats, grab your notebooks, and let's dive into the world of plant vascular systems like never before. The mysteries are waiting, and it's time for us to unlock even more secrets together!
- To prep for the exploration of water conduction by plants prepare the following setup.
    - Preparation may be done in advance or included as student procedure to be performed with later subsequent observation. This activity itself is performed as a lab practicum in which students manipulate, and identify vascular structures, observing their action in the process.
        - It is further recommended that the non-dissected carrots are kept as running experiments to be thoroughly examined once the effects are more evident.
    - Prepare as follows:
        - One carrot placed in freshwater
        - One carrot placed in Saltwater
        - One carrot for dissection

- Carrot root structures are responsible for the rapid absorption of water and nutrients, but must also screen the material entering the plant for unwanted materials.
    - This is done by separating the outer absorbing section of the root from the inner section which conducts water and nutrients up towards the stem.
    - The outer section is composed of an epidermis featuring long root hair cells with increased surface areas and spongier tissue called cortex.
    - The cells of the epidermis and cortex are conjoined to one another through cavities in their shared cell wall called plasmodesmota.
        - Additionally the cells of the cortex may have extra cellular spaces between them. This means that any and all materials absorbed through the cells of the epidermis can flow through, and between all of the subsequent cells up to the inner section.

    - The Endodermis, or inner skin of the root however possesses a thick, fused cell wall between all of its cells called the Casparian strip.
- The strip ensures that all of the material entering inner section must be more intensely screened through the semipermeable membrane of the of the endodermis cells. Past this point there is only a thin sheath called the pericycle around xylem tissue, which carries water and minerals up from the roots, and Phloem which distributes organic compounds such as sugars and vitamins produced in the leaves.
- While all of this might technically be possible to view through the microscope, the boundary set by the endodermis between the inner and outer sections of the root is most easily seen by the naked eye when the carrot is cut in cross section.
    - The inner vascular section, seen as a darker interior circle, can be traced directly up to the stem if the carrot is cut in half lengthways. It is recommended that teachers instruct students to cut the lower half of the carrot into circular cross sections and split the upper half longways to see both views.

- Because the endodermis and casparian strip operate very strictly as a semipermeable membrane while the outer absorbing sections are spongey, the whole structure of the carrot is extremely subject to the osmosis and diffusion.
- The inner boundary pulls in and holds solutes beneficial to the plant while excluding others, but water will flow to wherever there is the greatest concentration of dissolved materials.
    - When soaked in freshwater, the water rushes into the carrots interior to join sugars, vitamins, and collected minerals.
    - When in saltwater, it rushes out towards the higher concentration of dissolved salt.

- Have students observe how the carrots become desiccated or plumped in each medium,



- Swap the carrots between containers
    - Note that osmotic potential is not the pump which drives water through the plant, it only serves to help absorption in the roots.
    - Some plants which grow in saltwater actually use a different, more active setup.
    - The effects of diffusion can appear to “revivify” wilted carrots and other produce when placed in fresh water.
        - Teachers who choose to prepare the saltwater carrots ahead of time may dramatize the mad science aspect of “zombie carrots” returning to a crisper, plumped state when swapped to freshwater.
        - Severed carrot tops may be regrown into live stalks from the meristem tissues they contain. However, since carrots are biennials, the plant will grow into the mature flowering stage which produces seeds and dies. It does not regenerate its taproot.
- In students science notebooks, students should record initial Observations:
    - Describe the appearance of the carrots before the experiment.
    - Note any differences in color, texture, and overall condition among the carrots.
    - Swapping Carrots:
        - Record your observations as the carrots are transferred from the saltwater container to the freshwater container.
        - What changes, if any, do you notice immediately after the swap?
    - Osmotic Potential Discussion:
        - Explain the role of osmotic potential in plant water absorption. How does it relate to this experiment?
        - Why is osmotic potential important for plants in their natural environments?
    - Effects of Diffusion:

        - Discuss how diffusion plays a role in the changes observed in the carrots when placed in freshwater.
        - Why do you think diffusion can appear to "revivify" wilted carrots and other produce?
    - Mad Science Aspect:
        - If your teacher prepared the saltwater carrots ahead of time, describe the changes you observed when they were swapped into freshwater.
        - How does this aspect of the experiment relate to real-life scenarios involving saltwater and freshwater environments?
    - Regrowth Potential:
        - Explain the concept of regrowing severed carrot tops using meristem tissues.
        - What do you expect to happen if the carrot tops were allowed to grow further? Why does the plant eventually reach the flowering stage?
- To further explore of water conduction by plants prepare the following setup. Preparation may be done in advance or included as student procedure to be performed with later subsequent observation.
    - As before, this activity is performed as a lab practicum in which students stain, and identify vascular structures.
    - However it is recommended that the simple setup of preparing the celery in a mixture of food coloring and water be done ahead of the formal examination so that the celery has time to pull the stain up through its vascular bundles.

- Specifically, this activity will have students observe the tree cookies and cross sections of the colored celery using microscopes/strong magnifiers.
  - Upon leaving the roots and rising into the stem, vascular tissues form into lines called vascular bundles.

  - In the stem, each vascular bundle contains xylem towards the inside of the plant, phloem tissue towards the outside, and the length of vascular cambium which grows sandwiched in between them.
    - Have students review the following points and identify the structures to confirm with their own eyes
  - Two major divisions of flowering plants are monocots and eudicots. While the distribution of vascular bundles in the stem form a round, scattered, firework-like pattern in monocots, dicots arrange theirs into a clear ring configuration.
    - Which does the woody tree cookie seem to be, a monocot or dicot?

    - Xylem tissue is actually composed of dead cell walls and consecutive layers of it are laid down by the vascular cambium each year to create wood in concentric tree rings. If this is the case, where do students suspect the living part of the tree trunk that contains the cambium

and phloem might be located? Is there a layer just below the bark with a different structure?
    - Since Xylem is effectively elongated dead cell walls students may be able to see the hollow cavities inside by examining the cut edge of the tree ring closely. Note this will be more difficult with fine grained woods, particularly conifers.
    - Notice that the vascular bundles in the celery are in neither a firework or ring arrangement.
- Explain. Is celery neither a monocot or eudicot or do the described arrangements of the vascular bundles not continue into other parts of the plant?
    - In other words, would we see the veins of eudicot leaves arranged in a ring, or is this pattern abandoned? Is the celery stalk a stem? It may be helpful to really examine a celery bunch.
    - The term Petiole refers to the stem of a leaf which connects the leafs blade to the branch or stem. Students observing the top end of a celery stick may be able to observe part of the leaf blade, particularly on smaller ones towards the center of the bunch which have not been cut. Celery simply has a very exaggerated petiole.
        - If possible examine the vascular bundles at either end of the petiole, coming from the stem and entering the leaf blade. How do they rearrange?
        - further examination of celery bundle shows how the petioles are arranged around a low central stem. The edible celery sticks are much larger basal leaves.

Unveiling the Secret Pathways of Plants (elaborate)

- Today, you're stepping into the role of scientists as you design and conduct your own experiments related to plant vascular systems.
- Think about questions you have or aspects you want to explore further. Remember, a good experiment starts with a clear question and a solid plan."
    - Experiment Design
        - Group Brainstorming:
            - Students work in small groups to brainstorm experiment ideas.
            - Emphasize the importance of a clear question, variables, and a controlled environment.
            - Circulate to guide and approve experiment plans.
                - How does the concentration of salt in water affect water absorption in plants?
                - Does the color of light impact plant growth and water transport?
                - What is the effect of different soil types on water uptake by plants?

- Clarify the Purpose:
    - Remind students of the importance of formulating a clear and specific question related to plant vascular systems.
    - Example: "How does [independent variable] affect [dependent variable] in the context of plant water transport?"
- Consider Variables:
    - Discuss the concept of variables: independent, dependent, and controlled.
    - Emphasize the need for controlled variables to ensure a fair experiment.
    - Example: "If we're testing the effect of light on plant growth, what other factors should we keep the same to make sure our results are accurate?"
- Selecting Plant Species:
    - Guide students in choosing appropriate plant species for their experiments.
    - Discuss factors such as growth rate, hardiness, and relevance to the chosen question.
    - Example: "Considering our question, which plant species would be most suitable for our experiment?"
- Drafting Experimental Procedures:
    - Encourage students to outline step-by-step procedures for their experiments.
    - Emphasize the importance of clarity and replicability.
    - Example: "How will you set up your experiment? What will you measure, and how often?"

        Sample Experiment Ideas:

        Effect of Light Color on Plant Growth:
        - Question: "How does the color of light impact the growth of a plant?"
        - Independent Variable: Color of light (red, blue, green, etc.).
        - Dependent Variable: Plant growth (measured by height or number of leaves).

        Watering Frequency and Growth:
        - Question: "Does the frequency of watering affect plant growth?"
        - Independent Variable: Watering frequency (daily, every other day, weekly).
        - Dependent Variable: Plant growth (height, leaf count).

        Salt Concentration and Water Uptake:
        - Question: "How does the concentration of salt in water impact a plant's water uptake?"
        - Independent Variable: Salt concentration in water.

- Dependent Variable: Rate of water uptake (measured by changes in plant weight).

Impact of Soil Types on Nutrient Absorption:
- Question: "Do different soil types affect the absorption of nutrients by plants?"
- Independent Variable: Soil type (sandy, loamy, clayey).
- Dependent Variable: Nutrient absorption (measured through leaf health or nutrient conte

- Experiment Implementation
  - Materials Distribution:
    - Provide the necessary materials for each group, ensuring they have what they need for their specific experiments.
    - Circulate among groups to offer guidance and ensure proper implementation of experimental procedures.
      - Variety of Potted Plants:
        - Different species to accommodate various experiment ideas.
        - Ensure the health and similar size of plants for fair comparisons.
      - Water:
        - Standard water for regular plant care and irrigation.
          - Consider distilled water if the experiment involves manipulating water composition.
      - Soil:
        - Different types of soil if investigating soil impact on plant growth.
        - Ensure consistency in the amount and quality of soil provided.
      - Watering Cans or Spray Bottles:
        - For controlling watering frequency and volume.
        - Ensure uniformity in watering application across experimental groups.
      - Containers or Trays:
        - To collect excess water and prevent spillage.
        - Essential for experiments involving watering or nutrient application.
      - Substances for Experimentation:
        - Depending on the experiment, this could include salt, sugar, vinegar, or other substances.
        - Ensure proper handling and measurement tools.

- Plastic Wrap:
    - For creating controlled environments in experiments related to humidity.
    - Provides consistency in conditions across experimental groups.
- Light Source (Lamp or Natural Sunlight):
    - Essential for experiments exploring the impact of light on plant growth.
    - Ensure consistent light exposure across experimental groups
- Fan:
    - For experiments assessing the effect of air movement on plant growth.
    - Ensure adjustable speed for controlled conditions.
- Magnifying Glasses:
    - Essential for detailed observations of plant structures and changes.
    - Facilitates closer examination of leaves, stems, and other plant parts.
- Science Notebooks and Pencils:
    - For recording experimental plans, observations, and data.
    - Encourage neat and organized record-keeping.
- Additional Considerations:
    - Labels:
    - Measuring Tools:
    - Camera or Smartphone:
    - Protective Gear:
    - Timer or Clock:
    - Discussion Boards or Whiteboards:
    - For groups to sketch out experiment designs during the planning phase.
    - Facilitates collaborative brainstorming and presentation.

Facilitator's Role:

- Ensure that materials are organized and readily accessible to groups.
- Emphasize the importance of using materials responsibly and adhering to safety guidelines.

Monitor and provide guidance during the experiment design phase to ensure feasibility and alignment with the learning objectives.

Conclusion of Materials Preparation:
- Conduct a brief overview of the available materials and their proper use.
- Emphasize the need for responsible experimentation and the importance of accurate data collection for meaningful results.
- Data Collection Student Tasks
    - Students collect data as the experiment progresses.
    - Encourage them to record observations, measurements, and any unexpected outcomes.
    - Use science notebooks for recording data.
- Recording Methods:
    - Students may use charts, diagrams, or tables to organize data.
    - Emphasize the importance of accurate and detailed record-keeping.
- Group Analysis and Discussion
    - Facilitate group discussions on their findings.
    - Encourage students to analyze data, identify patterns, and draw connections to plant vascular systems.
        - What were the main findings of your experiment?
        - How do your results relate to the principles of plant vascular systems?
        - Were there any unexpected outcomes, and why might they have occurred?
            - Lead a discussion on the diversity of experiments and the broader implications for understanding plant vascular systems.
            - Encourage critical thinking and reflections on the experimental process.

- Further Exploration:
    - Challenge students to think about how their experiments could be modified or extended for different plant species or environmental conditions.
    - Discuss potential real-world applications or implications for agriculture and environmental science.

- Individual Reflection:
    - Assign individual reflections where students consider what they learned from both designing and conducting the experiment.
    - Ask them to reflect on challenges faced and how they might improve their experiments in the future.

Physiology and Photosynthesis—Leaf Anatomy

Educator Background Information—Leaf Anatomy

In the intricate world of plant biology, leaves emerge as the unsung heroes, playing a pivotal role in the vitality of plants. As educators embark on the journey of teaching plant anatomy, unraveling the intricacies of leaves becomes a fundamental pursuit. Let's delve into the narrative of leaf anatomy, where the green canvases of photosynthesis come to life.

Imagine a leaf as a masterfully designed structure, each part serving a distinct purpose in the grand symphony of plant life. At first glance, the leaf presents its broad, flattened canvas known as the blade or lamina, characterized by a myriad of shapes and margins, a testament to the diversity within the plant kingdom. This expansive surface is the stage for the most crucial biochemical performance in the botanical theater—photosynthesis.

The journey into the leaf's microcosm begins with the petiole, the graceful stalk that cradles the leaf and connects it to the plant's stem. More than a mere conduit, the petiole allows the leaf to dance in response to the sun, optimizing its exposure to life-giving light. As we venture further, we encounter the leaf's protective armor—the epidermis. This outermost layer is a shield against the elements, housing specialized cells like the vigilant guard cells that govern the openings of stomata.

Beneath the epidermis lies the mesophyll, the heart of the leaf's photosynthetic prowess. Here, the palisade mesophyll, with its orderly arrangement, diligently absorbs the sun's rays, while the spongy mesophyll ensures efficient gas exchange. Vascular bundles, resembling intricate highway systems, traverse the leaf in the form of veins, carrying the lifeblood—xylem transporting water from roots to leaves, and phloem ferrying the sugars crafted in the leaf's green laboratories.

Zooming into the microscopic realm, we encounter chloroplasts, the tiny green factories housing chlorophyll—the molecular maestro orchestrating the enchanting dance of photosynthesis. These organelles transform carbon dioxide and water into the currency of life—glucose. It is within the chloroplasts that the magical alchemy of sunlight conversion unfolds.

The leaf, however, is no passive entity; it is a dynamic player adapting to diverse environments. Guard cells and stomata regulate the delicate balance of gas exchange, while trichomes stand guard, offering protection against potential threats. Leaves display a fascinating diversity in arrangements—alternate, opposite, or whorled—and manifest unique adaptations, transforming into tendrils, spines, or storage organs based on the demands of their surroundings.

For educators navigating the landscape of leaf anatomy, imparting this narrative involves more than conveying facts; it entails igniting curiosity and fostering an appreciation for the green wonders sustaining life. Through visual aids, comparative explorations, and interactive demonstrations, educators can guide students through the vibrant narrative of leaves—a narrative where each element plays a vital role in the botanical saga, and where the leaf emerges as a living testament to the brilliance of nature.

Leaf transpiration is a crucial physiological process in plants that involves the loss of water vapor from the leaf surface to the atmosphere. This intricate mechanism plays a pivotal role in the overall health and functioning of plants, contributing to water absorption, nutrient transport, and the maintenance of turgor pressure. Stomata, microscopic pores on the leaf surface, regulate the exchange of gases during transpiration. As water is drawn up through the plant's xylem vessels from the roots, it evaporates from the stomata, creating a suction force that facilitates the upward movement of water. Transpiration not only ensures the continuous flow of water and nutrients to the entire plant but also aids in the cooling of leaves and the prevention of wilting. Understanding leaf transpiration provides insights into the dynamic relationship between plants and their environment, highlighting the interconnectedness of water, photosynthesis, and plant survival.

Real world connections:
In the expansive realm of plant biology, professionals specializing in leaf anatomy contribute to our understanding of plant structures, functions, and ecological interactions. The following careers utilize leaf anatomy : botanist, plant physiologist, ecologist, forestry technician, environmental consultant and horticulturist.

Next Generation Science Standards

- MS-LS1-3Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- MS-LS1-6: Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.
- MS-LS1-7: Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.

Students will be able to:
- Identify and describe key structures of leaf anatomy.
- Pose questions about the functions of different leaf structures.
- Understand the connection between leaf anatomy and the process of photosynthesis.

Student Vocabulary:

- Leaf: The main photosynthetic organ of a plant, typically flat and thin, responsible for capturing sunlight and exchanging gases.
- Blade: The flat, expanded part of a leaf that is attached to the petiole; also known as the lamina.
- Petiole: The stalk that attaches the leaf blade to the stem of the plant.
- Vein: Vascular bundles within a leaf that transport water, nutrients, and sugars to and from the leaf.
- Midrib: The central vein running down the center of the leaf blade.
- Veinlets: Smaller veins branching off from the midrib to distribute water and nutrients throughout the leaf.
- Leaf Margin: The edge or border of the leaf blade, which can have various shapes (e.g., serrated, entire, lobed).
- Epidermis: The outermost layer of cells on both the upper and lower surfaces of the leaf, providing protection.

- Cuticle: A waxy, waterproof layer on the outer surface of the leaf epidermis that reduces water loss.
- Stomata (Stoma, Singular): Small openings or pores on the leaf's surface, primarily on th underside, responsible for gas exchange and transpiration.
- Guard Cells: Specialized cells surrounding each stomate that control its opening and closing to regulate gas exchange and water loss.
- Chloroplast: Organelles within plant cells that contain chlorophyll and are responsible for photosynthesis.
- Palisade Mesophyll: A layer of elongated, tightly packed cells in the upper part of the leaf responsible for most of the photosynthesis.
- Spongy Mesophyll: A layer of loosely arranged cells beneath the palisade mesophyll that allows for gas exchange and some photosynthesis.
- Photosynthesis: The process by which green plants and some other organisms use sunlight to synthesize food with carbon dioxide and water, producing glucose and oxygen.
- Transpiration: The loss of water vapor from the aerial parts of a plant, primarily through stomata.
- Adaptation: Structural or functional characteristics that help a plant survive and thrive in its environment.
- Xylem: The vascular tissue responsible for transporting water and minerals from the roots to the leaves.
- Phloem: The vascular tissue responsible for transporting sugars and other organic compounds from the leaves to other parts of the plant.
- Vascular Bundle: A bundle of xylem and phloem tissues found in the veins of leaves, stems, and roots.

Exploring the Wonders of Leaf Anatomy (engage)
- Begin the lesson by engaging students' curiosity. Ask them to share their prior knowledge about leaves and any questions they have.
    - Discuss the importance of leaves as the primary sites for photosynthesis and gas exchange in plants.
    - Leaves are vital organs in the plant kingdom, serving multiple crucial functions. Among these functions, two stand out as fundamental: photosynthesis and gas exchange.
        - Photosynthesis: Leaves are often referred to as the "kitchens" of plants because they are where photosynthesis primarily takes place. Photosynthesis is the remarkable process by which plants convert light energy from the sun, carbon dioxide (CO_2) from the atmosphere, and water (H_2O) from the soil into glucose (a form of sugar) and oxygen (O_2).
        - Key Components of Photosynthesis in Leaves:
            - Chloroplasts: These green, disk-like organelles contain pigments called chlorophyll, which capture light energy. Chloroplasts are abundant in leaf cells, especially in the mesophyll layer.
            - Mesophyll Cells: The mesophyll is the inner tissue of a leaf, rich in chloroplasts. It's where the majority of photosynthesis occurs.
            - Stomata: Tiny pores on the leaf's surface, primarily located in the epidermis, allow for the exchange of gases. Stomata open to take in CO_2 for photosynthesis and release O_2.
        - The Photosynthesis Process:

        - Light Absorption: Chlorophyll molecules capture light energy from the sun.
        - Carbon Dioxide Uptake: Through stomata, leaves take in CO2 from the atmosphere.
        - Water Uptake: Roots absorb water from the soil and transport it to the leaves.
        - Glucose Production: In the chloroplasts of mesophyll cells, light energy is used to split water molecules into oxygen and hydrogen. The oxygen is released, while the hydrogen combines with CO2 to produce glucose.
        - Oxygen Release: Oxygen generated during photosynthesis is released through the stomata.
    - Significance: Photosynthesis is the foundation of the food chain on Earth. It provides energy and organic compounds necessary for the survival of plants and other organisms. Without leaves and the photosynthesis process, life as we know it would not be sustainable.
    - Leaves are also critical for the exchange of gases between the plant and the atmosphere. While CO2 is taken in for photosynthesis, oxygen (O2) is released as a byproduct. This exchange is essential for respiration, a process where plants and animals release energy from glucose.
    - Key Components of Gas Exchange in Leaves:
        - Stomata: These microscopic openings on the leaf's surface enable the exchange of gases with the surrounding air.
        - Guard Cells: Surrounding each stomatal pore, guard cells regulate the opening and closing of stomata. They respond to environmental factors like light, humidity, and CO2 levels.
    - The Gas Exchange Process:
        - Oxygen Release: During photosynthesis, O2 is produced in the mesophyll cells and released through open stomata.
        - Carbon Dioxide Uptake: Stomata open to allow CO2 to enter the leaf for photosynthesis. This exchange is also essential for the plant's respiration.
        - Significance: Gas exchange ensures that plants have a constant supply of O2 for respiration and access to CO2 for photosynthesis. It helps maintain the plant's metabolic processes and overall health.
- Arrange the leaves on tables, with each table representing a different plant species. Create an inviting atmosphere with colorful visuals and intriguing leaf patterns.
    - Instruct students to form small groups and rotate among the tables, examining the leaves closely. They should use magnifying glasses or microscopes to explore the details.
    - Encourage students to record their observations in their science notebooks or on observation sheets. They should note patterns, structures, and any unique features they identify.
    - Observation of Leaf Structures
        - Leaf Identification: Examine the leaves on this table closely. Can you identify the plant species they belong to? Write down your observations about their shape, size, and overall appearance.

        - Leaf Patterns: Look for any distinct patterns on the leaves, such as veins, serrations, or markings. Describe these patterns in detail.
        - Texture and Color: Touch the leaves gently. How would you describe the texture of the leaves? Note any variations in color. Are there differences in texture and color among the leaves from different species?
    - Magnified Leaf Exploration
        - Microscopic Details: Use magnifying glasses or microscopes to zoom in on specific areas of the leaves. What microscopic details can you observe? Look for cells, stomata (tiny pores), and any other structures that stand out.
        - Cell Arrangement: Describe the arrangement of cells you observe. Are they densely packed or more spread out? How does cell arrangement vary between different leaves?
        - Special Features: If you find any unique features under the microscope, such as trichomes (hair-like structures) or glandular cells, make note of them.
    - Comparing Leaves from Different Species
        - Leaf Diversity: Examine leaves from at least two different plant species at this table. Compare and contrast their characteristics. What are the notable differences and similarities?
        - Adaptations: Based on your observations, can you make any hypotheses about how the leaf structures are adapted to the environments where these plants grow?
        - Functional Analysis: Consider the function of leaves in plants. How might the observed leaf structures relate to their roles in photosynthesis, transpiration, or protection?
    - General Prompts:
        - Recording Measurements: If you have access to rulers or measuring tools, record the measurements of the leaves, such as their length and width. Are there variations in size among different leaves?
        - Questions and Hypotheses: As you examine the leaves, what questions arise in your mind? Formulate hypotheses about why certain features or patterns exist on these leaves.
        - Sketches and Diagrams: Create detailed sketches or diagrams in your science notebook to illustrate the leaves and their structures. Label any parts or features you observe.
- Gather the students and create a shared discussion space. Use a whiteboard or chart paper to illustrate key points.
    - Ask students to share their observations and findings. Discuss the diversity of leaf shapes, sizes, and textures they observed.
    - Introduce the key vocabulary terms related to leaf anatomy, such as "blade," "petiole," "vein," "stomata," and "chloroplast."
        - Blade: The flat, typically green, expanded part of a leaf where photosynthesis primarily occurs. It is the broad, outermost portion of the leaf.

        - Petiole: The slender, stalk-like structure that connects the leaf blade to the stem of the plant. It provides support and allows the leaf to position itself for maximum exposure to sunlight.
        - Vein: The vascular tissue that runs through the leaf, transporting water, nutrients, and sugars. Veins also provide structural support to the leaf.
        - Stomata (singular: stoma): Tiny pores or openings on the surface of leaves that facilitate gas exchange. They allow carbon dioxide to enter for photosynthesis and release oxygen and excess water vapor.
        - Chloroplast: The organelle within plant cells responsible for photosynthesis. Chloroplasts contain chlorophyll, a pigment that captures light energy and converts it into chemical energy.
- Start by gathering all students in one location, where you've introduced the concept of leaf anatomy and generated curiosity about leaves.
    - Explain that students will now have the opportunity to explore different aspects of leaves through six interactive stations.
    - Divide the class into small groups (each group should ideally consist of 3-4 students). Assign a group number to each group.
        - Display a chart or poster with group numbers and the corresponding station they will start at.
        - Let students know that they will have the opportunity to explore multiple stations, gaining insights into various aspects of leaf anatomy.
        - Emphasize that they should work cooperatively within their groups and follow the rotation schedule.
            - Continue the rotation process until each group has visited all stations. You can choose the number of rotations based on the available time and the number of station
    - Instruct groups to move to their assigned station.
    - Remind them to work together, observe carefully, and record their findings in their science notebooks.
        - Station 1: Welcome to the Leaf Gallery
            - Objective: Explore the diversity of leaves and observe their unique characteristics.
            - Instructions:
                - Use the magnifying glass provided to examine the leaves on this table.
                - Observe the leaf's color, shape, and any patterns you notice.
                - Sketch the leaf in your observation journal, paying attention to details.
                - Write a brief description of what makes this leaf interesting to you.
                - If you know the name of the plant the leaf belongs to, write it down.
            - Science Notebook Prompt:
                - Sketch the leaf and label its key features.
                - Write a short description of the leaf's characteristics.

- What do you think this leaf's shape might reveal about the plant's environment?
- Station 2: The Microscopic World of Veins
  - Objective: Investigate the intricate vein patterns in different leaves.
  - Instructions:
    - Use the magnifying glass to closely inspect the veins of the leaves.
    - Sketch the vein patterns in your observation journal.
    - Describe any variations in vein structure you observe.
    - Consider why plants might have different vein patterns.
  - Science Notebook Prompt:
    - Sketch and label the vein patterns you observe.
    - Describe any unique features or patterns in the veins.
    - Why do you think leaves have different vein structures?
- Station 3: Colors and Textures
  - Objective: Explore how leaves use colors and textures.
  - Instructions:
    - Examine the colors and textures of the leaves on this table.
    - Sketch a section of the leaf focusing on colors and textures.
    - Write down how you think the colors and textures might benefit the plant.
    - Discuss your observations with your group members.
  - Science Notebook Prompt:
    - Sketch the leaf section with its colors and textures.
    - Describe how the colors and textures might serve the plant's needs.
    - Share your thoughts on why certain colors or textures might be advantageous for leaves.
- Station 4: The Mystery Leaf Challenge
  - Objective: Engage in a mystery challenge to identify a unique leaf.
  - Instructions:
    - Examine the mystery leaf without discussing it with your group.
    - Sketch the mystery leaf in your observation journal.
    - Write down any clues or features that might help identify the plant.
    - In your group, discuss your observations and try to guess the plant species.
  - Science Notebook Prompt:

        - Sketch the mystery leaf.
        - List any distinctive features that stand out.
        - Make a group hypothesis about the plant species based on your observations.
- Station 5: Leaf Adaptations in Action
    - Objective: Explore how leaves adapt to their environments.
    - Instructions:
        - Use the magnifying glass to find evidence of leaf adaptations.
        - Sketch and describe any adaptations you observe.
        - Consider how these adaptations might help the plant survive.
        - Share your findings with your group members.
    - Science Notebook Prompt:
        - Sketch and label any leaf adaptations you discover.
        - Explain how each adaptation might benefit the plant.
        - Discuss the role of adaptations in a plant's ability to thrive.
- Station 6: Creating Leaf Art
    - Objective: Express your creativity by creating leaf art.
    - Instructions:
        - Choose a leaf that inspires you.
        - Use the art supplies provided to create a leaf-inspired piece.
        - Consider the shapes, colors, and patterns of the leaf in your artwork.
        - Share your leaf art with your group and explain your creative choices.
    - Science Notebook Prompt:
        - Include a picture or description of your leaf-inspired artwork.
        - Explain how the leaf influenced your creative choices.
        - Reflect on the relationship between science and art in this activity.

- Group Discussion
    - Gather all groups together for a concluding discussion.
    - Have each group share one interesting observation or discovery from their stations
    - Encourage students to ask questions and make connections between their findings

Exploring the Wonders of Leaf Anatomy (explore)

- To observe the process of transpiration directly and its related anatomy students will need a tree or plant with green leaves.
  - Select a branch with a cluster of leaves and place a clear plastic bag around them.
    - Secure the mouth of the bag securely around and against the branch below the leaf cluster capturing air and the leaf cluster inside.
      - Before collecting leaves, discuss the importance of choosing healthy and diverse specimens.
      - Emphasize the need for gentle handling to prevent damage to the leaves.
    - Demonstrate how to place the leaf inside the plastic bag without tearing or damaging it.
      - Guide students in securely sealing the bag around the stem to create a closed system.
      - The idea is to create a balloon into which the branch sticks while the whole assembly remains largely airtight.
      - Next gather several leaves from elsewhere on the plant for closer inspection in the lab.
    - <u>Ensure the plant has adequate sun and water</u> for activity in the leaf and leave the bag to collect the moisture released by the leaves over time, and return later to observe the humidity/condensation which collects inside.
      - Assist students in finding an appropriate location for hanging the transpiration bags.
    - Discuss the importance of consistency in sunlight exposure for fair observations.
      - Initial Tree Leaf Observations:
        - Provide magnifying glasses and guide students in making initial observations of the selected tree leaf.
        - Encourage them to note features such as leaf size, shape, color, and any visible characteristics.
          - Gather the students under the tree and explain the natural process of transpiration.

- Discuss how water is drawn up through the tree's xylem, which is like its water transportation system.
- Emphasize the importance of transpiration for a tree's health and the movement of water from roots to leaves.

- Watering the Leaves :
    - Instruct each student to lightly mist or sprinkle water on the leaves using a spray bottle.
    - Encourage them to be gentle and avoid soaking the leaves excessively. The goal is to simulate a light rain or dew.
- Observation Time

    - Ask students to observe the tree leaves closely, emphasizing patience and careful attention.
    - Instruct them to look for changes on the leaves, such as the formation of water droplets, changes in leaf turgidity (how firm or limp the leaves are), or any other observable effects.
- Post-Watering On-Tree Observations (5 minutes):
    - Guide students in examining the leaves again after the watering.
    - Prompt them to look for visible changes that occurred due to the misting, comparing them to the initial state.
- Water Loss Measurement
    - Discuss the challenges of directly measuring water loss on a living tree.
        - If feasible, demonstrate how to collect dew or water droplets from leaves for qualitative observation.
    - Emphasize the complexity of water movement in living trees and the limitations of measuring it directly.
- Data Recording and Sketching
    - Instruct students to record their observations and any changes in their science notebooks.

- Encourage them to sketch the on-tree leaf, capturing its appearance both before and after watering.
- Discuss the importance of documenting qualitative data in ecological studies.

- Group Discussion (5 minutes):
    - Facilitate a group discussion under the tree or in a shaded area.
    - Ask open-ended questions to prompt students to share their observations and thoughts.
    - Discuss the uniqueness of studying transpiration in a living tree context.
    - Guide students in reflecting on their experience of studying transpiration on a living tree.
        - Encourage critical analysis of their observations and any unexpected findings.
        - Discuss the ecological implications of transpiration in maintaining tree health.
        - Discuss how the on-tree experience added depth to their understanding of leaf transpiration.
        - Explore connections between tree health, transpiration, and environmental conditions.

Exploring the Wonders of Leaf Anatomy (explain)

- To emphasize that water loss through evapotranspiration the process produces negative pressure in the water circulatory system of plants
    - Prompt students with the following discussion questions
        - While water only expands or contracts slightly in a vacuum, gasses are more “elastic” spreading to fill whatever contains them.
            - Will a solid column of water “stretch”, or mostly be pulled along like a chain? How does this affect the pressure and flow of water in the plants vascular When bubbles form or air enters through a hole along the plants vascular system we refer to it as cavitation.
            - Is there a similar phenomenon in cardiovascular medicine?
            - On a similar note, why does the water being pulled up into a plant not come spilling out the bottom when the stem is cut?
                - Is the pressure in the stem negative/pulling from the leaves or positive/being pushed from the roots?
                - Botanists listening with stethoscope like tools report hearing a “water snap” in the top portions of vines when they are severed on hot days. What might this be?
            - Why are plants important for the environment?
            - How do plants make their own food?
            - Have you ever noticed tiny openings on leaves? What do you think they are for?

- Introduce the term "stomata" and explain that they play a crucial role in plant life.
    - Stomata are the microscopic pores through which the water vapor exits and CO_2 enters, they connect to the porous space of an interior tissue of the leaf called the spongey mesophyll.
    - Allow students to participate in a stomata role play activity
    - Begin by revisiting the concept of stomata and their role in gas exchange. Emphasize the movement of gases, specifically carbon dioxide entering and oxygen leaving through stomatal openings.
    - Mark different areas of the open space with colored markers or cones to represent stomata on a leaf surface. Space them out to allow for movement.
        - Distribute index cards or stickers to students:
            - Stomata: These students control the opening and closing of their "stomatal pores." They can move around freely.
            - Carbon Dioxide Molecules: These students represent carbon dioxide and move toward stomata.
            - Oxygen Molecules: These students represent oxygen and move away from stomata.
            - Explain the rules: Stomata (students) can open and close their "pores" by raising or lowering their arms. Carbon dioxide molecules move toward open stomata, and oxygen molecules move away from stomata.
            - Before starting the role-play, discuss how environmental factors can influence stomatal behavior. For example, mention that during hot and dry conditions, stomata tend to close to conserve water.
        - Announce simulated environmental changes during the role-play:
            - "It's getting hotter, so stomata, consider closing your pores!"
            - "A rain shower is passing by, stomata, feel free to open up!
            - Emphasize the importance of guard cells in controlling stomatal openings.
                - Designate a few students as "guard cells" who accompany stomata and help in regulating their opening and closing.
                - Instruct guard cells to communicate with stomata and respond to environmental changes. For instance, they might signal stomata to close when it's sunny and open when it's cloudy.
        - Create scenarios to simulate different levels of carbon dioxide in the air.
            - For example, shout, "Carbon dioxide molecules, there's a lot of you now! Stomata, get ready to open!"

- Discuss how this mimics the plant's response to changes in carbon dioxide concentration for photosynthesis.
- Conduct multiple rounds of the role-play with different scenarios:
  - Round 1: Normal conditions with a balanced gas exchange.
  - Round 2: Hot and dry conditions, simulate stomata closing.
  - Round 3: Increased carbon dioxide concentration, simulate stomata opening wider.
  - Round 4: Guard cells signaling stomata to respond to changing conditions.
    - After each round, pause and facilitate discussions:
      - What happened during that round? How did stomata respond?
      - How did guard cells help in regulating stomatal openings?
      - What challenges did stomata face in maintaining a balance?
- Have students reflect on the experience. Ask questions like:
  - What did you learn about the role of stomata in gas exchange?
  - How might environmental factors affect stomatal behavior in real plants?
  - Why is the controlled opening and closing of stomata important for plants?
- Tips:
  - Encourage students to be creative in their movements and interactions.
  - Emphasize the cooperative nature of stomata and the need for balance in gas exchange.
  - Use the role-play as an opportunity to address any misconceptions and reinforce key concepts.

Extension activity

- Next gather several leaves from elsewhere on the plant for closer inspection in the lab.
  - To emphasize that water loss through evapotranspiration the process produces negative pressure in the water circulatory system of plants
    - challenge students with the following questions:
      - While water only expands or contracts slightly in a vacuum, gasses are more “elastic” spreading to fill whatever contains them.
      - Will a solid column of water “stretch”, or mostly be pulled along like a chain? How does this affect the pressure and flow of water in the plants vascular system?
  - Stomata are the microscopic pores through which the water vapor exits and CO2 enters, they connect to the porous space of an interior tissue of the leaf called the spongey mesophyll.

- Here both compounds are available to the leafs cells for photosynthesis. While it can be hard to view stomata directly, a proper casting with the right material will highlight the contours of the guard cells, a pair of sausage shaped cells on either side of the pore which swell and deflate to close and open the stomata.

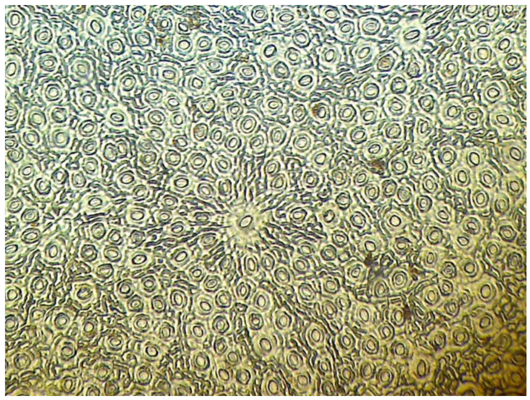
  - To make the cast,
    - paint a patch of clear nail polish on the underside of the leaf.

    - Once it has dried, press a section of clear tape to the nail polish, applying strong pressure, then slowly peel back the tape and nail polish casting from the undersurface of the leaf.

    - Some cells will come away with the casting, but this is alright. The single layer of cells should not obscure students ability to view the important features
    - Show student microscope images of stomata and have them look for these features using magnifiers and microscopes themselves.
      - Dessert and arid plants have been found to use an alternative form of photosynthesis called Crassulacean acid metabolism or CAM for short.
        - In cam, CO_2 pulled in during the night is stored in vacuoles as an intermediate carbon compound for later use during the day, when the plants stomata completely seal up.
          - Given what we know about evapotranspiration and stomata, why

might these plants have evolved to “hold their breath” during the day?

- Below is an image of a nail polish stomata casting. Patterns and distributions of pores may vary according to leaf used.



Exploring the Wonders of Leaf Anatomy (explain)

- Show students an anatomical diagram of the interior structure of a leaf, including vascular bundles and the differing layers of cells.
    - The spongey Mesophyll tissue mentioned before and layer of Palisade cells above are also sometimes referred to as parenchyma because of the space between cells that allows CO_2 from the stomata to permeate.
        - The vascular bundles provide water and basic nutrients.
            - Meanwhile, the vertical palisade cells are set under a clear epidermis and waxy cuticle for protection, but filled with chloroplasts which rotate from the top to bottom as each becomes oversaturated with energy from the sun; the leaf top is effectively a rotating system of scratch resistant solar panels, while the bottom provides a supply line of raw chemical materials. Altogether, it’s an organic compound factory.
    - To observe the characteristics of leaf structure, collect a number of green, preferably veiny leaves, divide them in half and prepare the treatments that follow.
        - Teachers should note this activity involves complex multistep procedure and subsequent observation.
            - They may wish to split the tasks and return to observe the effect at a later point or otherwise manage the timing of their execution as they deem appropriate:

- Prepare a 0.2% baking soda solution (16 grams $NaHCO_3$ per liter H2O), and add one heavy drop of liquid soap to this solution.

- Using a hole-puncher, cut out 10 or more “leaf disks

- place the leaf disks in the syringe and suck up bicarbonate solution one third of the volume, avoiding air bubbles (as long as the chamber is wide enough that the hole punched leaf disks don't clog it up, and the plunger holds a seal

- Place a finger over end of syringe, and pull back on plunger to create a vacuum, holding this position for 30 seconds.
    - At this point, the oxygen in the spongy layer of the leaf is being replaced by the sodium bicarbonate solution, which will act as the plant's source of carbon dioxide.
- Repeat this procedure 2-3 times until the leaf disks sink.
    - If you have difficulty getting your disks to sink after about 3 tries, add a little more soap.
- Once the disks are prepared, remove the plunger and eject the content of the syringe (discs and bicarbonate solution) into a clear plastic cup

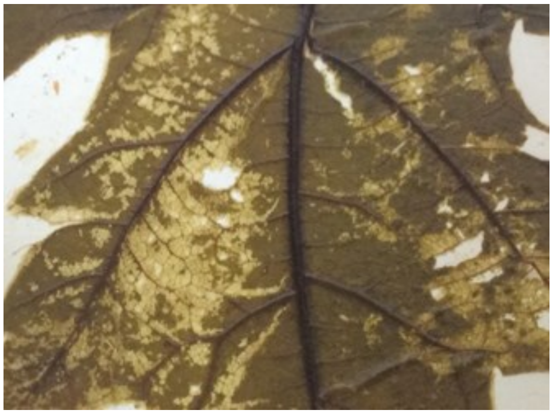
-
    - top it up with the solution about an inch and a half.
- Place plastic cups under the light source.
    - Periodically return throughout the calls period to observe the increasing number of floating disks.

            - You may also need to swirl the disks to dislodge any that are stuck against the sides of the cups.
- As the chloroplasts within the leaves parenchyma tissues photosynthesize, they will create oxygen gas which dissolves less readily in water than carbonation.
    - Oxygen bubbles will then form in the parenchyma space, causing the sunken disks to become buoyant.
        - Note that this effect depends both on the action of chloroplasts and the porous space within the leaf where gas can collect.
    - Ask students to theorize what would happen within the leaf if the spongey mesophyll were not spongey.
        - Could CO2 entering through the leaf permeate to the cells with chloroplasts?
        - Could the oxygen escape?
    - Plant cells burn sugar with oxygen for usable energy at a lower rate than animals, thereby producing more O2 than they consume.
        - What might happen to plant cells in high oxygen conditions.
            - Does the students answer change when informed Rubisco, an enzyme tasked with grabbing CO2 for carbon fixation, sometimes grabs oxygen by mistake, resulting in a wasteful and sometimes toxic byproduct?
        - How does the flotation of the disks give an indication of the leafs interior structure? Why is this ventilation space so important? What animal structures might have a cavity filled anatomy with lots of surface area for gas exchange

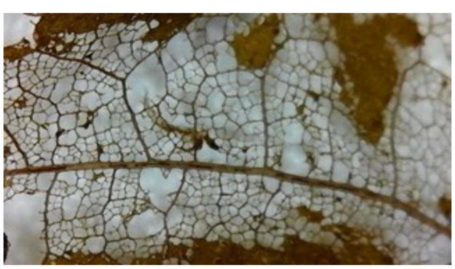
Exploring the Wonders of Leaf Anatomy (explain)
- Using the other half of the leaves collected in the previous activity students will next observe the vascular bundles running through the leaves in a skeletal condition by removing the softer tissue.
    - Teachers should note this activity also involves complex multistep procedure and subsequent observation. They may there wish to split the tasks across multiple class sessions or otherwise manage the timing of their execution as they deem appropriate.

- Put a half liter (2.2 cups) of water into a pot (large enough to submerge materials with 4 ¼ teaspoons of sodium carbonate (washing soda) to the water.

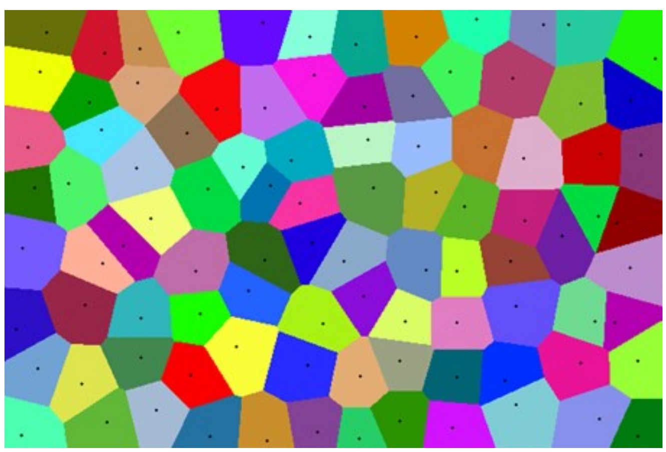
- Heat the solution on a stove burner and stir to dissolve the sodium carbonate in the water.
- Continue until it begins to simmer, then add the leaves to the mixture and hold the temperature for about 30 minutes.
- Put an inch of cool water in a shallow dish and have it next to the pot of leaves.
- Remove the heat source after the allotted time and use forceps tocarefully remove the leaves from the pot and transfer them to the shallow dish.
- Using rubber gloves have students very gently swirl the leaves in the fresh water.
    - Observe laboratory safety precautions as sodium carbonate can irritate the eyes and skin.
- Students should next remove one leaf at a time and transfer it to a coated paper plate.
- Carefully spread out the leaf so no parts are folded over or underneath, then use a soft brush to carefully brush away the green parts of the leaf.



- Start where the stem attaches, and use short, gentle strokes to brush the green leaf tissue toward the ends and outer edges of the leaf.
    - It may be helpful to occasionally rinse the green gel off the paper plate, just be careful not to disturb the leaf. Keep brushing until you have brushed away as much of the soft tissue as possible. Be gentle and patient!
- Let the cleaned leaf rest in the water for 20 minutes, then and let it air dry on a clean paper plate.



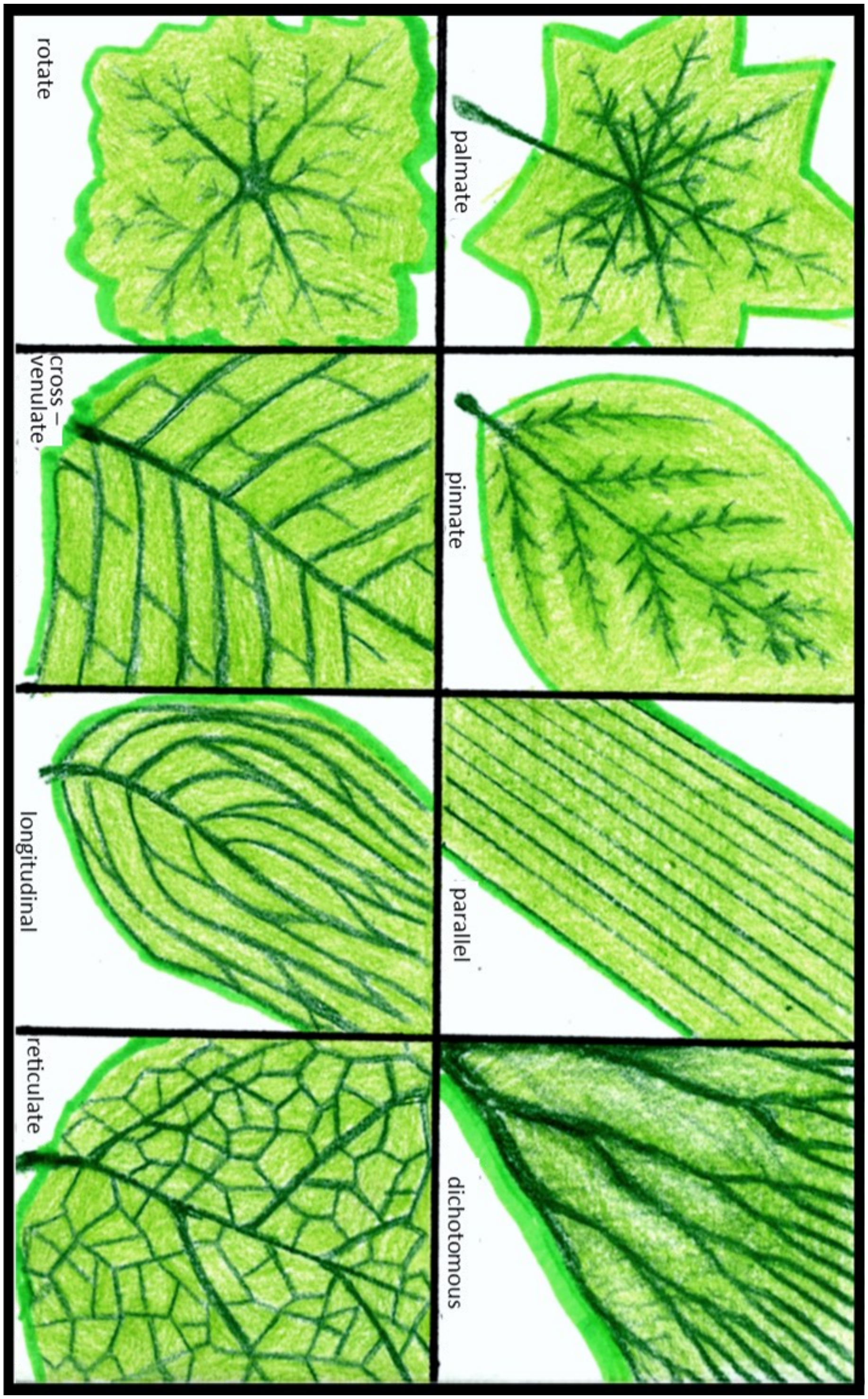
- Dried skeletonized leaves may be pressed in a book for preservation or even spray painted and set against a contrasting background for display.
  - Have students reflect and make observations on the following:
    - Investigate patterns of venation in other leaves such as ginkgos, conifers, or grasses.
    - How and why might they vary?
    - How does the shape of the leaf blade relate to the venation? Do all leaves have a petiole? A midrib?
    - Use internet references to compare and contrast patterns of leaf venation and suggest advantages that different patterns may confer.
  - While studying vascular systems in other parts of the plant students will have seen different configurations of the vascular bundles and associated structures, such as surrounding woody tree rings, or running down the lengths carrots and celery.
  - How and why does the vasculature take on a different shape upon reaching the leaf?
    - Mathematicians sometimes use models to visualize issues relating to the distribution of materials, resources, and jurisdictions across space.
      - Let students perform a google image search on “voronoi diagrams” and scan the Wikipedia article on them.

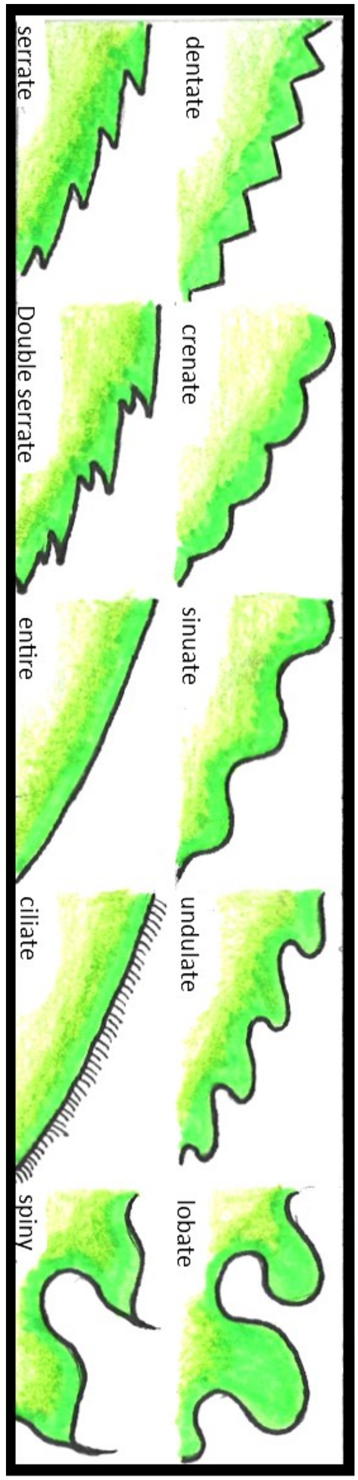


  - How does the shape of these patterns compare to the vasculature of the skeletonized leaves? How might the distribution of stomata on the underside relate? How could leafs be used to inform design decisions in applications such as city planning or routing resources?
    - What resemblance does the venation bear to river tributaries or deltas?

        - Can students provide theories as to how vascular bundles in the leaves differentiate from surrounding cells as they develop from immature tissue? (hint, cells are exposed to different concentrations of developmental hormones as these chemicals drain from the leaf.)
- While leaves are arguably the most complex working structures one will ever find on plants, we often walk past thousands of them in a single day without directing much thought or attention to their inner workings.
    - Though treated like passive objects, the massive amount of work that takes place here generates great amounts of both oxygen and atmospheric humidity. While absorbing solar radiation on a dark surface, leaves manage to do so in a manner that prevents the transformation of light to a rise in temperature, producing their own power supply and useful organic compounds instead.
    - In the process, they absorb the number one greenhouse gas.
    - By taking a look under the hood, students should realize they complex machinery that silently regulates temperatures and gives us breathable air for free.
    - Photosynthesis, and the structures which facilitate it, are the biggest, most elaborate freebie benefit provided to us by nature, and considering the extent of its operation plants would have made their contribution to life on earth if they stopped there.
        - However, as we will see in further investigations, the products and services plants provide continue much further, even in the presence of natural and manmade disruption.

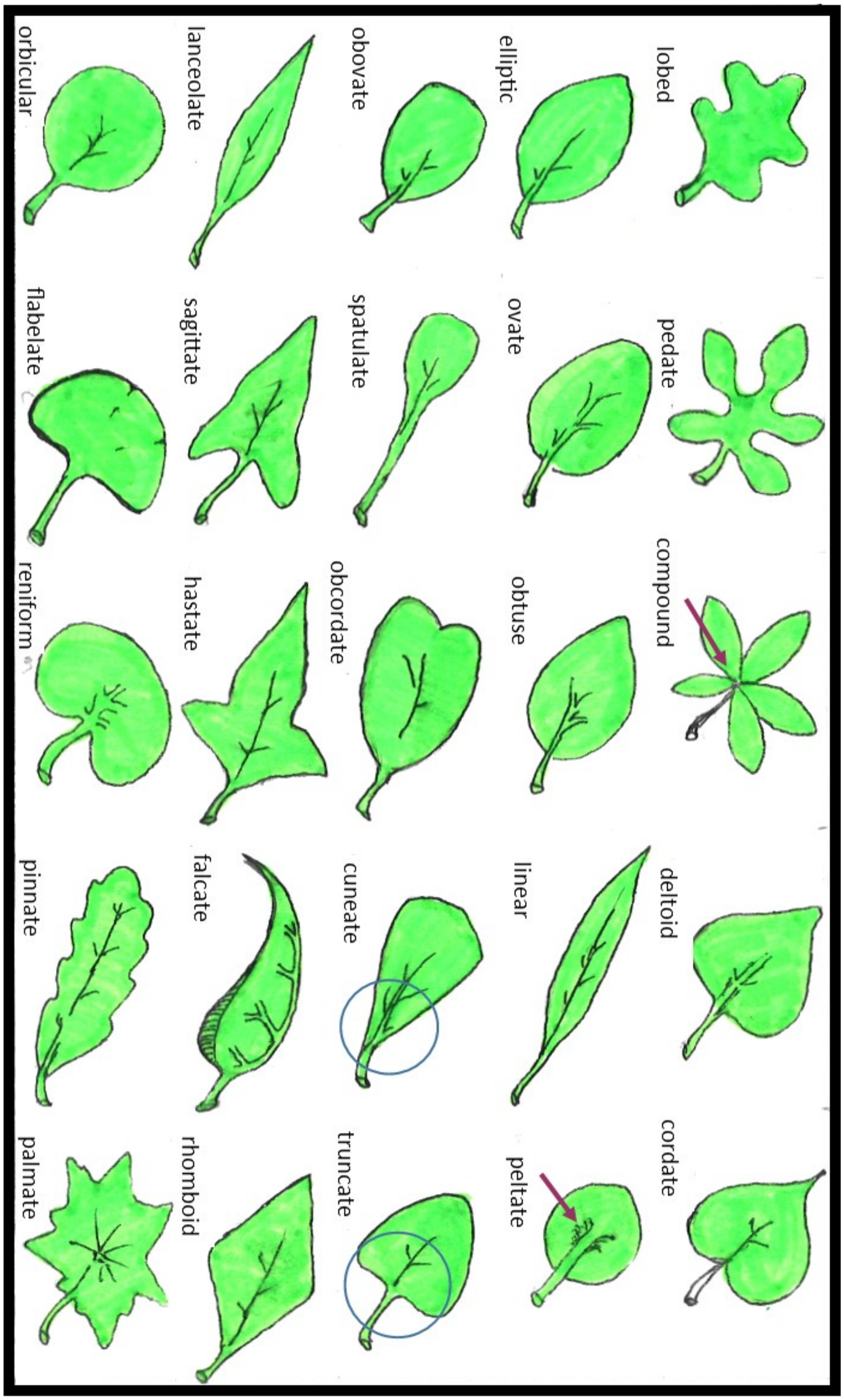
Margins– the leafs edge pattern

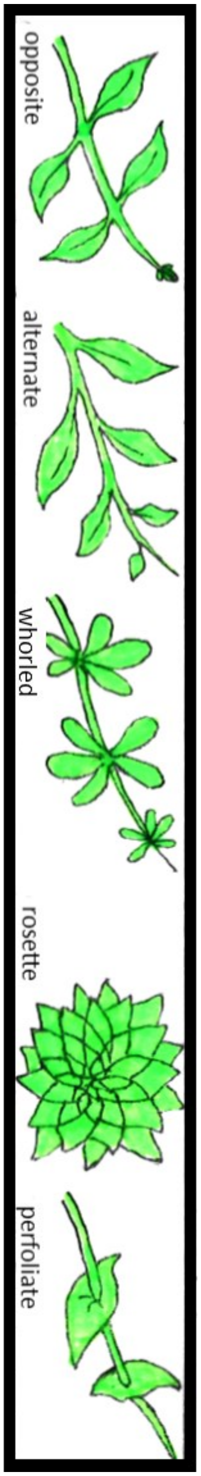




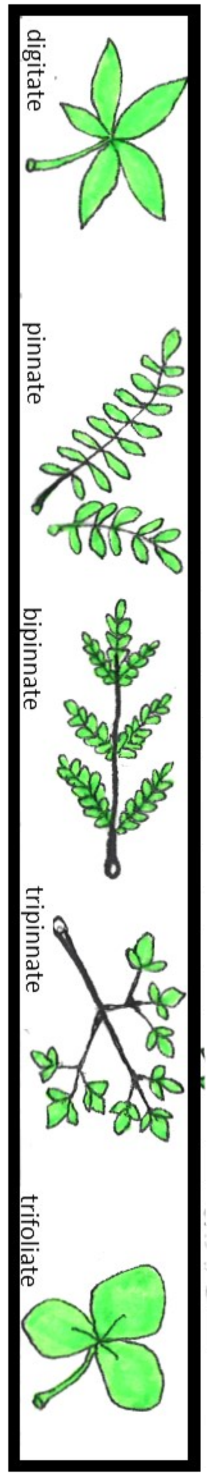
Margins— the leafs edge pattern

Leaf shapes – determined by outline





Arrangements– how leaves emerge from stem and branches



Compound leaves – separate leaflets sharing a petiole (leaf stem)

Biomes and Ecosystem Services

Investigations and Application
Biomes and Ecosystem Services—Forest Biomes

Educator Background Information—Forest Biomes

Biomes, distinct ecological regions characterized by specific climate, vegetation, and fauna, are crucial components of Earth's biodiversity. Forests, one of the most extensive and vital biomes, play a significant role in sustaining life and providing essential ecosystem services. At the heart of these services lies the pivotal role of plants, shaping the health and functionality of forest ecosystems.

Understanding Biomes and Forests: Biomes are classified based on climatic conditions, and forests are prevalent in temperate, tropical, and boreal regions. Forests are characterized by dense vegetation, primarily trees, and are essential for carbon sequestration, biodiversity, and numerous ecosystem services.

Plants as Keystone Species in Forest Ecosystems: In healthy forest ecosystems, plants serve as the foundation and keystone species. Trees, shrubs, and various understory plants collectively form complex and interconnected communities. Trees, with their towering canopies, contribute to habitat diversity by providing niches for other organisms.

Ecosystem Services Provided by Plants in Forests:
- Carbon Sequestration: Forests act as significant carbon sinks, with trees absorbing carbon dioxide during photosynthesis and storing carbon in their biomass and soil.
- Biodiversity Support: The diversity of plant species in forests provides habitats and food sources for a wide array of organisms, contributing to overall ecosystem biodiversity.
- Oxygen Production: Through photosynthesis, plants release oxygen into the atmosphere, crucial for the survival of many organisms, including humans.
- Soil Health: Plant roots stabilize soil, preventing erosion, and contribute to nutrient cycling, promoting soil fertility.
- Water Regulation: Forests play a crucial role in regulating water cycles, influencing rainfall patterns, preventing floods, and maintaining streamflow.

Interdependence of Plants and Ecosystem Services: The health of forest ecosystems is intricately linked to the well-being of plant communities. As primary producers, plants sustain the intricate web of life in forests. They influence nutrient cycling, create microenvironments, and form symbiotic relationships with fungi and other organisms, contributing to the overall resilience and functionality of the ecosystem.
Educational Focus on Forest Ecosystems: In this lesson, the emphasis will be on exploring the diverse roles of plants in maintaining a healthy forest ecosystem. Students will learn about the specific adaptations of forest plants, the interactions between different plant species, and the ecological services that make forests vital for the planet.
Real world connections:

Biomes and Ecosystem Services

In the dynamic field of biomes and ecosystem services, a myriad of careers beckons individuals passionate about understanding, conserving, and harnessing the power of Earth's diverse ecosystems. These careers not only contribute to scientific knowledge but also play pivotal roles in sustainable resource management, environmental conservation, and climate change mitigation. Careers include: Ecologist, environmental scientist, conservation biologist, climate change analyst, forester, policy analyst in environmental agencies

Next Generation Science Standards
MS-LS2-1: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

Students will be able to:
Recognize and appreciate the biodiversity within forest ecosystems, understanding the adaptations of flora and fauna to specific forest conditions.

Student Vocabulary:

- Biltmore sticks: is a tool used by foresters to estimate tree trunk diameter at breast height.
- Diversity: The degree of variation of living things present in a particular ecosystem
- ecological disturbance: a disturbance is a temporary change in environmental conditions that causes a pronounced change in an ecosystem.
- Intermediate disturbance hypothesis: The intermediate disturbance hypothesis (IDH) suggests that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent
- intermediate levels of disturbance:
- Old growth: (of a tree or forested area) never felled, harvested, or cleared; mature.
- Patch dynamics: is an ecological perspective that the structure, function, and dynamics of ecological systems can be understood through studying their interactive patches
- Taiga/Boreal forest: is a biome characterized by coniferous forests consisting mostly of pines, spruces, and larches.
- Temperate forest: A temperate forest is a forest found between the tropical and boreal regions, located in the temperate zone
- Tropical rainforest: rainforests that occur in areas of tropical rainforest climate in which there is no dry season – all months have an average precipitation of at least 60 mm

Exploring Biomes and Ecosystem Services (engage)
- Begin by discussing the concept of biomes and their importance in the study of ecosystems.

- Show images or diagrams of different biomes (e.g., rainforest, desert, tundra) and briefly explain their characteristics.
  - Rainforest Biome:
    - Location: Found near the equator in South America, Central America, Africa, and Southeast Asia.
    - Characteristics: High annual rainfall, lush vegetation, incredible biodiversity, with numerous species of plants, animals, and insects. Tall trees with broad leaves form the canopy layer, creating a dense and humid environment.
  - Desert Biome:
    - Location: Found in arid regions around the world, including the Sahara Desert, Arabian Desert, and southwestern United States.
    - Characteristics: Extremely low precipitation, high temperatures during the day, and cold temperatures at night. Sparse vegetation, including cacti and succulents, adapted to conserve water.
  - Tundra Biome:
    - Location: Found in the northern regions of North America, Europe, and Asia, as well as in Antarctica.
    - Characteristics: Extreme cold, short growing seasons, and low biodiversity. Dominated by permafrost (permanently frozen soil) and characterized by low-lying plants like mosses, lichens, and hardy shrubs.
  - Grassland (Prairie) Biome:
    - Location: Found in regions such as the Great Plains of North America, the African savannah, and parts of South America and Eurasia.
    - Characteristics: Moderate rainfall, vast expanses of grasses, and occasional scattered trees. Home to grazing animals like bison, antelope, and zebras.
  - Deciduous Forest Biome:
    - Location: Found in North America, Europe, and parts of Asia.
    - Characteristics: Moderate rainfall, distinct seasons with changing temperatures. Dominated by deciduous trees like oak, maple, and beech, which shed their leaves in the fall.
  - Coniferous Forest (Taiga) Biome:
    - Location: Found in northern regions of North America, Europe, and Asia, including Canada and Siberia.
    - Characteristics: Cold winters, short growing seasons, and coniferous trees like pine, spruce, and fir. Home to animals like moose, wolves, and bears.

- Coral Reef Biome:
  - Location: Found in warm, clear waters in tropical oceans around the world.
  - Characteristics: Rich marine biodiversity, colorful coral formations, and a wide variety of fish and invertebrates. Coral reefs provide important habitat for marine life.
- Freshwater Biome:
  - Location: Includes rivers, lakes, ponds, and wetlands found worldwide.
  - Characteristics: Varies widely in terms of temperature, depth, and flow. Home to diverse aquatic life, including fish, amphibians, and waterfowl.
- Mountain Biome:
  - Location: Found in mountain ranges such as the Himalayas, the Rockies, and the Andes.
  - Characteristics: High elevations, steep terrain, and varying climates with temperature and vegetation zones. Unique species adapted to high altitudes.

- Group Formation:
  - Divide students into small groups, ensuring each group has a designated container for creating their miniature biome.
- Creating Your Miniature Biome:
  - Materials Needed (per group or student):
    - Clear plastic container or jar with a lid (for each group or student)
    - Soil or potting mix
    - Small rocks or pebbles
      - Small potted plants or seeds (appropriate for the chosen biome)
    - Small plastic animals (optional, for representing wildlife)
    - Water spray bottle
    - Ruler (for measuring and arranging)
  - Instructions:
    - Select Your Biome:
      - Begin by deciding which biome you would like to recreate in your miniature ecosystem. Choose from options like a rainforest, desert, grassland, tundra, or deciduous forest.
    - Prepare Your Container:
      - Take your clear plastic container or jar and ensure it is clean and dry. The container should have a lid for sealing.
    - Create the Ground Layer:
      - Fill the bottom of your container with a layer of soil or potting mix. This layer will represent the ground of your biome. Use enough soil to cover the

    - bottom with a thickness of about 1-2 inches (2.5-5 cm).
- Mimic the Landscape:
    - Arrange small rocks or pebbles on top of the soil to mimic the landscape features of your chosen biome. You can create hills, streams, or other landscape elements using these rocks.
- Plant Your Flora:
    - Depending on your chosen biome, either plant small potted plants appropriate for that environment or scatter seeds on the soil's surface. Follow any planting instructions that come with the plants or seeds.
    - Ensure that the plants are spaced appropriately and evenly within the container.
- Optional Wildlife:
    - If you have small plastic animals available, you can place them strategically within your miniature biome to represent wildlife. Position them near appropriate plant species or landscape features to simulate natural interactions.
- Add Water:
    - Use a water spray bottle to gently moisten the soil and plants. Be careful not to overwater; just ensure that the soil is damp, not waterlogged.
- Seal the Container:
    - Carefully place the lid on the container to seal it. This will create a closed environment similar to a terrarium.
- Observation and Care:
    - Place your miniature biome in an appropriate location with adequate light. Make sure it receives the right amount of sunlight for your chosen biome.
    - Over the coming days and weeks, observe your miniature biome regularly. Monitor plant growth, moisture levels, and any interactions between plants and, if applicable, plastic animals.
- Record Your Observations:
    - Keep a journal or notebook to record your observations. Note any changes you observe in plant growth, wildlife interactions, or any other interesting developments within your miniature biome.
- Encourage creativity in representing different biomes. For example, if a group chooses a desert biome, they can use sand instead of soil, and if they choose a rainforest, they can add small toy figurines of tropical animals.

- After setting up the miniature biomes, gather the groups and discuss the key components of biomes, including climate, flora, fauna, and landscape features.
- Discussion Questions for Biome Components:
    - Climate:
        - What is the climate like in the biome you've chosen for your miniature ecosystem?
        - How does temperature and precipitation vary in different biomes?
        - How might climate affect the types of plants and animals that can survive in a biome?
    - Flora (Plants):
        - What types of plants did you include in your miniature biome, and why?
        - How do plants in your biome adapt to the local climate and soil conditions?
        - Do plants in different biomes have unique adaptations? Explain.
    - Fauna (Animals):
        - Did you include any plastic animals in your miniature biome? If so, which ones?
        - How do animals in your chosen biome interact with the plants and climate?
        - Are there any specific animal adaptations you find interesting in your chosen biome?
    - Landscape Features:
        - Did you incorporate any landscape features like rocks, rivers, or hills in your miniature biome?
        - How do these landscape features contribute to the overall ecosystem?
        - How do landscape features differ between various biomes?
- After students have had a chance to create and observe their miniature biomes for some time, gather them together for a brief discussion and reflection.
    - Ask students to share their observations, any challenges they faced, and what they found most interesting about their miniature ecosystems.
- Emphasize the idea that they've had a hands-on experience with a small-scale ecosystem, and now they'll have the opportunity to explore and compare real-world biomes through virtual reality.

- Introduction to Introduce the concept of virtual reality (VR) and explain that it's a technology that allows us to immerse ourselves in different environments using special headsets.
    - Highlight the purpose of using VR to explore real-world biomes and ecosystems.
- Begin with a virtual biome expedition using online platforms or virtual reality tools. Students can explore different biomes, from

rainforests to deserts, through interactive simulations.

- Here is a list of online platforms and virtual reality tools that students can use to explore different biomes through interactive simulations:
  - **Google Earth Voyager:**
    - Google Earth Voyager offers guided tours of various biomes, allowing students to explore interactive stories, videos, and 360-degree images.
  - **Explore.org:**
    - Explore.org provides live cams from different locations around the world, including diverse ecosystems. Students can observe wildlife and environmental conditions in real-time.
  - **BBC Earth's Biome Explorer:**
    - The BBC Earth Biome Explorer offers interactive maps and multimedia content, allowing students to virtually explore different biomes and learn about the flora and fauna.
  - **National Geographic Education:**
    - National Geographic Education offers a variety of resources, including interactive maps, videos, and articles, to explore different biomes and ecosystems.
  - **ARKive:**
    - ARKive provides a collection of images, videos, and facts about various species in different habitats. It's a great resource for understanding biodiversity in different biomes.
- Virtual Reality Tools:
  - **Google Expeditions:**
    - Google Expeditions allows students to take virtual reality field trips to different biomes. Teachers can guide students through immersive experiences using VR headsets.
  - **Nearpod VR:**
    - Nearpod VR offers virtual reality lessons, including biome explorations, which can be experienced using VR headsets. Teachers can create interactive lessons to engage students in virtual field trips.
  - **YouTube VR:**
    - YouTube VR has 360-degree videos that provide immersive experiences of different biomes. Students can use VR headsets or explore these videos on a computer or mobile device.
  - **Unimersiv:**
    - Unimersiv is an educational VR platform that offers experiences related to science and nature. It may include simulations and virtual field trips related to various biomes.
  - **MEL Chemistry VR:**
    - MEL Chemistry VR focuses on science education in virtual

reality. While it primarily covers chemistry, it may have simulations related to environmental science and biomes.

- Remember to check the compatibility of these tools with the devices available to your students and ensure that they meet any technical requirements. Additionally, always review the content to ensure it aligns with the educational goals and standards of your lesson.

- Encourage students to actively participate in the virtual experience, making observations about the unique features, biodiversity, and climate of each biome.
    - What intrigued you the most during the virtual biome expedition?
    - Why do you think preserving biodiversity in different ecosystems is important?
        - Can you think of any ways in which ecosystems contribute to our daily lives?

Exploring Biomes and Ecosystem Services (explore)

- "Having marveled at the grand tapestry of biomes across the globe, we now zoom in to examine a biome that stands as a symbol of life's resilience and interconnectedness – the forest.
    - The lessons from our exploration of various ecosystems laid the groundwork for understanding the complexities that make each biome unique.
    - Now, we turn our attention to the intricate web of life woven within the forest ecosystem.
        - Get ready to witness the magic that unfolds within the shadowed canopies and vibrant undergrowth as we explore the wonders of the forest biome, unlocking the secrets of its biodiversity, resilience, and unparalleled contribution to the health of our planet."
    - Briefly explain the purpose of the activity: to create a miniature forest ecosystem. Emphasize the importance of considering biodiversity, plant -animal interactions, and overall balance within the ecosystem.
        - In the forest, biodiversity reigns supreme. Picture a forest floor adorned with ferns, mosses, and a myriad of flowering plants. Each species, whether towering trees or delicate wildflowers, plays a crucial role. Consider the Amazon rainforest, home to a staggering variety of plant and animal species. The diverse flora, from towering mahogany to tiny orchids, sustains an equally diverse array of fauna, from jaguars to colorful poison dart frogs. This richness isn't just a spectacle; it's the heartbeat of the forest, ensuring resilience in the face of change.
        - Plant-Animal Interactions:: Step into the depths of a temperate forest, and witness the intricate ballet between plants and animals. Bees buzzing from flower to flower, collecting nectar

and inadvertently pollinating as they go. Deer graze on the underbrush, dispersing seeds with every movement. This dance, repeated in forests worldwide, demonstrates the profound interdependence between flora and fauna. Just as bees benefit from nectar, plants rely on these pollinators for reproduction. Animals, in turn, find sustenance and shelter among the diverse plant life. It's a partnership that ensures the continuation of life within the forest's embrace.

- Overall Balance:: Now, envision a forest where every element exists in harmony – a balance that is delicate yet robust. Picture a mangrove forest along coastal shores, where the intertwining roots of mangrove trees create a natural barrier, protecting against erosion and providing a vital nursery for marine life. This equilibrium extends beyond the visible, as decomposing plant matter enriches the soil, sustaining the entire ecosystem. This balance isn't just a fleeting state; it's a dynamic process where each component, from microscopic fungi to towering trees, contributes to the forest's health and resilience.
    - To begin our miniature forest ecosystem, divide the class into small groups of 3-4 students.
    - Distribute the necessary materials to each group. Ensure that materials include soil, small plants (real or artificial), twigs or small branches, small rocks or pebbles, and toy animals representing different species.
    - Emphasize that the selection of materials is crucial in representing the layers and diversity of a real forest ecosystem.
        - Encourage students to consider the roles of different components within the ecosystem.
            - Guide students in discussing the roles of each element they have been provided. For instance, discuss the importance of different plant species in creating a multi-layered canopy, the significance of rocks and soil in supporting plant growth, and the role of toy animals in representing the fauna of the forest.
            - Prompt groups to consider the placement of each component within their ecosystem, thinking about spatial arrangements that mimic natural forest structures.
        - Stress the importance of biodiversity in the design.
            - Encourage groups to incorporate a diverse range of plant species, ensuring representation from various forest layers (canopy, understory, forest floor).

    - Remind students that biodiversity contributes to the resilience and sustainability of the ecosystem. Discuss how a variety of species can provide different ecological services, such as nutrient cycling, pest control, and habitat provision.
- Prompt students to think about the interactions between plants and animals.
    - Ask groups to consider how they can represent mutualistic relationships within their miniature ecosystems. For example, discuss the placement of plants that may attract certain animals and how those animals contribute to the health of the plants.
    - Emphasize the interconnectedness of life in the forest and how each component plays a role in supporting the others.
- Guide students to ensure a balanced representation of the ecosystem.
    - Instruct groups to step back and assess their designs periodically to ensure that no single element dominates the ecosystem and that there is a harmonious balance between plants, animals, and environmental elements.
    - Discuss the consequences of imbalance in a forest ecosystem and how the miniature representation mirrors real-world dynamics.
- Encourage students to share their ideas openly within their groups. Discuss how different perspectives contribute to a more comprehensive understanding of forest ecosystems.
- Facilitate brief check-ins with each group to ensure that ideas are being communicated effectively and that tasks are distributed evenly among group members.
    - Remind students that creativity in representing the forest ecosystem is encouraged.
    - Encourage them to think beyond literal representations and consider symbolic elements that convey the ecosystem's dynamics.
        - Discuss the importance of effective presentation during the group share-

out. Remind students to articulate the reasoning behind their choices and to use scientific concepts learned in class to support their designs.

- Instruct students to collaboratively design their miniature forest ecosystems within the provided containers. Encourage discussions on the placement of different elements and the relationships between them.
- "Consider the roles of different elements in your ecosystem. How did you decide which plants and animals to include?"
- "How did your group ensure that the ecosystem is balanced? What challenges did you face?"
  "Discuss the importance of biodiversity in a forest ecosystem. Why is it crucial for the health of the environment?"

- Each group presents their miniature forest ecosystem to the class. Students should explain their choices, such as the types of plants and animals selected, and discuss how they aimed to represent a balanced and sustainable ecosystem.
  - Facilitate a brief class discussion on the challenges and decisions made during the activity. Encourage students to reflect on the importance of biodiversity and the interdependence of species within a forest ecosystem.

- Gather students and explain that they will participate in a simulation game representing a forest ecosystem.
  - Emphasize that each student will be assigned a specific role (e.g., trees, animals, environmental factors) and that scenarios will be introduced to challenge the ecosystem.
  - Distribute role cards to each student, clearly outlining their assigned roles. Roles may include trees, animals (e.g., herbivores, carnivores), and environmental factors (e.g., sunlight, water availability, temperature).
    - Encourage students to read and familiarize themselves with their roles.
  - Present the first scenario card, describing a change or challenge within the ecosystem. Examples include a drought, deforestation, invasive species, or human development.
    - Explain that each role must adapt to the introduced scenario, considering how it affects their specific component of the ecosystem.
    - Start the simulation and allow students to interact within their roles. Encourage creativity and collaboration as they navigate the challenges presented by the scenarios.

        - Remind students to consider the potential impacts of their decisions on the overall health of the simulated forest ecosystem.
    - Conclude the simulation round and gather students for a debriefing session.
        - Encourage each role to share their experiences and decisions during the simulation. Discuss how external changes affected the balance and resilience of the forest ecosystem.
    - Introduce subsequent scenario cards, each presenting a new challenge to the forest ecosystem.
        - Emphasize the importance of adaptability and resilience in responding to changing conditions.
- Facilitate a discussion on the interconnectedness of the roles, the importance of biodiversity, and the challenges posed by external factors.
    - Encourage students to draw connections between the simulated scenarios and real-world environmental issues.
        - "How did your role within the simulation represent the real-life functions of trees, animals, or environmental factors in a forest ecosystem?"
        - "What adaptations did your group make to respond to the introduced scenarios? How did these adaptations affect the overall balance of the ecosystem?"
        - "Reflect on the simulation. How does it mirror the complexities of real forest ecosystems and their responses to external changes?"

Exploring Biomes and Ecosystem Services (explain)

- Forests may represent the most biologically productive, structurally diverse and truly ancient types of biomes that historically have occupied the planet.
    - Due to the lifespan of woody trees, the timescale for ecological succession presents an illusion that these habitats are permanent. The reality however is that they simply become more established with time, despite being subject to disturbance all the same.
        - Some forests, such as those in the western united states, behave like prairies in terms of their cycles of fire disturbance but with a great deal more fuel.
        - Some of the greater stretches of forest type may be divided as
            - Taiga/Boreal forest- composed of extremely densely packed coniferous trees at high latitudes. Here litter and remains of dead trees pile into rough terrain on the forest floor.
                - Due to the structural stresses of harsh winters, trees remain comparatively stout and “huddled”.
                - The ecological pattern may be mirrored to some extent in high altitude alpine forests, but often the

    - structure there is often affected by slope, snow, fire, and other factors which present a more open understory.
- Temperate forest- generally composed of deciduous trees that drop their leaves annually each winter.
    - As a result, a great deal of biomass and nutrients are added and cycled annually through the ecology of the forest floor. Temperate rainforest occur in narrow strips of land that typically receive excess moisture as a result of being near ocean currents, these are more often “old growth” coniferous or broadleaf evergreen forest with a carpet of moss and ferns.
- Tropical rainforest- Highly diverse forests which depend upon and promote their own wet, warm microclimate. Biomass and nutrients are concentrated almost exclusively in living organisms with the greatest biodiversity concentrated in the canopy.
    - Rainforests have remained largely stable and undisturbed for most of their history, which has allowed ancient ecosystems including many “living fossil” and endemic species to evolve.
- In addition, there are also a number of forest types which may be confined to smaller ranges or unique ecosystems that punctuate the landscape of larger biomes. Swamps, pocosins and mangroves form extensive but comparatively narrow margins of wetland in specific settings; “barrens” of trees uniquely suited to harsh soil or other conditions may thrive where other plants are kept out.
    - Alpine forests are actually concentric ribbons of several unique habitats determined by altitude and the conditions it creates as one goes uphill. However in all cases, forests are dominated by trees, large woody perennial plants that fix tremendous amounts of carbon to generate structure and food, create shade and humidity with their canopy, and provide the anchor of a stable and growing natural community which matures and persists across decades, if not centuries.
    - The carbon capture of photosynthesis which is continuous across this time builds not only a towering structural component which other organisms use for shelter at multiple levels, but a steady supply of chemical energy to feed them.
        - Temperate and boreal forests also feed themselves, as leaf litter, fallen branches, and dead or burnt trees build a shaded,

moisture retaining, and nutrient laden carpet layer that nurtures trees from later successional stages.

- Meanwhile human societies have depended on the generation of products and materials which without forests, would not exist.

- Primary productivity procedures for student groups
    - Provide students with a small sensitive scale for use in the classroom, Biltmore stick
        - Introduction to the Biltmore Stick:
        - Explanation: The Biltmore Stick is a forestry tool used to quickly estimate the diameter and height of a tree without needing to climb it or use complex equipment.
        - Components: The stick has a series of scales and marks that correspond ttree diameters and heights.
        - Understanding the Scales
            - Diameter Scale:
                - Locate the side of the Biltmore Stick that has the diameter scale.
                - Explain that each set of numbers represents the diameter of a tree at a certain distance from the observer (usually 66 feet or 20 meters).
            - Height Scale:
                - Locate the side of the Biltmore Stick that has the height scale.
                - Explain that this scale helps estimate the height of a tree based on its diameter.
                - Estimating Tree Diameter:
                    - Selecting the Appropriate Scale:
                    - Identify the tree you want to measure and stand at a distance of approximately 66 feet (20 meters) away.
                    - Choose the appropriate diameter scale on the Biltmore Stick.
                - Aligning the Stick:
                    - Hold the Biltmore Stick vertically and align it with the tree trunk at your eye level.
                    - Ensure that the scale matches the apparent diameter of the tree trunk.
                - Reading the Diameter:
                    - Read the diameter measurement directly from the scale where the tree

trunk edge aligns. This is an estimation of the tree's diameter at breast height (DBH), which is typically 4.5 feet above the ground.

- Estimating Tree Height:
  - Selecting the Appropriate Scale:
  - Based on the estimated diameter, find the corresponding height scale on the Biltmore Stick.
- Aligning the Stick:
  - Hold the stick vertically, aligning the bottom of the stick with the base of the tree trunk.
- Reading the Height:
  - Read the estimated tree height directly from the height scale where the top of the tree aligns with the stick. This provides an estimation of the tree's height.
- Recording Measurements:
  - Using a Notebook:
  - Encourage students to record their tree measurements in a notebook, including the tree's location, estimated diameter, and estimated height.

- Take students to a local wooded area or use the school grounds to practice using the Biltmore Stick on different trees.
- Divide students into small groups, ensuring each group has a Biltmore Stick, a measuring tape, and a science notebook.
  - Instructions for Tree Measurements:
  - Instruct each group to select a tree on the school grounds for measurement.
    - Demonstrate how to use the Biltmore Stick to estimate tree diameter and height.
    - Encourage students to also measure the actual diameter using a measuring tape for comparison.
    - Facilitation Questions:
      - "What challenges do you anticipate in aligning the Biltmore Stick with the tree trunk?"
      - "How does the estimated diameter compare with the actual measured diameter? Any differences?"
      - "How might variations in tree shape and density affect your measurements?"

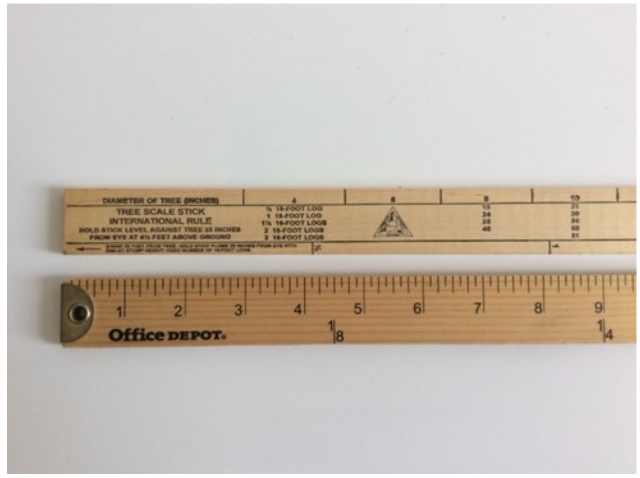
- "What factors could impact the accuracy of height estimation using the Biltmore Stick?"
- Exploration and Data Collection:
  - Each group should carefully select a tree on the school grounds that is accessible and safe to measure.
    - Encourage groups to choose a variety of tree species, if possible, to observe differences in measurements.
  - Demonstrate how to use the Biltmore Stick to estimate tree diameter and height
  - Guide students in aligning the stick with the tree trunk and interpreting the measurements.
    - Emphasize the importance of keeping the stick vertical and aligning it with the tree at eye level.
  - In addition to using the Biltmore Stick, instruct each group to measure the actual diameter of the tree using a measuring tape.
    - Encourage students to work together to ensure accurate measurements.
    - Rotate roles within each group so that each student has the opportunity to use the Biltmore Stick, hold the measuring tape, and record data in the science notebook.
      - This rotation ensures that every student actively engages in the exploration.
      - Encourage students to discuss their observations and measurements within their groups.
      - Prompt them to compare the Biltmore Stick estimates with the actual measurements using the measuring tape.
        - Discuss any variations or challenges encountered during the process.
  - Instruct each group to repeat the process for at least two or three different trees.
    - This allows students to observe variations between tree species and understand the importance of taking multiple measurements for accuracy.
      - While in the field, ask students to record their observations, Biltmore Stick

measurements, and actual measuring tape measurements in their science notebooks.

- Encourage them to note any challenges faced, unexpected findings, or patterns observed.

- Facilitation Questions:
  - "How did the estimated tree diameter using the Biltmore Stick compare to the actual measured diameter?"
  - "What challenges did you face in aligning the stick or using the measuring tape?"
  - "Did you observe any patterns or differences when measuring different tree species?"
  - How might the variations in measurements impact the accuracy of our data?"
    - Circulate among the groups, providing support, answering questions, and encouraging thoughtful discussions.
    - Observe student interactions and measurements to ensure understanding and accurate data collection.
      - Emphasize the importance of precision in measurements and the role each student plays in contributing to accurate data collection. Discuss the significance of these skills in scientific research and forestry management.
- Science Notebook Prompts:
  - "Compare the estimated and actual tree diameters. Note any patterns or differences."
  - "Reflect on the challenges you encountered while using the Biltmore Stick. How did you overcome them?"
  - "Discuss the variability in height estimates. What factors might contribute to this variability?"

- Class Discussion:
  - Bring the groups together for a class discussion.
  - Share findings, discuss variations, and address any challenges faced during the activity.
  - Summarize the importance of estimating tree dimensions for ecological studies and forestry management.
  - Real-World Application: Discuss how professionals use tools like the Biltmore Stick in real-world forestry practices.



Exploring Biomes and Ecosystem Services (explain)

- While students may be quick to realize that forests perform a great deal of photosynthesis and carbon fixation, it may be harder to realize the implications of this as a resource which feeds wild and human food webs.
    - Historically, this has been a source of cross-cultural confusion, as European colonizers were blind to the same fact and jumped to the manifest destiny based conclusion that Native Americans “weren’t using” North America for agricultural purposes.
        - In fact, the natural productivity of forests is so deceptively complex as to be cryptic, and we are only recently rediscovering the concept of “food forests” long practiced by those cultures which make this habitat their home.
            - these surveys will consist of estimating two measures of consumption taking place off of what the tree produces.
        - Take students outside to a forested area or tree of substantial size to collect the data and sample mast.

- Examine the selected tree and identify signs of live consumption.
    - Look for organisms such as insects, birds, or other wildlife feeding off the tree.
    - Record your observations regarding the observed organisms on the provided forestry survey sheet.
- First students will estimate measures of live consumption from the tree itself.
    - It should be noted that organisms feeding off the tree do not necessarily indicate bad health.
    - Certain tree species produce extra leaf growth anticipating that it will be preyed upon, or play host to certain mushrooms or pest species without taking damage which proves to be fatal. In other cases, these infestations may occur when the tree itself is already in poor health as a form of secondary symptom.
    - We are going to measure how much living organisms like insects or birds are feeding off a tree. This helps us understand how healthy the tree is and how it supports wildlife. Here's what we'll do:
        - We'll place a big glass jar under the part of the tree where we see animals or insects feeding.
        - We'll wait for about 5 minutes to collect any debris or organisms that fall into the jar while they are feeding.
        - After that, we'll measure how much stuff we collected in the jar, which will tell us how much the organisms are eating.
    - Why We're Doing This:
        - We want to understand how the tree provides food for animals and insects.
        - It helps us see if the tree is healthy because some trees produce extra leaves or food when they're being eaten, while others might be in trouble.
        - This information helps us learn about the forest and how everything in it is connected. It's like a puzzle piece in understanding how nature works.
    - Instructions**:**
        - Choose a tree with observable signs of live consumption (organisms feeding off the tree).

- Use the provided tools (large graduated beakers, forestry survey sheets part 2, and pencils) for accurate estimation.
- Follow the steps below to estimate the live consumption from the selected tree.
- Reflect on the significance of the live consumption rate for the tree and its potential impact on tree health.
- Consider how live consumption contributes to the overall ecosystem dynamics.

- Reflection Questions
    - How does live consumption contribute to the overall health of the forest ecosystem?
    - Explore how the consumption of parts of the tree by various organisms contributes to nutrient cycling and ecosystem dynamics.
    - Discuss the role of these interactions in maintaining biodiversity within the forest.
    - What are some potential reasons for live consumption on a tree? (Consider both healthy and stressed tree scenarios.)
    - Describe different scenarios where organisms consume parts of a tree.
    - Explain why a tree might produce extra leaves or food, even when it's being eaten
    - Discuss how live consumption can be a natural and healthy part of an ecosystem.
    - How might the observed live consumption impact the surrounding environment?
    - Consider the ripple effects of live consumption. For example, if insects feed on a tree, how might this affect the bird population that relies on those insects for food?
    - Explore the idea that these interactions create a delicate balance within the forest ecosystem.
- Science Notebook Prompts:
    - Observation and Data: In your science notebook, record the specific observations you made while measuring live consumption. Include details about the types of organisms you saw, their behavior, and any other noteworthy information.
    - Interpretation: Write about why live consumption is important in a forest ecosystem. Explain how it contributes to the overall health and functioning of the

ecosystem.

- Ecosystem Dynamics: Consider how the relationships between organisms, like those you observed during live consumption, influence the balance of the forest ecosystem. Draw a simple food web to illustrate these relationships.
- Healthy vs. Stressed Trees: Reflect on the potential reasons for live consumption on a tree. Describe scenarios where a tree might be stressed and still experiencing live consumption. What might be the consequences of this?
- Impact on Biodiversity: Explore the concept of biodiversity in the context of live consumption. How do interactions between organisms on a tree contribute to the overall biodiversity of the forest?
- Environmental Implications: Discuss how the observed live consumption might have wider effects on the forest environment. Consider the habitat, food availability, and interactions between different species in the forest.

Tree Information:
Tree Species: ______________________
Location: _________________________
Date: _____________________________
Procedure:
Observation:
Examine the selected tree and identify signs of live consumption.
Look for organisms such as insects, birds, or other wildlife feeding off the tree.
Observed Live Consumption: _____ (describe the observed organisms)

Select a Measurement Area:
Choose a section of the tree where live consumption is actively occurring.
Use the graduated beaker to measure the volume of live consumption.
Selected Measurement Area: _____ ft^2

Measure Live Consumption:
Carefully place the graduated beaker under the area of live consumption to capture any falling debris or organisms.
Allow a sufficient amount of time for the collection.
Collected Live Consumption: _____ (record the volume in milliliters or other appropriate unit)

Calculate Live Consumption Rate:

Use the formula: Live Consumption Rate = Collected Volume / Selected Measurement Area

Live Consumption Rate Calculation:

Live Consumption Rate = Collected Volume / Selected Measurement Area

- Live Consumption Rate = _____ (express the rate in appropriate units per sqare foot)

- The second estimate that students will make concerns mast, the seeds and fruit dropped by the tree which is consumed by wildlife.
    - Discuss the concept of mast (seeds and fruit) production by trees and its importance for wildlife in forest ecosystems.
        - Importance of Mast Production for Wildlife:
            - Food Source: Mast, which includes nuts, seeds, and fruits produced by trees, serves as a primary food source for many wildlife species. This abundant and energy-rich food provides essential nutrition for animals throughout the year.
            - Seasonal Variation: Mast production often exhibits seasonal variation, with some years having more abundant mast than others. This natural variation can impact the populations of wildlife that rely on it. In years of plentiful mast, many species thrive, while in lean years, food scarcity can lead to challenges for wildlife.
            - Winter Survival: For many species, mast is a critical resource for surviving the winter months when other food sources may be scarce. Animals like squirrels, chipmunks, and certain bird species store mast to sustain themselves during the cold season.
            - Seed Dispersal: Trees produce mast as part of their reproductive strategy. When wildlife consumes seeds and fruit, they often play a role in seed dispersal. Animals may carry seeds away from the parent tree, helping to establish new trees in different locations.
            - Biodiversity: The availability of mast can influence the diversity of wildlife within a forest ecosystem. Different species have varying preferences for types of mast, leading to niche specialization and coexistence.
            - Predator-Prey Relationships: The abundance of mast can impact predator-prey

relationships in the forest. When mast is plentiful, populations of seed-eating animals increase, which can, in turn, support predators that feed on them.
    - Ecosystem Health: The health and vigor of trees are often linked to their mast production. A tree capable of producing abundant mast is typically healthier and more resilient to environmental stressors, benefiting the overall health of the forest.
    - Human Impact: Mast production can also have implications for human activities such as hunting and forestry. It can influence the abundance and distribution of game species and affect forest management practices
- Explain that students will estimate the volume of mast produced by a tree in the forested area.
    - Understanding mast production is essential because it's a vital food source for many animals in the forest. By estimating the mast volume, we can gauge how much food is available for wildlife, which impacts their survival and the health of the ecosystem.
- Procedure:
    - Choose a tree with a substantial canopy in the forested area. Look for a tree with plenty of seeds or fruit on the ground underneath it.
    - Collect the provided tools: graduated beakers, forestry survey sheets part 2, and pencils.
    - Identify a representative square foot area under the tree's canopy.
    - Use a measuring tape or visually estimate a square foot area.
- Science Notebook Prompts:
    - Mast Observation: In your science notebook, record your observations about the tree you selected. Describe the tree species, the number of seeds or fruit on the ground, and any other relevant details.
    - Interpretation: Explain why it's important to estimate mast volume in a forest ecosystem. Consider how this information can help us understand the forest's health and the animals that depend on it.
    - Sampling Area Description: Document your chosen square foot area under the tree's

        - canopy. Explain why this area was selected for estimating mast volume.
        - Calculations: Show your calculations for estimating the mast volume. Include the average depth of mast in your sampled square foot area and the formula used to calculate the volume.
- Discussion Questions:
    - Wildlife and Mast: Discuss the significance of mast (seeds and fruit) as a food source for wildlife in the forest. Why is it important for animals to have access to this food?
    - Ecosystem Impact: Consider how the availability of mast impacts the behavior of wildlife in the forest. How might animals adapt their behavior based on the mast production of trees?
    - Estimation Accuracy: Reflect on the accuracy of your mast volume estimation based on a single square foot. Discuss how considering the entire canopy area would provide a more precise estimate.
    - Forest Health: Explore the connection between mast production, the health of individual trees, and the overall health of the forest ecosystem. How might mast production serve as an indicator of forest productivity?
    - Conservation Implications: Discuss how the data on mast production can be valuable for conservation efforts. How can this information be used to manage and protect forested areas?

Tree Information:

- Tree Species: ______________________
- Location: _________________________
- Date: _____________________________

Procedure:

Select a Sampling Area:

Identify a representative square foot area under the tree's canopy.
Use a measuring tape or visually estimate a square foot area.

Sampling Area: _____ ft^2

Collect Mast:

Carefully collect all the mast (seeds and fruit) within the selected square foot area. Use hands or tools to gather mast without causing damage to the tree or its surroundings.
Collected Mast: _____ (record the quantity)

Calculate Mast Volume:
Estimate the average depth of the mast in the sampled square foot area (in inches).
Use the formula: Mast Volume = Area of Canopy × Average Depth of Mast
Average Depth of Mast: _____ inches Area of Canopy: _____ ft^2 (consider the entire canopy area)
Mast Volume Calculation:
Mast Volume = Area of Canopy × Average Depth of Mast
Mast Volume = _____ ft^3

Exploring Biomes and Ecosystem Services (elaborate)

- Begin with a brief discussion on the importance of forests in maintaining ecological balance.
    - Emphasize that students will express their understanding through the creation of tangible artifacts.
    - Divide students into small groups and have them rotate through the stations.
    - Encourage creativity and attention to detail at each station.
    - Artifact Creation Stations:
        - Set up different stations within the classroom, each focused on a specific type of artifact creation.
        - Station 1: Diorama Creation
            - Provide shoeboxes, art supplies, and figurines.
            - Students create dioramas representing a forest ecosystem, considering layers like the forest floor, understory, and canopy.
            - Facilitation Questions:
                - What layers of a forest ecosystem will you include in your diorama?
                - How will you represent the interactions between different elements in your diorama?
            - Creativity Strategy: Encourage the use of recycled materials and challenge students to think about unique ways to represent each layer of the forest.
        - Station 2: Collage Making
            - Provide magazines, glue, and large sheets of paper.
            - Students cut out images and create collages showcasing the diversity of flora and fauna in forest ecosystems.
            - Facilitation Questions:

        - What specific flora and fauna do you want to include in your collage?
        - How can you arrange the images to represent the interconnectedness of the forest ecosystem?
    - Creativity Strategy: Encourage students to think beyond literal representations and consider symbolic elements in their collages
- Station 3: Nature Sketching
    - Provide sketching paper, colored pencils, and markers.
    - Students sketch various elements of forest ecosystems, such as trees, plants, and animals.
    - Facilitation Questions:
        - What species will you focus on in your sketches, and why?
        - How can you capture the diversity of the forest ecosystem in your drawings?
    - Creativity Strategy: Encourage experimentation with colors and styles to bring out the vibrancy and diversity of the forest.
- Station 4: Clay Sculpting
    - Provide modeling clay in different colors.
    - Students sculpt representations of key elements in a forest, like trees, animals, and natural features.
    - Facilitation Questions:
        - Which elements of the forest ecosystem will you sculpt, and how will you arrange them?
        - How can you use different colors and textures to represent the different components of the forest?
    - Creativity Strategy: Encourage students to explore different sculpting techniques and to think about the tactile qualities of their chosen elements.

- Students pair up with a partner who created a different type of artifact.
    - They share their creations and discuss how well each artifact represents the forest ecosystem.
    - Encourage specific feedback, such as pointing out accurate details or suggesting improvements.
- Distribute reflective journals to students.
    - Ask them to write about their creative process, any challenges faced during the refinement, and how their artifact represents their understanding of forest ecosystems.
    - Prompt them to reflect on the feedback received from their peers.

Strategies for Creativity:

- Encourage Cross-Pollination: Prompt students to gather ideas from

Forest Ecosystem Simulation Game - Scenario Cards:

1. **Drought Strikes:**

Description: A prolonged period of drought has hit the forest. Water sources are diminishing, and the availability of water is severely limited.

Impact on Roles:

- Trees: Water stress may affect growth and overall health.
- Herbivores: Limited water sources may lead to decreased food availability.
- Carnivores: Changes in herbivore abundance may impact predator-prey dynamics.
- Sunlight: Drought may lead to changes in plant physiology and productivity.
- Water Availability: Role is critically affected; assess the impact on the entire ecosystem.

2. **Human Logging Activity:**

Description: Humans have initiated logging activities in a part of the forest, leading to the removal of several trees.

Impact on Roles:

- Trees: Some trees are removed, impacting the forest structure.
- Herbivores: Changes in available habitats and food sources.
- Carnivores: Altered hunting grounds and potential changes in prey abundance.
- Sunlight: Increased sunlight in certain areas due to tree removal.
- Human Development: Role is actively involved in the scenario; assess the consequences of logging.

3. **Introduction of Invasive Species:**

Description: An invasive plant species has been introduced to the forest, rapidly spreading and competing with native vegetation.

Impact on Roles:

- Trees: Competition for resources and potential displacement.
- Herbivores: Changes in available plant species for grazing.
- Carnivores: Altered prey availability and potential impacts on the food web.
- Invasive Species: Role is actively involved; assess the consequences on native species.
- Overall Ecosystem: Consider the broader impact on ecosystem health.

4. **Climate Change:**

Description: The climate is changing, leading to shifts in temperature and precipitation patterns.

Impact on Roles:
- Trees: Altered growth patterns and potential changes in species composition.
- Herbivores: Changes in plant availability and distribution.
- Carnivores: Potential shifts in prey abundance and distribution.
- Sunlight: Changes in cloud cover and sunlight availability.
- Water Availability: Changes in precipitation patterns affecting water sources.

5. **Forest Fire:**

Description: A forest fire has occurred, affecting a part of the ecosystem.
Impact on Roles:
- Trees: Some trees are damaged or destroyed, impacting forest structure.
- Herbivores: Changes in available habitats and potential food scarcity.
- Carnivores: Potential loss of prey and habitat disruption.
- Sunlight: Increased sunlight in burned areas; assess the recovery process.
- Water Availability: Potential impact on water sources due to soil erosion.
-

These scenario cards are designed to introduce challenges that reflect real-world issues affecting forest ecosystems. Customize them based on the focus of your lesson and the concepts you want to explore with your students.

Forest Ecosystem Simulation Game - Role Cards:

1. **Tree Role:**

- You are a towering tree in the forest.
- Role Responsibilities:
- Provide shade and shelter for animals.
- Contribute to the overall structure and stability of the ecosystem.

Adaption to Scenario: How does the tree respond to changes in sunlight, water availability, or other environmental factors?

2. **Herbivore Role (e.g., Deer):**

- You are a herbivorous animal that grazes in the forest.
- Role Responsibilities:
- Consume plants for sustenance.
- Aid in seed dispersal through grazing.

Adaption to Scenario: How does the herbivore adapt to changes in plant availability or the introduction of a new predator?

3. **Carnivore Role (e.g., Cougar):**

- You are a carnivorous predator in the forest.
- Role Responsibilities:
- Regulate herbivore populations.
- Maintain the balance between different animal species.

Adaption to Scenario: How does the carnivore respond to changes in the abundance of herbivores or the introduction of new competitors?

4. **Sunlight Role:**

- You represent sunlight, a crucial factor for photosynthesis.
- Role Responsibilities:
- Influence plant growth and productivity.
- Affect the availability of resources for all components of the ecosystem

Adaption to Scenario: How does sunlight adapt to changes in cloud cover, deforestation, or other factors affecting its availability?

5. **Water Availability Role:**

- You represent water availability within the forest ecosystem.
- Role Responsibilities:
- Sustain plant and animal life.
- Impact the overall health of the ecosystem.

Adaption to Scenario: How does water availability adapt to changes in precipitation patterns, drought, or other alterations?

6. **Human Development Role:**

- You represent human activities encroaching on the forest.
- Role Responsibilities:
- Introduce challenges such as deforestation, pollution, or habitat destruction.

Adaption to Scenario: How does human development impact the various components of the forest ecosystem, and how can it be mitigated?

7. **Invasive Species Role:**

- You represent an invasive species introduced to the forest.
- Role Responsibilities:
- Compete with native species for resources.
- Potentially disrupt the existing balance.
- Adaption to Scenario: How does the invasive species affect native flora and fauna, and how does it adapt to the new environment?

Feel free to adjust the roles and responsibilities based on the specific concepts you want to emphasize in your simulation. Each role card should prompt students to think critically about their contributions to the ecosystem and how they adapt to changing conditions.

Tree Measurement Data Worksheet

Group Name: ____________________
Tree Species: ____________________
Observer's Name (Rotation 1): ____________________

Tree 1:

Measurement Type **Reading**

Estimated Diameter (Biltmore Stick) _______ inches/centimeters

Estimated Height (Biltmore Stick) _______ feet/meters

Measurement Type **Reading**

Actual Diameter (Measuring Tape) _______ inches/centimeters

Tree 2:

Measurement Type **Reading**

Estimated Diameter (Biltmore Stick) _______ inches/centimeters

Estimated Height (Biltmore Stick) _______ feet/meters

Measurement Type **Reading**

Actual Diameter (Measuring Tape) _______ inches/centimeters

Tree 3:

Measurement Type **Reading**

Estimated Diameter (Biltmore Stick) _______ inches/centimeters

Estimated Height (Biltmore Stick) _______ feet/meters

Measurement Type **Reading**

Actual Diameter (Measuring Tape) _______ inches/centimeters

Group Reflection:

- What challenges did you encounter during the measurements?
- Did you observe any patterns or differences between tree species?
- How did the estimated diameter using the Biltmore Stick compare to the actual measured diameter?

Additional Notes:

- ____________________
-
- ____________________
-
- ____________________
-

____

Feel free to customize the worksheet based on your specific lesson objectives and the level of detail you want students to record. This worksheet includes sections for multiple trees and encourages reflection on the measurement process.

Investigations and Application—Biomes and Ecosystem Services

Educator Background information—Grassland Disturbances

Grasslands are dynamic ecosystems that can experience various disturbances, both natural and anthropogenic. Understanding these disturbances is crucial for effective grassland management and conservation. Here's an overview of key background information:
1. Natural Disturbances:
a. Fire:
Role in Grasslands: Fire is a natural ecological process that plays a vital role in shaping grassland ecosystems. It helps control woody vegetation, recycle nutrients, and stimulate seed germination.
Adaptations: Many grassland species have evolved adaptations to fire, such as fire-resistant root systems and the ability to resprout after a fire event.
b. Drought:
Impact on Grasslands: Periodic droughts are common in grasslands and can affect plant growth, reproduction, and overall ecosystem structure.
Resilience: Grassland species are often adapted to survive and recover from drought, but prolonged and severe droughts can have lasting impacts.
c. Grazing:
Herbivores: Native herbivores, such as bison and various ungulates, historically played a crucial role in shaping grassland structure through grazing.
Biotic Interactions: Grazing can influence plant diversity, nutrient cycling, and the spatial distribution of different plant species.

2. Anthropogenic Disturbances:
a. Overgrazing:
Livestock Impact: Intensive grazing by domestic livestock can lead to overgrazing, reducing plant cover and biodiversity.
Degradation: Overgrazing is a significant driver of grassland degradation, impacting soil structure and promoting invasive species.
b. Agricultural Practices:
Plowing and Crop Cultivation: Conversion of grasslands to croplands through plowing can result in habitat loss and fragmentation.
Fertilizer Use: Agricultural runoff from fertilizers can introduce excess nutrients into grassland ecosystems, affecting native plant communities.
c. Urbanization:
Infrastructure Development: Urban expansion and infrastructure projects can fragment grassland habitats, leading to habitat loss for many species.
Altered Hydrology: Changes in land use can alter natural hydrological patterns, impacting water availability and soil moisture in grasslands.
d. Invasive Species:
Introduction: Non-native plant species can outcompete native grasses, disrupting ecosystem balance.
Altered Ecosystem Dynamics: Invasive species can alter fire regimes, nutrient cycling, and the composition of plant and animal communities.

3. Climate Change:
a. Temperature and Precipitation Changes:

Shifts in Grassland Boundaries: Climate change can lead to shifts in the boundaries of grassland ecosystems as temperature and precipitation patterns change.
Altered Phenology: Changes in temperature can affect the timing of plant growth, flowering, and seed production.
b. Extreme Weather Events:
Intensification of Disturbances: Increased frequency and intensity of extreme weather events, such as storms and wildfires, can exacerbate disturbances in grasslands.
Erosion and Soil Loss: Extreme weather events can lead to soil erosion, impacting grassland productivity.
4. Ecological Consequences:
a. Biodiversity Loss:
Species Declines: Disturbances can lead to declines in plant and animal species, particularly those adapted to specific grassland conditions.
Shifts in Community Structure: Altered disturbance regimes can result in shifts in the relative abundance of different species.
b. Soil Erosion:
Impact on Soil Health: Intensive disturbances can lead to soil erosion, reducing soil fertility and disrupting nutrient cycling.
Long-term Consequences: Soil erosion can have lasting impacts on grassland ecosystems, affecting plant growth and community composition.
Conclusion:
Understanding grassland disturbances involves recognizing the complex interplay of natural and human-induced factors. Effective management and conservation strategies require a holistic approach that considers the ecological processes, species interactions, and external drivers influencing these dynamic ecosystems. Ongoing research and monitoring efforts are essential to develop sustainable practices that maintain the resilience and biodiversity of grasslands in the face of disturbances.

Next Generation Science Standards

- MS-LS2-4 Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-ESS3-3 Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

Students will be able to:
Explore natural disturbances in grasslands, such as fire, drought, and grazing, and understand their ecological roles and adaptations.

Student Vocabulary:

- Ecotone: a region of transition between two biological communities.
- Rootstock: is part of a plant, often an underground part, from which new above-ground growth can be produced.
- Succession: is the process of change in the species structure of an ecological community over time. The time scale can be decades, or even millions of years after a mass extinction

Exploring Biomes and Ecosystem Services (engage)

- Begin by asking students to share what they already know about ecosystems and biomes.
  - Encourage them to think about different types of environments and the living organisms within them.
  - Provide a concise explanation of biomes as large geographical areas with distinct climates, ecosystems, and biodiversity.
    - Use visuals like maps or images to illustrate the concept. Highlight major biomes globally, such as forests, deserts, tundras, and, of course, grasslands.
    - Transition to the focus on grassland biomes by discussing their significance in the global ecosystem.
      - Briefly mention the role of grasslands in supporting diverse wildlife, their contribution to carbon sequestration, and their importance for human activities like agriculture.
        - Show a short video or a slideshow featuring visually stunning images and videos of different grassland biomes worldwide.
          - YouTube:
            - Search for keywords like "grassland biome," "savanna ecosystem," or "prairie landscape." Look for channels dedicated to nature documentaries or educational content.
          - National Geographic:
            - Visit the National Geographic website or their YouTube channel for high-quality videos and images related to grassland biomes.
          - BBC Earth:
            - Check the BBC Earth website or YouTube channel for documentaries and visual content on various ecosystems, including grasslands.
          - Discovery Channel:
            - Explore the Discovery Channel website or YouTube channel for documentaries on different biomes, which may include grasslands.
          - Planet Earth and Planet Earth II:
            - Look for clips or episodes from the "Planet Earth" and "Planet Earth II" documentary series. These series often feature breathtaking visuals of diverse ecosystems.

            - Vimeo:
              - Search for grassland biome-related videos on Vimeo, which may include

independent documentaries and visually stunning content.

- Educational Websites:
  - Explore educational websites like Khan Academy, TED-Ed, or educational platforms associated with museums and science institutions for curated content on ecosystems.
- Stock Footage Websites:
  - Websites like Shutterstock, Adobe Stock, or Pond5 may have stock footage or images of grassland biomes. Some of these may require purchase or licensing.
- Nature Conservation Organizations:
  - Check websites of nature conservation organizations like the World Wildlife Fund (WWF) or The Nature Conservancy. They might have educational materials featuring grassland ecosystems.
- Online Learning Platforms:
  - Platforms like Coursera or edX might have courses related to ecosystems, including videos or slideshows on grassland biomes.
    - Remember to preview the content to ensure it aligns with your educational goals and is suitable for your students. Additionally, check for any licensing or usage restrictions associated with the content you find.

- Emphasize the unique characteristics of grasslands, such as the vast open landscapes, diverse plant life, and the coexistence of various animal species.

- Pose questions to the class to stimulate curiosity, such as "Why do you think grasslands are so widespread?" or "What challenges might organisms face in these environments?"
  - Encourage students to share their thoughts and hypotheses.
  - Discuss briefly how human activities and environmental changes can impact grassland biomes.
    - Mention current issues, such as habitat loss, climate change, and the importance of conservation efforts in these ecosystems.
- Divide the class into small groups of 3-4 students.
  - Provide each group with a map or globe and a set of pictures/diagrams representing various grassland biomes.

- Instruct groups to work together to identify and label the different grassland biomes on their maps.
    - Encourage discussions within the groups about the characteristics that define each grassland biome.
        - Emphasize the importance of collaboration and effective communication.
    - Have each group share one interesting fact or observation about the grassland biomes they identified.
    - Facilitate a brief class discussion on commonalities and differences among the identified grassland biomes.
- Explain that each group will be assigned a specific type of grassland biome to research and present to the class.
    - Assigning Biomes
        - Randomly or strategically assign each group a grassland biome (e.g., temperate grasslands, savannas, or steppes)
- Provide guidelines for the research, emphasizing key points such as climate, vegetation, wildlife, and any unique features of their assigned grassland biome.
    - Encourage the use of multiple sources to gather comprehensive information.

- Allow each group to present their findings to the class.
    - Encourage students to ask questions after each presentation.
    - Take note of interesting details and connections between different grassland biomes.
        - Ask students to reflect individually on what they have learned about grassland biomes.
            - Provide prompts such as "What surprised you the most?" or "How do human activities impact grasslands?"
                - Allow a few students to share their reflections with the class.
    - Instruct students to use art supplies to create a visual representation of a grassland biome.
        - Encourage creativity and the incorporation of key elements discussed during the lesson, such as specific plants, animals, and climate features.
            - Arrange the created artwork around the classroom for a gallery walk.
                - Encourage students to observe and discuss their peers' representations of grassland biomes.
        - Summarize the key points about grassland biomes, emphasizing the diversity and importance of these ecosystems.
    - Provide a brief overview of the upcoming activities and assignments related to the exploration of grassland biomes.
    - Highlight the collaborative and hands-on nature of the unit,

emphasizing that students will actively explore, research, and present their findings.

Exploring Biomes and Ecosystem Services (explore)

- Briefly recap the previous lesson on grassland biomes, emphasizing the historical uses of fire and the impact of fire suppression and farming.
    - Introduction to Grassland Biomes:
        - Defined grassland biomes as ecosystems dominated by grasses, with minimal trees and shrubs.
        - Explored the global distribution of grasslands on a world map or globe.
    - Historical Uses of Fire:
        - Discussed how indigenous cultures historically used controlled fires as a management tool for grasslands.
        - Explored the role of fire in maintaining ecosystem health, promoting biodiversity, and preventing the encroachment of woody vegetation.
    - Impact of Fire Suppression:
        - Explored the historical shift in fire management policies, emphasizing the impact of suppressing natural fires.
        - Discussed the unintended consequences, including changes in vegetation structure, the invasion of non-native species, and alterations in overall ecosystem health.
    - Farming and Grassland Transformation:
        - Examined how the expansion of agriculture has led to the conversion of grasslands into croplands and pastures.
        - Discussed the implications of farming practices on soil health, biodiversity, and the overall structure of grassland ecosystems.
    - Interconnectedness of Human Actions and Ecosystem Health:
        - Emphasized the interconnectedness of historical human activities and the health of grassland biomes.
        - Explored the delicate balance needed to maintain these ecosystems for both human needs and ecological sustainability.
    - Relevance to Modern Challenges:
        - Discussed the relevance of understanding historical practices in the context of modern challenges such as conservation, sustainable land management, and the preservation of biodiversity.
- Introduction to the Project:
    - Begin by showing examples of well-designed dioramas to inspire creativity.
        - Clearly articulate the purpose of the diorama project: to visually represent a grassland biome, showcasing its biodiversity and illustrating the impact of historical human activities.
        - Discuss the importance of hands-on projects in enhancing understanding. Highlight how creating a diorama allows students to apply their knowledge creatively and visually.
        - Outline the specific goals of the project, such as:
            - Creating a realistic representation of a grassland biome.

    - Incorporating elements related to historical uses of fire.
    - Depicting the impact of human activities on the ecosystem.
  - Display the materials students will use, including shoeboxes or small cardboard boxes, art supplies (colored paper, markers, glue, scissors), and small figurines or cut-out images representing grassland animals and plants.
    - Set clear guidelines for the diorama project, such as size constraints for the shoeboxes or specific elements that must be included (e.g., grasses, animals, and historical features).
    - Emphasize the importance of accuracy in representing the grassland biome and encourage creativity in the design.
      - Reiterate how the diorama project aligns with the learning objectives of the grassland biome unit, emphasizing the integration of knowledge about historical human activities into a creative and visually impactful representation.
      - Display examples of well-designed grassland biome dioramas or dioramas from other ecosystems. Discuss what makes them effective and visually appealing.
        - Encourage a brief discussion on potential concepts and ideas for their dioramas, linking back to the historical uses of fire and the consequences
- Research and Planning
  - Provide access to reference materials, books, online resources, or images that focus on grassland ecosystems, their biodiversity, and historical uses of fire. Consider curating a list of reliable online sources for students.
  - Guide students in exploring these resources, encouraging them to take notes on key features, native species, climate, and any historical information related to fire usage in grasslands.
    - Instruct students to sketch a rough layout of their diorama on a piece of paper. This should include the placement of grasses, animals, and any human elements representing historical activities. Encourage them to consider the visual storytelling aspect.
      - Encourage collaboration within groups. Discussing and sketching together can help ensure a cohesive vision for the diorama.
        - Circulate the room, offering guidance and answering questions. Provide insights effective diorama design, including the balance of elements and how to visually represent historical human activities.
          - Key Elements to Include
          - Natural Features:
          - Emphasize the inclusion of natural features like grasses, vegetation, and appropriate

animal species. Discuss the importance of representing biodiversity.

- Historical Features:
    - Highlight the significance of incorporating elements related to historical uses of fire. This could involve depicting controlled burns or other human activities that shaped the grassland biome.
- Balance:
    - Discuss the need for balance in their dioramas. Ensure that both natural and human elements are represented thoughtfully to convey the interconnectedness of these aspects.
        - Have brief check-ins with each group to review their sketches and discuss their plans. Offer constructive feedback and suggestions.
        - Encourage students to ask questions and seek clarification on any aspects of the project or grassland biome concepts.

- Facilitate group discussions to finalize their diorama plans. Encourage students to make decisions collaboratively and ensure that each group member understands their role in the project.
- Collect or have students submit their finalized sketches and plans. This could include a written description of their diorama concept and key features

- Creation Phase
    - Start the creation phase by building excitement and emphasizing the importance of translating their research and planning into a visually captivating and accurate representation of a grassland biome.
        - Distribute the necessary materials, including shoeboxes or small cardboard boxes, art supplies (colored paper, markers, glue, scissors), and small figurines or cut-out images representing grassland animals and plants.
            - Remind students of the guidelines and constraints for the diorama project, emphasizing the size limits for the shoeboxes and the specific elements that must be included (e.g., grasses, animals, and historical features).
    - Instruct students to prepare their shoeboxes by reinforcing the sides if necessary. This ensures stability for the diorama.
        - Begin with a base layer by covering the bottom of the shoebox with colored paper or creating a textured surface to represent the ground of the grassland.
        - Encourage students to create realistic landscapes by adding layers of colored paper to represent hills, plains, or other

geographical features found in grasslands.

- Integrate various shades of green paper to represent different types of grasses and vegetation.
- Discuss the importance of biodiversity in their representation.
- Place figurines or cut-out images of grassland animals in appropriate locations within the diorama.
    - Encourage students to consider the natural behavior and habitat preferences of the chosen animals.
- Integrate human elements representing historical activities related to the use of fire.
    - This could include miniature figures engaging in controlled burns or other relevant activities.
- Encourage students to add details such as rocks, water features, or other natural elements that contribute to the overall realism of the diorama.
    - Circulate the room, offering guidance and support. Provide constructive feedback on the placement of elements and the overall composition.
    - Address any questions students may have and clarify any issues that arise during the construction phase.
        - Encourage groups to pause periodically to reflect on their progress. Ask questions like:
            - "How well are we representing the grassland biome?"
            - "Are our historical elements effectively integrated into the scene?"
                - If necessary, guide students in making adjustments or improvements based on their reflections. Encourage a dynamic and iterative approach to the construction.

- Summarize the creation phase by applauding students for their efforts and creativity. Remind them to finalize their dioramas by the end of the next class period. Encourage collaboration and teamwork as they bring their grassland biomes to life.
    - Arrange completed dioramas around the room for a gallery walk.
    - Each group briefly presents their diorama to the class, explaining design choices and elements.
    - Encourage groups to highlight specific features related to historical human activities in their presentations.
        - After each presentation, provide time for classmates to offer positive feedback and ask questions.
        - Encourage constructive comments by asking peers to consider what elements were particularly effective or what they found most informative.
        - Lead a class discussion on common themes and variations

observed in the dioramas.
- Discuss the students' reflections on representing historical human activities in their projects.
    - Prompt questions such as "How did including historical elements enhance the understanding of the grassland biome?"
- Ask students to write a short reflection on the challenges and benefits of creating a diorama to represent a complex ecosystem.
    - Encourage them to reflect on what they learned about grassland biomes through the process.

Exploring Biomes and Ecosystem Services (explain)

To execute this section according to the best time management, it is advised that teachers begin the long, running experiment early on with plans to periodically check it's progress and pose the associated discussion points related to prairie ecology and resource management.

- Within clear plastic tubes or another tall rootviewing setup which the teacher may select, track root growth of Kentucky bluegrass vs the tallgrass prairie native, compass plant (Silphium laciniatum).

- Set Up the Root-Viewing Setups:
    - Fill the clear plastic tubes or root-viewing setups with potting soil, leaving enough space at the top for planting seeds.
    - Plant Kentucky bluegrass seeds on one side and compass plant seeds on the other, ensuring uniform depth.
    - Water the setups thoroughly and place them in a location with access to natural light.
        - Maintain consistent watering to ensure optimal growth conditions for both grass species.

- Begin making regular observations of the setups, recording details such as germination, shoot growth, and overall plant health.
  - As roots begin to develop, use a ruler or measuring tape to carefully track and measure the length of roots for both Kentucky bluegrass and compass plants.
  - Record measurements in your science notebook at designated intervals (e.g., weekly).
  - Analyze and compare the rate of root growth between Kentucky bluegrass and compass plants.
    - Note any differences in root structure, density, or patterns.

Data Collection Table

Week	**Kentucky Bluegrass Root Length (cm)**	**Compass Plant Root Length (cm)**
Week 1		
Week 2		
Week 3		

- Compare the root growth patterns of Kentucky bluegrass and compass plants.
- Reflect on any observed differences and consider the potential ecological implications of these variations.
- Discuss how root structures contribute to the overall health and adaptability of each plant species.
- (bison, antelope, wildebeest) and frequent largescale fire.
  - While these destructive events occur above ground, the rootstock and buried stems of these plants are secure

below, and readily able to regrow in shorter order than species that may invade from neighboring communities.

- However, when such disturbance is removed, the prairie species are shaded and outcompeted.
    - Additionally, the deep rooting, combined with the ashes of prairie blazes, the dung dropped by herding grazers, and the annual die back of the grasses over winter has, over the centuries, created a tremendous amount of organic material continuously tilled into the soil by the prairies burrowing wildlife.

- To illustrate this ecology you may share with students the example of the shortgrass prairie species buffalo grass (Bouteloua dactyloides).
    - Core samples taken from American rangelands have shown trace genetic material of buffalo grass at a depth of up to thirty feet (due to the depth of living roots compounded by the action of burrowing rodents like prairie dogs and pocket gophers).
        - And while the grass is the first thing to bounce back after buffalo herds nibble all of the surrounding vegetation down to nubs, it fails to thrive outside of areas regularly grazed by buffalo.
        - When the grass is eaten above ground, the plant actually also sheds root material into the soil to maintain a metabolic balance.
            - As students track the downward growth of the compass plant you may spread the following discussion points over several days.
    - Given the depth of the roots and the disturbances above ground, do students think there is more dead plant material buried or on the surface of the ground when many prairie plants die back each winter?
    - How might prairies compare to the productivity and biomass generated by deciduous forests and their leaf litter?
            - Certain native steppe/shortgrass prairie plants thrive in the presence of pronghorn antelope or buffalo, but are overgrazed by cattle and sheep which do not, or are not allowed to wander as far afield.
- Take a moment to look up and read through the lyrics of the song “home, home on the range”.

        - Where is the range? How might ranching and agriculture have historically depended on, and affected this plant community?
        - Fire disturbance is necessary to maintain tallgrass prairies since it removes invading, more competitive species, and because many tallgrass prairie species have seeds which will not germinate unless triggered by conditions indicating a fire has just occurred (changes in pH, exposure to high temperature, etc).
    - How might farmers settling in flat fertile areas respond to and try to manage giant walls of flames slowly sweeping across the entire landscape?
        - Is the farmer's response to large raging infernos good for the prairie ecosystem?
        - Does it reinforce or negate the conditions which contribute to the rich soils these farmers wish to utilize?
            - While the amount of dark rich soil generated by prairies over the centuries becomes highly fertile, prairie grassland are unlike the valleys of river floodplains because they are high and dry.
    - Overall, does agricultural use of land naturally occupied by prairie communities have a long history or is it a recent development?
        - Does it seem to be easily sustainable over the long term or do certain practices need to be tightly managed to avoid economic and environmental problems. Prior to settlement by farming societies, do students think native and indigenous peoples might have employed environmental management strategies that might be worth researching today?
        - Can some disruptive events/practices maintain native ecosystems while others are destructive to them? What determines the difference.
            - Today, the area occupied by natural tallgrass prairie is reduced to less than 1% of its original range.
            - Meanwhile farmland occupying the habitat's former space is losing topsoil faster than it is replaced. Is restoring large sections of US farmland to native prairie a practical strategy for restoring this natural resource? Could it be a necessary one? Do students think other soil conservation strategies might have to be adopted, also or instead.
- Grassland communities occupy a wide variety of frequently disturbed ecosystems, often in close proximity to, or as an ecotone with, spaces left unmolested.
    - By quickly colonizing in the early stages of succession, these plats capitalize on the destruction.

- By adopting features which may withstand or even facilitate such events in the future, they may repeat this success across so many cycles as to become the permanent fixtures of said environment.
- Despite, and because of, the regularity of such catastrophe, disturbed grasslands find refuge from species which would otherwise outcompete them. In the process, grasslands are able to rapidly establish working ecosystems which maintain clean water and arable soil, two services vital to human health and civilization.
- While all so important, grassland communities are often the victims of their own success, subjected to intense changes of land use as the societies they foster spread and convert the surrounding environment.
  - To set the stage for class activities, ask students to research and summarize one or more the following historical events: The “great flood of 1993”, The channelization of the Kissimmee river by the army corps of engineers, the dust bowl, the 2020 breach of the Edenville and Sanford dams, and The 2020 Australian wildfires as they played out in aboriginal controlled areas. Students should specifically prepare to answer the following questions in class:
  - Which resources were people trying to make use of?
  - Which natural processes were beyond full human control?
  - How do the natural ecosystems respond to these events?
  - Were the problems caused or mitigated by how people used the landscape?
  - What changes should people consider making to avoid future conflicts with the environment?

Exploring Biomes and Ecosystem Services (elaborate)

- Begin with a brief discussion on the importance of grassland biomes and their role in supporting biodiversity.
  - Grasslands play a pivotal role in fostering biodiversity by offering a diverse array of habitats and ecological niches. Characterized by various landscapes such as savannas, prairies, and meadows, grasslands support a rich tapestry of plant and animal life. Herbaceous plants, including an array of grasses and wildflowers, create microhabitats for insects, while large herbivores like bison and deer thrive on the abundant vegetation. Grasslands also host predator-prey dynamics, with carnivores like wolves relying on the presence of herbivores for sustenance. Avian diversity flourishes in grasslands, providing habitats for ground-nesting birds and birds of prey. Below-ground, diverse microbial communities contribute to nutrient cycling and soil health. Certain grassland regions, recognized as biodiversity hotspots, showcase a concentration of unique species. Beyond their ecological significance, grasslands serve as migration routes, offer essential ecosystem services, and hold cultural importance for indigenous communities, emphasizing the critical role these ecosystems play in sustaining life and fostering biodiversity.
    - Pose the question: "How might farming practices impact the nutrient

content of grassland soils?"

- Ask students to generate hypotheses about the potential effects of farming on soil nutrient levels in grasslands.
  - Record hypotheses in student science notebooks.

- Provide students with grassland soil samples. Discuss the importance of starting with a baseline measurement.
  - Divide students into small groups and provide each group with grassland soil samples from different locations within the grassland area.
    - Encourage them to collect samples systematically, considering variations in vegetation and topography.
  - In each group, provide pots or containers and various crops or grass seeds.
    - Discuss the selection of crops that are commonly grown in agricultural practices affecting grasslands, such as wheat or corn.
  - In one set of pots, simulate a farming scenario by planting these crops. In another set, leave the soil undisturbed as a control group.
    - In the farming simulation group, add fertilizer to represent typical agricultural practices. Discuss the purpose of fertilization in modern farming and its potential impact on soil nutrients.
      - Instruct students to regularly monitor the growth of plants in both sets of pots over the next few weeks. This includes measuring plant height, observing color changes, and noting any visible differences in overall health.
- Conduct pH testing on soil samples from both the farming simulation and control groups using pH testing kits.
  - Discuss the significance of pH levels in relation to nutrient availability and potential soil degradation.
    - Measure the height of plants in both the farming simulation and control groups using rulers or measuring tapes. Encourage students to record these measurements in a data table in their science notebooks.
    - Carefully extract plants from the pots and measure the length and density of roots.
      - Emphasize the importance of below-ground observations in understanding nutrient absorption and potential nutrient loss.
      - Instruct students to make visual observations of plant health, color, and overall appearance. Encourage them to note any signs of stress, discoloration, or stunted growth in the farming simulation group compared to the control group.
        - Facilitate group discussions where students share their observations and preliminary findings. Encourage them to consider how farming practices may have influenced soil and plant health in the

            simulated agricultural setting.
        - In their science notebooks, ask students to reflect on their data, considering the observed differences in soil and plant parameters between the farming simulation and control groups.
            - Discuss the real-world implications of nutrient loss in grasslands due to farming practices. Encourage students to think about sustainable agriculture methods that mitigate these effects.
    - Invite groups to share their findings and discuss the potential impact of farming on nutrient levels in grassland soils.
- Begin with a compelling image or short video showcasing the beauty and importance of grassland ecosystems. Ask: "What do you find intriguing or valuable about this ecosystem?"
- Discuss the concept of ecosystems and their role in maintaining ecological balance. Introduce the idea that human activities can influence these ecosystems.
    - Ask: "Can you think of any ways in which human activities might impact the environment?"
- Briefly re-introduce the terms "disturbances" and "grassland ecosystems."
    - Define disturbances as events that disrupt the natural balance of an ecosystem.
    - Share examples such as fires and changes in land use (farmland practices).
        - Ask: "How might disturbances affect the delicate balance of grassland ecosystems?"
    - Further discussion questions include
        - "Why are grassland ecosystems important for the environment?"
        - "What types of plants and animals might rely on grasslands for their habitat?"
        - "In what ways might human activities impact these ecosystems?"
            - Have students individually jot down their thoughts on a piece of paper.
            - Then, pair them up to discuss their ideas.
            - Finally, invite pairs to share their thoughts with the class. .
- Introduce the lesson's focus on disturbances in grassland ecosystems, specifically fire and farmland practices.
    - Explain that students will be researching these disturbances and designing methods to monitor and minimize their impact.
        - Emphasize the importance of their role as scientists and environmental stewards. Connect the lesson to real-world scenarios, mentioning how scientists work to understand and mitigate human impacts on ecosystems.
            - The introduction is a crucial phase to capture students' interest and set the context for the lesson. Use visuals, real

-world examples, and thought-provoking questions to engage students. Encourage curiosity and emphasize the relevance of their learning to the world around them.

- Form small research teams, ensuring a mix of strengths and interests in each group. Emphasize the importance of collaboration and pooling diverse perspective
  - Assign each team either the impact of fire or farmland practices on grassland ecosystems. Clearly communicate that each team will become an "expert" on their assigned disturbance.
    - Provide clear guidelines for research, including:
    - Causes: What human activities or natural processes lead to the disturbance?
    - Effects: How does the disturbance impact grassland ecosystems?
    - Monitoring Methods: Explore potential methods scientists use to monitor and study the disturbance.
      - Allocate time for teams to conduct research. Encourage them to use reputable sources such as scientific articles, reports, and online databases. Remind them to critically evaluate information for reliability.
  - During research, circulate among groups and ask:
    - "What specific aspects of the assigned disturbance are you finding most interesting or surprising?"
    - "How might the causes and effects of the disturbance be interconnected?"
    - "What kinds of monitoring methods are scientists currently using to study these disturbances?"
      - Gather the class for a brief group discussion where each team shares key findings. Encourage questions and cross-team dialogue to foster a comprehensive understanding of both disturbances.
  - Facilitate a class discussion to synthesize the information gathered. Ask:
    - "What are commonalities between the disturbances in terms of their impact on grassland ecosystems?"
    - "Can we identify key indicators that might signal the presence or effects of these disturbances?"
      - Instruct teams to design a monitoring method (poster or digital presentation) based on their research. The method should:
        - Address identified key indicators.
        - Be scientifically sound and feasible for real-world application.
      - Allocate time for teams to brainstorm and create

their monitoring method. Encourage creativity and thoughtful consideration of practical implementation.

- During the design process, ask:
    - "What are the key indicators that could help us monitor the impact of disturbances on grassland ecosystems?"
    - "How can we ensure that our monitoring methods are both scientifically sound and practical?"
    - "How are you incorporating scientific principles into your monitoring method?"
    - "What challenges are you encountering, and how are you addressing them?"
    - "How might your monitoring method contribute to minimizing human impact on grassland ecosystems?"
        - Emphasize the importance of effective teamwork. Encourage students to leverage each other's strengths and expertise.
            - The research and monitoring design phases aim to deepen students' understanding of disturbances in grassland ecosystems and foster critical thinking in designing effective monitoring methods. Emphasize the interconnectedness of scientific principles, real-world applications, and the role of scientists in addressing environmental challenges.

- Encourage teams to consider visuals, data representation, and clarity in their presentations.
    - During presentations, facilitate peer review with questions like: "How well does the monitoring method align with scientific principles? Can you suggest improvements?"
        - Peer review:What elements make a presentation effective in conveying scientific information?"
        - Peer review"As a reviewer, what criteria would you consider in assessing the monitoring methods presented by your peers?"
        - Reflective Journaling: Prompt: "Reflect on the design process. How did scientific principles guide your decisions?"

      - Group Discussion: Ask: "What were the challenges in designing monitoring methods, and how might these methods be applied in real-world scenarios?"
- Today, we embarked on a journey to understand the intricate dance between human activities and grassland ecosystems. We've explored the disturbances of fire and farmland practices, delving into their causes, effects, and potential monitoring methods.

- Now, it's time to wrap up our discoveries.

    - Let's take a moment to reflect on what we've learned.
      - In your teams, consider the following questions:
        - What surprised you the most during your research?
        - How might the causes and effects of disturbances be interconnected? Share your reflections with your teammates."
  - Now, let's hear some insights from each team.
    - What did you find most intriguing about your assigned disturbance?
    - How do you think your monitoring method could contribute to minimizing human impact?"
  - Our discussions and designs today have real-world implications. Scientists work tirelessly to understand these disturbances and implement effective monitoring methods. By doing so, we contribute to the broader goal of preserving and sustaining our precious grassland ecosystems."

Science Notebook Data Collection Worksheet: Exploring Nutrient Loss in Grassland Biomes Due to Farming

Student Name: ___________________ **Date:** ______________

Objective: To observe and record data on the effects of farming practices on nutrient levels in grassland soils and plant growth.
Activity Overview: In this experiment, we are simulating farming practices in grassland soils to understand how they may impact nutrient levels and plant growth. We will compare a farming simulation group with a control group to observe differences in soil and plant parameters.

Data Collection:
1. **Soil Sampling and pH Testing:Location:** __________________________________

Farming Simulation Group:
Collect soil samples before planting.
Conduct pH testing on the soil.

Control Group:
Collect soil samples before planting.
Conduct pH testing on the soil.

Pot Planting and Fertilization:
Farming Simulation Group:
Plant crops (e.g., wheat or corn) in the pots.
Add fertilizer according to instructions.

Control Group:
Leave the soil undisturbed in the pots.

Monitoring and Measurements (Weekly):
Week 1:
Measure plant height in both groups.
Visual observations of plant health.

Week 2:
Measure plant height in both groups.
Visual observations of plant health.

Week 3:
Measure plant height in both groups.
Visual observations of plant health.

Below-Ground Root Measurements:
Week 3:
Carefully extract plants from the pots.
Measure the length and density of roots for both groups.

Visual observations of plant health.

Below-Ground Root Measurements:
Week 3:
Carefully extract plants from the pots.
Measure the length and density of roots for both groups.

Sample/Group	pH Level	Plant Height (Week 1)	Plant Height (Week 2)	Plant Height (Week 3)	Root Length (Week 3)	Visual Observations
Farming Simulation						
Control						

Biomes and Ecosystem Services—Energy Flows

Educator Background Information—Energy Flows

Ecosystems are intricate webs of life where energy flows play a pivotal role in sustaining various life forms. The sun is the primary source of energy, and this energy is harnessed by plants through photosynthesis, converting it into chemical energy stored in their tissues. This process forms the foundation of the food chain.
As energy moves through an ecosystem, it is transferred from one organism to another. This lesson will delve into the dynamics of energy flow within ecosystems, exploring how energy sustains life and influences the behavior, growth, and survival of animals.

The transfer of energy occurs through feeding relationships, with each trophic level in the ecosystem representing a step in the energy pyramid. Producers, such as plants, harness sunlight to produce energy-rich compounds. Herbivores consume these plants, transferring energy to the next trophic level. Carnivores, in turn, consume herbivores, further transferring energy along the chain.
Understanding energy flows is crucial for comprehending the delicate balance within ecosystems. It influences the population dynamics of species, migration patterns, and the overall health of the environment. Moreover, human activities can disrupt these energy flows, impacting ecosystems and biodiversity.

This lesson will not only focus on the principles of energy flow but will also address the importance of conservation and sustainable practices to maintain the delicate balance of ecosystems.

Next Generation Science Standards (NGSS):
MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
MS-ESS3-3: Apply scientific principles to design a method

Students will be able to do
By the end of the "Exploring Energy Flows in Ecosystems" lesson, students will be able to:

- Explain how energy flows through ecosystems, moving from producers to consumers in trophic levels.
- Illustrate the concept of energy transfer through feeding relationships.

Vocabulary
Ecosystem: A community of living organisms (plants, animals, and microorganisms) interacting with each other and their non-living environment.
Photosynthesis: The process by which green plants and some other organisms use sunlight to synthesize foods with the help of chlorophyll pigments.
Trophic Level: Each level in a food chain or food web representing a functional role in the transfer of energy and matter.
Producer: Organisms, usually plants, that produce their own food through photosynthesis.
Consumer: Organisms, including animals, that obtain energy by consuming other organisms.
Decomposer: Organisms, such as bacteria and fungi, that break down and recycle dead organic matter.
Energy Transfer: The movement of energy from one organism to another within an ecosystem.
Trophic Pyramid: A graphical representation of the distribution of biomass, numbers, or energy among trophic levels in an ecosystem.
Population Dynamics: The study of the changes in the number and composition of individuals in a population over time.
Migration Patterns: Regular, usually seasonal, journeys undertaken by animals to move from one region to another and back.
Biodiversity: The variety of life in a particular habitat or ecosystem, including the variety of species, genetic differences within species, and ecosystems.
Conservation: The sustainable use and management of natural resources to ensure their continued availability.
Human Impact: The influence of human activities on ecosystems, including both positive and negative effects.
Sustainable Practices: Actions and strategies that promote the long-term well-being of ecosystems and the planet while minimizing negative environmental impacts.

Energy Flows (engage)

- Begin with a brief classroom discussion about ecosystems, emphasizing the definition and importance of both living and nonliving components.
    - Definition: An ecosystem is a community of living organisms (biotic factors) interacting with each other and their non-living environment (abiotic factors) in a specific area.
        - Discussion: Why is it important to understand ecosystems? How do ecosystems contribute to the overall health of the planet?
    - Living and Nonliving Components:
        - Discussion: Identify examples of living components (plants, animals, microorganisms) and nonliving components (air, water, soil, sunlight) in an ecosystem.
    - How are these components interconnected?
    - Key Vocabulary Introduction:
        - Ecosystem: The complex network of interactions between living organisms and their environment.
        - Producer: Organisms, usually plants, that produce their own food through photosynthesis.
        - Consumer: Organisms, including animals, that obtain energy by consuming other organisms.
        - Decomposer: Organisms, such as bacteria and fungi, that break down and recycle dead organic matter.
        - Biodiversity: The variety of life in a particular habitat or ecosystem.
        - Trophic Level: Each level in a food chain or food web representing a functional role in the transfer of energy and matter.
            - Display images or diagrams representing various ecosystems, such as a forest, grassland, desert, aquatic environments, and urban ecosystems.
                - Provide a brief overview of each ecosystem's unique features, climate, and the diversity of life it supports.
                    - Rainforest Ecosystem:
                        - Unique Features: Lush vegetation, high annual rainfall, and a layered structure with emergent, canopy, understory, and forest floor.
                        - Climate: Warm and humid, with consistently high temperatures and abundant rainfall throughout the year.
                        - Diversity of Life: Home to a vast array of plant and animal species, including unique insects, vibrant birds, and diverse mammals. High biodiversity due to the

favorable conditions.

- Desert Ecosystem:
  - Unique Features: Sparse vegetation, arid landscapes, and adaptions such as succulents and camouflaged animals.
  - Climate: Extremely dry with high temperatures during the day and significant temperature fluctuations between day and night.
  - Diversity of Life: Despite harsh conditions, deserts support specially adapted plant species, reptiles, and small mammals. Organisms exhibit water-saving mechanisms and nocturnal behaviors.
- Grassland Ecosystem:
  - Unique Features: Dominated by grasses, few trees, and occasional shrubs. Open landscapes with seasonal wildfires.
  - Climate: Moderate temperatures with distinct wet and dry seasons. Not as much rainfall as in a forest but more than in a desert.
  - Diversity of Life: Home to large herbivores like grazers (e.g., bison, zebras) and their predators (e.g., lions, wolves). Rich biodiversity with a mix of mammals, birds, and insects.
- Aquatic Ecosystem:
  - Unique Features: Subdivided into freshwater (rivers, lakes) and marine (oceans, seas) ecosystems. Varying depths, temperatures, and salinity levels.
  - Climate: Depends on the location, with marine ecosystems experiencing less temperature variation than freshwater ecosystems.
  - Diversity of Life: Teems with a wide range of aquatic organisms, from microscopic plankton to large whales. Coral reefs, found in marine ecosystems, are particularly known for their high biodiversity.
- Urban Ecosystem:

- Unique Features: Human-made environments with a mix of buildings, roads, and green spaces. Altered landscapes due to human activities.
- Climate: Influenced by the surrounding natural climate but often modified due to urbanization, leading to the urban heat island effect.
- Diversity of Life: While human-dominated, urban areas support a variety of wildlife, including birds, insects, and sometimes even larger mammals. Adaptations to urban living are common.

- Polar Ecosystem:
    - Unique Features: Extreme cold temperatures, ice-covered landscapes, and unique adaptations for survival in freezing conditions.
    - Climate: Extremely cold with long, harsh winters and short, cool summers.
    - Diversity of Life: Home to cold-adapted species such as polar bears, penguins, seals, and various cold-water fish. Limited diversity compared to warmer ecosystems.
- Discussion Points:
    - How do the unique features of each ecosystem contribute to the diversity of life it supports?
    - What adaptations do organisms in these ecosystems have to thrive in their specific climates?
    - How might human activities impact these diverse ecosystems?
    - Discuss the interconnectedness of different ecosystems on a global scale.
    - Producers, Consumers, Decomposers:
    - Present visuals illustrating the roles of producers, consumers, and decomposers within ecosystems.
    - Producers Example: Display images of different plants like ferns, grasses, and trees. Explain how these organisms,

        through photosynthesis, produce energy-rich compounds.
        - Producers Example: Display images of a sunflower, a pine tree, and algae. Explain that these organisms produce their own food through photosynthesis, converting sunlight into energy.
    - Consumers Example: Show pictures of various animals, including herbivores, carnivores, and omnivores. Discuss their feeding habits and how they obtain energy by consuming other organisms.
        - Consumers Example: Present pictures of a rabbit (herbivore), a fox (carnivore), and a bear (omnivore). Discuss how these animals obtain energy by consuming other organisms.
    - Decomposers Example: Illustrate decomposers such as fungi and bacteria breaking down dead organic matter. Emphasize their crucial role in nutrient recycling.
        - Decomposers Example: Show visuals of fungi breaking down fallen leaves and bacteria decomposing organic matter. Describe how decomposers play a vital role in nutrient cycling.
- Word Wall: Create a word wall with the introduced vocabulary words. Include definitions and visual representations next to each term for reinforcement
    - Ecosystem:
        - Definition: A community of living organisms interacting with their non-living environment.
        - Visual: Display an image of a vibrant ecosystem with diverse flora and fauna.
    - Producer:
        - Definition: Organisms that produce their own food through photosynthesis.
            - Visual: Show a diagram of a plant with labeled parts involved in photosynthesis.
        - Consumer:
            - Definition: Organisms that obtain energy by consuming other organisms.
            - Visual: Display a food chain illustration, highlighting different consumers and their prey.
        - Decomposer:
            - Definition: Organisms that break down and recycle dead organic matter.

  - Visual: Showcase an image of fungi and bacteria working on decomposing plant material.
- Biodiversity:
  - Definition: The variety of life in a particular habitat or ecosystem.
  - Visual: Present a collage featuring a diverse range of species from different ecosystems.
- Trophic Level:
  - Definition: Each level in a food chain or food web representing a functional role in energy transfer.
  - Visual: Display a trophic pyramid, illustrating the hierarchical structure of energy flow.
- Discussion Questions:
  - How does the visual representation of diverse ecosystems help you understand the range of environments on Earth?
  - Can you identify specific producers, consumers, and decomposers in the visuals?
  - What adaptations do organisms in different ecosystems have to survive in their specific environments?
  - How does the interdependence of producers, consumers, and decomposers contribute to the overall balance of an ecosystem?
  - Discuss the importance of biodiversity in sustaining ecosystems.
  - Begin by revisiting the discussed concepts of ecosystems, producers, consumers, decomposers, biodiversity, and trophic levels. Emphasize that these concepts will guide their observations during the upcoming Ecosystem Scavenger Hunt.
- Roles in Ecosystems:
  - Engage students in a brief discussion about how the introduced vocabulary words relate to the school environment. Encourage them to brainstorm examples of producers (plants), consumers (animals), and decomposers they might encounter during the scavenger hunt.
- Importance of Observation:
  - Stress the significance of keen observation during the scavenger hunt. Remind students that this hands-on activity will allow them to directly apply

what they've learned in class and deepen their understanding of the roles each component plays in the ecosystem.

- Scavenger Hunt Ideas:
    - Identify Producers:
        - Task: Explore the school grounds to find and document at least three examples of plants or other organisms that are producers.
        - Science Notebook Log Entry: Sketch and describe each identified producer in your science notebook. Include details like leaf shape, color, and any observable adaptations.
    - Consumer Observations:
        - Task: Observe and record evidence of animal life, including insects, birds, or small mammals, and categorize them as consumers.
        - Science Notebook Log Entry: Draw and annotate the observed consumers, noting their behaviors and interactions with the environment. Consider how they obtain their food.
    - Decomposer Spotting:
        - Task: Look for signs of decomposers, such as mushrooms, fungi, or areas with decomposing plant material.
        - Science Notebook Log Entry: Take a photo or draw the decomposer you find. Describe its role in breaking down organic matter and how it contributes to nutrient recycling.
    - Biodiversity Inventory:
        - Task: Document at least five different species (plants, animals) and note their characteristics.
            - Science Notebook Log Entry: Create a biodiversity chart in your science notebook, listing each species, their characteristics, and potential interactions between them.
        - Trophic Level Exploration:
            - Task: Consider the food chain or web by identifying organisms at different trophic levels.
            - Science Notebook Log Entry: Illustrate a simplified food chain or web, placing the identified organisms in their respective trophic levels. Describe the flow of energy.

        - Abiotic Factor Investigation:
            - Task: Identify and record nonliving components such as rocks, soil, sunlight, or water features.
            - Science Notebook Log Entry: Create a section in your science notebook dedicated to abiotic factors. Sketch and describe each one, explaining its significance to the ecosystem.
- As we conclude today's exploration of ecosystems, let's reinforce the connections between the scavenger hunt tasks and the key vocabulary words we discussed earlier. Your journey through the school grounds mirrors the interactions we find in diverse ecosystems around the world.
    - Ecosystem: Think about how the living and nonliving components you identified come together to form a unique ecosystem within our school environment.
    - Producer, Consumer, Decomposer: Reflect on the organisms you encountered during the scavenger hunt. How did they fit into the roles of producers, consumers, or decomposers?
    - Biodiversity: Consider the variety of life you observed. How does biodiversity contribute to the resilience and health of an ecosystem?
    - Trophic Level: Did you notice any feeding relationships or interactions between different organisms that align with the concept of trophic levels?
- Encouraging Reflection in Science Notebooks:
    - Now, open your science notebooks and create a comprehensive log of your observations. Include sketches, labels, and any reflections you have about the relationships between different components.
        - Take this opportunity to jot down questions or curiosities that arose during the scavenger hunt. What aspects of the ecosystem intrigued you or left you wanting to learn more?
    - Discussion Points:
        - How did the scavenger hunt enhance your understanding of ecosystems and the roles of different organisms?
        - In what ways do your observations align with the vocabulary words we explored today?
        - Share one interesting discovery you made during the scavenger hunt and discuss its significance in

the context of ecosystems.
- How might your reflections in the science notebook contribute to your ongoing exploration of ecosystems?
- Remember, each observation you made today contributes to your growing knowledge as an ecosystem explorer. We'll continue this journey together, building on these foundations in our upcoming lessons.

Energy Flows (explore)

- Begin with are interactive activity to engage students' memories. Display images or keywords related to ecosystems, trophic levels, population dynamics, and biodiversity on the board or slides.
    - Prompt students to recall definitions, characteristics, or examples associated with each term.
    - Ecosystem:
        - Definition: A community of living organisms interacting with their non-living environment.
            - Real-World Example: Discuss a coral reef ecosystem, highlighting the diverse marine life (living organisms) and the surrounding ocean environment (non-living components).
    - Trophic Levels:
        - Definition: Each level in a food chain or food web representing a functional role in energy transfer.
            - Real-World Example: Explore a savanna ecosystem where grasses (producers) are eaten by zebras (primary consumers), which, in turn, are preyed upon by lions (secondary consumers). Discuss how energy flows through these trophic levels.
    - Population Dynamics:
        - Definition: The study of how populations change in size, density, and structure over time.
            - Real-World Example: Examine the population dynamics of a rabbit population in a meadow. Discuss factors such as birth rates, predation, and competition influencing population fluctuations.
    - Biodiversity:
        - Definition: The variety of life in a particular habitat or ecosystem.
            - Real-World Example: Explore the Amazon rainforest, known for its unparalleled biodiversity with a vast array of plant and animal species coexisting in a complex web of interactions.
    - Facilitate a discussion on how these concepts manifest in real-world scenarios. Ask questions such as:

- How does the diversity of life in the Amazon rainforest contribute to the resilience of that ecosystem?
- What happens to trophic levels when a new predator is introduced to an ecosystem?
  - Real-world Examples:
    - Share real-world examples or case studies related to ecosystems, trophic levels, population dynamics, and biodiversity. For instance:
      - Discuss the impact of invasive species on native populations and ecosystems.
      - Explore how population dynamics play a role in the conservation of endangered species.
- Group Reflection:
  - Have students discuss in small groups, reflecting on their understanding of these concepts. Encourage them to connect these concepts to the ecosystems they are about to explore in the EcoFlow Challenge.

- Explain how the EcoFlow Challenge will provide an opportunity to apply and deepen their understanding of these concepts in a dynamic and interactive setting.
  - Emphasize the importance of using the vocabulary words during the game discussions to enhance their ecological literacy.
  - Get students excited about the hands-on exploration of energy flows in ecosystems through the upcoming board game.
    - EcoFlow board game pieces
      - Design or print a visually appealing game board with distinct sections representing various ecosystems (e.g., forest, ocean, desert, urban area).
      - Label each section clearly and add visual elements to represent the unique features of each ecosystem.
    - Game Cards
      - Card 1 - "Algae Bloom in the River":
        - Scenario: A river experiences an algae bloom due to agricultural runoff. Discuss the effects on trophic levels and biodiversity. Move forward one space if you can propose a solution to mitigate the impact.
      - Card 2 - "Human-Wildlife Conflict":
        - Scenario: Urban expansion leads to increased human-wildlife conflicts. Discuss the consequences on trophic interactions and population dynamics. Move forward two spaces if you suggest strategies for coexistence.
      - Card 3 - "Oil Spill Disaster":
        - Scenario: An oil spill occurs in a coastal ecosystem.

Discuss the immediate and long-term impacts on trophic levels and biodiversity. Move forward one space if you propose effective cleanup measures.

- Card 4 - "Insect Outbreak":
  - Scenario: An insect outbreak affects a forest, causing defoliation. Discuss the repercussions on trophic interactions and population dynamics. Move forward two spaces if you suggest natural ways to control the outbreak.
- Card 5 - "Coral Bleaching Event":
  - Scenario: A coral bleaching event impacts a coral reef ecosystem. Discuss the consequences on trophic levels and biodiversity. Move forward one space if you propose actions to address climate change.
- Card 6 - "Overgrazing Challenge":
  - Scenario: Overgrazing by herbivores leads to vegetation loss in a grassland. Discuss the effects on trophic levels and population dynamics. Move forward two spaces if you propose sustainable grazing practices.
- Card 7 - "Pollinator Decline":
  - Scenario: Decline in pollinator populations affects a meadow ecosystem. Discuss the implications for trophic interactions and biodiversity. Move forward one space if you propose initiatives to support pollinator habitats.
- Card 8 - "Eutrophication Trouble":
  - Scenario: Eutrophication impacts a lake, causing oxygen depletion. Discuss the consequences on trophic levels and biodiversity. Move forward two spaces if you suggest methods to prevent eutrophication.
- Card 9 - "Land Degradation Challenge":
  - Scenario: Land degradation affects a steppe ecosystem. Discuss the impacts on trophic interactions and population dynamics. Move forward one space if you propose restoration strategies.
- Card 10 - "Climate Refugees":
  - Scenario: Climate change displaces species from their native habitats. Discuss how this migration influences trophic levels and biodiversity. Move forward two spaces if you suggest conservation corridors for climate-induced migrations.
- Card 11 - "Invasive Plant Species":
  - Scenario: An invasive plant species spreads rapidly in a

wetland. Discuss the effects on trophic interactions and biodiversity. Move forward one space if you propose methods to control invasive plants.

- Card 12 - "Fishing Quotas":
    - Scenario: Implementing fishing quotas to manage fish populations in a river. Discuss the effects on trophic levels and population dynamics. Move forward two spaces if you propose ways to enforce sustainable fishing practices.
- Card 13 - "Avalanche in the Mountains":
    - Scenario: An avalanche occurs in a mountain ecosystem, altering the landscape. Discuss the immediate and long-term effects on trophic levels and population dynamics. Move forward one space if you propose strategies for habitat recovery.
- Card 14 - "Forest Fire Management":
    - Scenario: Implementing controlled burns in a forest to manage vegetation. Discuss the effects on trophic interactions and biodiversity. Move forward two spaces if you suggest ways to balance fire management and ecological health.
- Card 15 - "Water Scarcity in the Wetlands":
    - Scenario: Water scarcity affects a wetland ecosystem. Discuss the consequences on trophic levels and biodiversity. Move forward one space if you propose water conservation measures.
- Card 16 - "Monoculture Challenges":
    - Scenario: Large-scale monoculture agriculture impacts a rural landscape. Discuss the effects on trophic interactions and population dynamics. Move forward two spaces if you propose sustainable farming practices.
- Card 17 - "Noise Pollution in Urban Areas":
    - Scenario: Increased noise pollution in urban areas affects wildlife behavior. Discuss the consequences on trophic levels and biodiversity. Move forward one space if you propose ways to mitigate noise pollution.
- Card 18 - "Migratory Bird Habitat Loss":
    - Scenario: Loss of habitat disrupts migratory bird patterns. Discuss the impacts on trophic interactions and population dynamics. Move forward two spaces if you propose initiatives to protect migratory bird habitats.
- Card 19 - "Wildfire Resilience Planning":

        - Scenario: Implementing wildfire resilience plans in a chaparral ecosystem. Discuss the effects on trophic levels and biodiversity. Move forward one space if you suggest community-based strategies for wildfire resilience.
    - Card 20 - "Insect Pollination Importance":
        - Scenario: Emphasizing the importance of insect pollination in an agricultural setting. Discuss the consequences on trophic interactions and biodiversity. Move forward two spaces if you propose initiatives to support pollinator populations.
    - Card 21 - "Sea Level Rise Impact":
        - Scenario: Sea level rise affects coastal ecosystems. Discuss the implications for trophic levels and population dynamics. Move forward one space if you propose adaptation strategies for coastal communities.
    - Card 22 - "Habitat Fragmentation":
        - Scenario: Increased habitat fragmentation in a forest ecosystem. Discuss the effects on trophic interactions and biodiversity. Move forward two spaces if you propose methods to connect fragmented habitats.
    - Card 23 - "Air Quality Index Concerns":
        - Scenario: High air pollution levels in an urban environment. Discuss the consequences on trophic levels and biodiversity. Move forward one space if you propose measures to improve air quality.
    - Card 24 - "Waste Management Challenge":
        - Scenario: Implementing effective waste management in a riverine ecosystem. Discuss the effects on trophic interactions and population dynamics. Move forward two spaces if you propose sustainable waste disposal practices.
    - Card 25 - "Snow Leopard Conservation":
        - Scenario: Implementing conservation efforts for snow leopards in a mountainous region. Discuss the impacts on trophic levels and biodiversity. Move forward one space if you propose community-based initiatives for snow leopard conservation.
  - Prepare tokens or markers for each student or group participating in the EcoFlow Challenge. These will be used to move along the game board.
- Place the game board in a central location where all small groups can gather.
- Distribute tokens or markers and science notebooks to each small group.

- Organize students into small groups, each consisting of multiple teams.
  - Within each small group, designate roles such as team captain, recorder, and spokesperson.
- Rules Overview:
  - Explain the objective of the EcoFlow Challenge: to navigate through different ecosystems, draw game cards, and engage in discussions related to energy flows.
  - Emphasize the importance of using the vocabulary words during the game discussions to enhance ecological literacy.
  - Teams within each small group take turns moving along the game board. Roll a dice or use a spinner to determine the number of spaces to move.
  - At each ecosystem, draw a game card and read the scenario aloud.
  - Teams discuss the scenario within their science notebooks, considering the impact on trophic levels, population dynamics, and biodiversity.
  - The recorder jots down key points in the science notebook.
  - Announcing Responses:
    - After discussion, each team announces their responses to the small group.
    - The small group, led by the team captain, confirms or denies the responses based on their own understanding and knowledge.
    - Encourage teams to share their reasoning and engage in a brief discussion within the small group.
  - Token and Scoring:
    - Assign point values to each game card based on the complexity of the scenario (e.g., 1 to 3 points).
    - Award tokens to teams for successful navigation through challenges and providing thoughtful contributions during discussions.
    - Keep track of points on a designated scoring sheet for each small group.
  - Discussion Questions During Gameplay:
    - Ecosystem Dynamics:
      - How does the introduced challenge impact the balance of the ecosystem?
      - What trophic levels are most affected, and why?
    - Population Interactions:
      - How do changes in population dynamics influence the overall ecosystem?
      - What strategies can organisms adopt to cope with

population shifts?
- Biodiversity Considerations:
  - In what ways does the scenario affect biodiversity within the ecosystem?
  - How can biodiversity be crucial for the ecosystem's resilience?
- Human Impact:
  - How do human activities contribute to the challenges faced by the ecosystem?
  - What sustainable practices can mitigate the negative effects of human impact?
- Adaptations and Resilience:
  - What adaptations might organisms exhibit to navigate the introduced challenge?
  - How can ecosystems demonstrate resilience in the face of environmental changes?

- Reflection and Conclusions:
  - Gather small groups for a reflective discussion after completing the EcoFlow Challenge.
  - Encourage teams to share their overall strategies, challenges faced, and successful navigation techniques.
  - Discuss how the game reflected real-world scenarios and the interconnected nature of ecosystems.
  - Ask students to reflect on their evolving understanding of trophic levels, population dynamics, and biodiversity.
- Consider the following concluding questions:
  - What Insights Did You Gain?
  - Ask students to share key insights they gained about energy flows in ecosystems and how challenges impact ecological dynamics.
- Connections to Real-World Ecology:
  - Discuss how the game scenarios mirror real-world ecological challenges. How do human activities influence ecosystems?
- Collaboration and Communication:
  - Highlight the importance of collaboration and effective communication within small groups. How did teamwork contribute to successful navigation?
- Strategies for Ecosystem Health:
  - Discuss strategies proposed by teams to address challenges. How can these strategies contribute to maintaining the health of ecosystems?
- Further Exploration:
  - Invite students to identify areas for further exploration and research related to energy flows in ecosystems. What questions or topics

sparked their interest?

- Conclusion:
    - Conclude the EcoFlow Challenge by acknowledging each small group's efforts and contributions.
    - Emphasize the interconnectedness of ecological concepts and the importance of considering multiple factors in understanding energy flows.
    - Reinforce the relevance of vocabulary words learned during the game to real-world ecological scenarios.
    - Encourage students to carry their newfound understanding of ecosystems into future science explorations and discussions.
    - Express enthusiasm for their engagement and thoughtful contributions throughout the EcoFlow Challenge, fostering a sense of accomplishment and ecological awareness.

Energy Flows (explain)

- Begin by creating an engaging atmosphere, perhaps with a brief energizer to capture students' attention.
    - Recap the EcoFlow Challenge, emphasizing its interactive nature and the exploration of various ecosystems.
    - Highlight key aspects such as:
        - Different Ecosystems: Mention the diversity of ecosystems explored during the game, ranging from forests and deserts to oceans and grasslands.
        - Challenges Faced: Discuss some notable challenges or scenarios presented in the game. Remind students of the decisions and discussions they engaged in to overcome these challenges.
        - Vocabulary Used: Revisit specific vocabulary words introduced in the game, including terms like trophic levels, biodiversity, and population dynamics.
    - Review Key Concepts:
        - Transition into a focused review of key ecological concepts covered in the EcoFlow Challenge.
        - Trophic Levels:
            - Remind students of the concept of trophic levels, representing the positions that organisms occupy in a food chain or food web.
                - Use visual aids like a pyramid to illustrate the hierarchy of producers, consumers, and decomposers.
                - Draw the Pyramid:
                    - Begin by drawing a large triangle or pyramid shape in the center of the whiteboard. This pyramid will represent the energy pyramid in an

ecosystem.

- Label Each Level:
    - Divide the pyramid into three horizontal levels to represent trophic levels.
    - At the base of the pyramid, write "Producers" as the first trophic level.
    - In the middle section, label it as "Primary Consumers" to represent the second trophic level.
    - At the top of the pyramid, write "Secondary Consumers" and "Tertiary Consumers" to illustrate higher trophic levels.
        - Optionally, add a fourth level labeled "Quaternary Consumers" if you want to emphasize additional trophic levels.
- Add Organisms:
- Within each trophic level, draw or list examples of organisms commonly found in ecosystems.
    - Producers (First Trophic Level):
        - Examples: Plants, algae, and other autotrophic organisms.
        - Draw or represent these organisms at the base of the pyramid.
    - Consumers (Second, Third, etc., Trophic Levels):
        - Examples: Herbivores (primary consumers), carnivores (secondary consumers), and top predators (tertiary and quaternary consumers).
        - Add these organisms in ascending order, moving towards the top of the pyramid.
- Arrows for Energy Flow:
    - Use arrows to depict the flow of energy through the trophic levels. Arrows should point from lower levels to higher levels, indicating the direction of energy transfer.
    - For instance, draw arrows from producers to primary consumers, then from primary consumers to secondary consumers, and so on.

- Include Decomposers:
  - Beside or below the pyramid, include a section for decomposers.
    - Examples: Bacteria, fungi, and other decomposing organisms.
    - Emphasize their crucial role in breaking down organic matter and recycling nutrients back into the ecosystem.
- Color Coding (Optional):
  - Optionally, use color coding to distinguish between different trophic levels. For example, color producers in green, primary consumers in yellow, secondary consumers in orange, and so on.

- Brief Explanation:
  - As you draw the pyramid, provide a brief explanation of each trophic level and the role of organisms within it.
  - Emphasize that energy is transferred from lower to higher trophic levels, and mention the importance of maintaining balance for a healthy ecosystem.
- Engage in Discussion:
  - Encourage students to ask questions and engage in a discussion about the depicted energy pyramid.
  - Discuss the implications of disruptions in the pyramid, such as the impact of changes in producer populations on higher trophic levels.
  - Explain to students that they will participate in a simulation called "EcoVille Dynamics," where they will represent different components of an ecosystem
  - Distribute small cards with roles (producers, consumers, decomposers) to each student. Clearly explain the roles and their functions within an ecosystem
  - Card Examples:
    - Producer Card:
      - Role: Plant/Producer
      - Function: Converts sunlight into energy through photosynthesis.
      - Action: Stand in an open area, representing a meadow or forest.
    - Herbivore Card:
      - Role: Herbivore/Consumer

    - Function: Consumes plants for energy.
    - Action: Move towards producers and interact by exchanging cards to represent herbivores feeding.
  - Carnivore Card:
    - Role: Carnivore/Consumer
    - Function: Consumes herbivores for energy.
    - Action: Move towards herbivores and interact by exchanging cards to represent carnivores hunting.
  - Decomposer Card:
    - Role: Decomposer
    - Function: Breaks down dead organisms and recycles nutrients.
    - Action: Collect cards from "dead" organisms and return them to the facilitator.
  - Immigration Card:
    - Role: Immigrant
    - Function: Represents individuals moving into EcoVille.
    - Action: Trade places with another student to simulate immigration.
  - Emigration Card:
    - Role: Emigrant
    - Function: Represents individuals leaving EcoVille.
    - Action: Move to a different part of the simulation area to simulate emigration.
  - Birth Card:
    - Role: New Offspring
    - Function: Represents the birth of new individuals.
    - Action: Exchange cards with another student to simulate the birth of offspring.
  - Death Card:
    - Role: Deceased Organism
    - Function: Represents the death of individuals.
    - Action: Return your card to the facilitator to simulate death.
- Instructions for Facilitator:

- Distribute one card to each student at the beginning of the simulation, assigning them their ecological role.
    - Role Explanation:
        - Briefly explain the role and function of each card to ensure students understand their ecological role within EcoVille.
    - Action Execution:
        - Instruct students to execute the actions described on their cards during each simulation round, responding to factors like births, deaths, immigration, and emigration.
- Round 1 - Establish Baseline:
    - Allow students to move freely within EcoVille for a few minutes, representing the natural state of the ecosystem.
    - Encourage them to interact according to their roles (e.g., consumers seeking producers).
- Round 1 Distribution:
    - Distribute the Round 1 cards (Producer, Herbivore, Carnivore, Decomposer) to each student at the beginning of the simulation.
    - Role Explanation:
        - Briefly explain the role and function of each card to ensure students understand their ecological role within EcoVille.
    - Discussion Questions:
        - Observe the initial interactions. How are producers, herbivores, carnivores, and decomposers interacting in EcoVille?
        - What roles seem to be essential for the basic functioning of the ecosystem in this initial round?
        - After the initial round, introduce factors like "births," "deaths," "immigration," and "emigration." Assign a specific action or movement for each factor.
            - For example, births could involve students exchanging cards to represent offspring, and deaths might involve students returning their cards to you.

- Run Simulation Rounds:
    - Run multiple rounds of the simulation, gradually introducing changes in birth rates, death rates, immigration, and emigration. Use a stopwatch to control the duration of each round.
- Observe Population Changes:
    - After each round, discuss how the population dynamics within EcoVille changed. Emphasize the effects of various factors on different roles.
- Simulation Rounds and Discussion Questions:
    - Round 1: Establish Baseline
        - Discussion Questions:
        - Observe the initial interactions. How are producers, herbivores, carnivores, and decomposers interacting in EcoVille?
        - What roles seem to be essential for the basic functioning of the ecosystem in this initial round?
    - Round 2: Introduce Births and Deaths
        - Simulation Actions:
            - Births: Students with Birth cards exchange cards to represent the birth of new individuals.
            - Deaths: Students with Death cards return their cards to the facilitator to simulate the death of individuals.
        - Discussion Questions:
            - How did the introduction of births and deaths affect the population dynamics within EcoVille?
                - Which roles experienced changes, and how did these changes influence the ecosystem?
    - Round 3: Introduce Immigration and Emigration
        - Simulation Actions:
            - Immigration: Students with Immigration cards trade places with another student to simulate immigration.
            - Emigration: Students with Emigration cards move to a different

part of the simulation area to simulate emigration.

- Discussion Questions:
    - Discuss the impact of immigration and emigration on the distribution of roles within EcoVille.
    - How did the movement of individuals influence the overall ecosystem dynamics?
- Round 4: Combine Factors
    - Simulation Actions:
        - Combine actions from previous rounds, introducing births, deaths, immigration, and emigration simultaneously.
    - Discussion Questions:
        - Observe the combined effects of multiple factors. How do births, deaths, immigration, and emigration interact within EcoVille?
        - Discuss any unexpected or emergent patterns in population dynamics.
- Additional Examples for Discussion:
    - Extreme Birth Rates: What happens if the birth rate is significantly higher than the death rate? How might this impact the balance of roles?
    - Isolation: What if a group of individuals becomes isolated due to emigration? How does this affect their roles and the overall ecosystem?
    - Limited Resources: Imagine a scenario where resources (represented by cards) become limited. How do different roles compete, and what adaptations might occur?
    - Environmental Changes: Introduce an environmental change, such as a simulated drought (limited water represented by cards). How do roles respond to environmental stress?
    - Human Impact: Discuss the concept of

human impact by introducing external disruptions like pollution or habitat destruction. How do these factors affect the simulated ecosystem?
        - Shift the focus to biodiversity by discussing how different species contribute to the overall health and resilience of EcoVille.
        - Diverse Ecosystems:
            - Allow students to adjust their roles to represent a more diverse ecosystem. Emphasize that a variety of species contributes to the overall stability of the environment.
    - Run Additional Rounds:
        - Run simulation rounds with an increased emphasis on biodiversity. Discuss how the introduction of more species influences population dynamics and ecosystem health.
    - Reflect on Simulation: - Gather students for an interactive discussion using open-ended questions: - How did the population dynamics change in different rounds? - Why is biodiversity crucial for the resilience of EcoVille? - Can you relate any challenges from the simulation to real-world ecosystems?
    - Connect to EcoFlow Challenge:
        - Relate insights from the simulation to challenges faced in the EcoFlow Challenge. Discuss parallels between the game and real-world ecological scenarios.
    - Using the whiteboard to create a visual recap. Draw diagrams representing population dynamics and biodiversity based on the simulation.
    - Encourage students to recall specific scenarios or decisions made during the simulation related to trophic levels, population dynamics, or biodiversity.
- Conclusion:
    - Conclude by reinforcing key concepts and their relevance to understanding ecosystems. Highlight the interconnected nature of population dynamics and

biodiversity.

Energy Flows (elaborate)

- Begin by asking students what comes to mind when they hear the word "ecosystem." Encourage them to share their thoughts and experiences related to ecosystems.
    - Define Ecosystem:
        - Provide a working definition of an ecosystem. Example: "An ecosystem is a community of living organisms interacting with each other and their physical environment."
        - Recap essential concepts related to ecosystems:
            - Trophic Levels: Discuss the hierarchy of trophic levels, including producers, consumers, and decomposers.
            - Energy Flow: Explain how energy moves through the ecosystem, starting from producers capturing sunlight through photosynthesis.
            - Biodiversity: Emphasize the importance of biodiversity, representing the variety of species within an ecosystem.
            - Interactive Questions:
        - Pose questions to stimulate discussion:
            - Why is understanding trophic levels crucial for comprehending how energy moves within an ecosystem?
            - How does biodiversity contribute to the resilience and stability of an ecosystem?
            - Can you think of an example of a trophic interaction in a specific ecosystem?
        - Real-World Examples:
            - Share real-world examples or anecdotes related to ecosystems to make the concepts more tangible. Discuss famous ecosystems or ecological events.
        - Vocabulary Introduction:
            - Introduce or review key vocabulary terms on the Word Wall:
                - Ecosystem
              - Trophic Levels
              - Energy Flow
              - Biodiversity
              - Application:
                - Discuss how these vocabulary terms connect to the concepts covered. For example, how trophic levels contribute to the energy flow or how biodiversity enhances ecosystem health.
              - Student Contributions:

- Encourage students to share their perspectives, ask questions, or provide examples from their own observations or experiences.

- Activity Explanation:
  - Introduce the "Model Ecosystems" activity. Explain that students will work in groups to design and create models representing different ecosystems.
    - Organize students into small groups, ensuring a mix of skills and strengths in each group. Consider diverse groupings to encourage collaboration.
      - Model Creation (60 minutes): 3. Group Formation:
      - Organize students into small groups, ensuring a mix of skills and strengths in each group.
      - Ecosystem Assignment:
      - Assign each group a specific ecosystem (e.g., forest, desert, ocean) or allow them to choose from a list. Provide reference materials to help them understand the characteristics of their assigned ecosystem.
        - 1. Forest Ecosystem:
          - Characteristics:
          - Dense vegetation, diverse tree species, canopy layers.
          - Abundant wildlife including mammals, birds, and insects.
          - Decomposition of organic matter on the forest floor.
          - Reference Materials:
            - National Geographic - Forest Biome
            - Books or articles on temperate and tropical forests.
            - Images of different forest layers.
            - Information on common flora and fauna in forest ecosystems.
        - 2. Desert Ecosystem:
          - Characteristics:
          - Arid climate, limited precipitation.
          - Adapted flora and fauna with water-conserving features.
          - Unique adaptations for temperature extremes.
            - Reference Materials:
              - World Wildlife Fund - Deserts
              - Desert ecology books or articles.

        - Diagrams explaining water conservation in plants.
        - Examples of desert animal adaptations.
- 3. Ocean Ecosystem:
    - Characteristics:
    - Vast marine environments with varying depths.
    - Diverse marine life including fish, mammals, and invertebrates.
    - Ocean currents influencing biodiversity.
    - Reference Materials:
        - Ocean Explorer - NOAA
        - Oceanography books or online resources.
        - Diagrams of ocean zones and currents.
        - Information on marine food webs.
- 4. Grassland Ecosystem:
    - Characteristics:
    - Open landscapes with grasses and scattered trees.
    - Herbivores and carnivores coexisting.
    - Frequent fires influencing vegetation.
    - Reference Materials:
        - World Wildlife Fund - Grasslands
        - Books or articles on grassland ecosystems.
        - Images depicting grassland biodiversity.
        - Information on fire ecology in grasslands.
- 5. Coral Reef Ecosystem:
    - Characteristics:
    - Underwater ecosystems with diverse coral formations.
    - High biodiversity including fish, invertebrates, and coral species.
    - Symbiotic relationships among organisms.
    - Reference Materials:
        - Coral Reef Alliance
        - Coral reef ecology books or

documentaries.
        - Diagrams of coral polyp anatomy.
        - Information on threats to coral reefs.
- 6. Tundra Ecosystem:
    - Characteristics:
    - Cold and treeless landscapes with permafrost.
    - Adapted flora and fauna to extreme cold.
    - Short growing season for vegetation.
    - Reference Materials:
        - Arctic Tundra - WWF
        - Tundra ecology books or articles.
        - Images of tundra landscapes and wildlife.
        - Information on permafrost and its impact.
- 7. Urban Ecosystem:
    - Characteristics:
    - Human-made environments with buildings, roads, and parks.
    - Altered habitats supporting diverse urban wildlife.
    - Influence of human activities on biodiversity.
    - Reference Materials:
        - National Geographic - Urban Ecology
        - Urban ecology resources.
        - Diagrams illustrating urban wildlife interactions.
        - Information on green spaces in urban environments.

- Model Design:
    - Instruct students to design and create a three-dimensional model of their assigned ecosystem using the provided art supplies. Encourage creativity and attention to detail.
- Materials Preparation:
    - Gather the provided art supplies, including paper, cardboard, markers, glue, and scissors.
- Ecosystem Selection:
    - Remind each group of their assigned ecosystem

(e.g., forest, desert, ocean). Ensure they have their reference materials on hand.

- Brainstorming Session:
    - Initiate a brief group discussion on the key features of their assigned ecosystem. Encourage students to share ideas on how to represent these features in their models.
- Concept Sketching:
    - Before diving into the actual model creation, have each group sketch a rough concept of their ecosystem model on a piece of paper. This should include major elements such as terrain, flora, and potential locations for different trophic levels.
- Choosing Materials:
    - Based on their concept sketches, guide students in selecting appropriate materials for different elements of their ecosystem. Discuss the use of colors, textures, and shapes to represent features accurately.
- Building the Terrain:
    - Start with the base layer, representing the ground or seabed of the ecosystem. Use cardboard or paper to create the foundational terrain. For example, if it's a forest, consider adding uneven surfaces to mimic the forest floor.
- Flora Representation:
    - Integrate plant life into the model. Use construction paper or other materials to craft trees, bushes, or underwater vegetation based on the characteristics of their assigned ecosystem.
- Fauna Placement:
    - Position animal representations (figures, drawings, or crafted models) within the ecosystem. Place them according to their trophic levels. For instance, predators might be near the top, while herbivores and decomposers are strategically located.
- Attention to Detail:

- Encourage students to pay attention to small details. Add features such as rocks, logs, or coral formations based on the specific characteristics of their ecosystem.
- Collaboration and Creativity:
    - Emphasize the importance of collaboration within the group. Encourage creative discussions on how to make their model both accurate and visually appealing.
- Labeling Trophic Levels Instructions:
    - Introduction to Trophic Levels:
    - Begin by revisiting the concept of trophic levels. Remind students of the roles of producers, consumers, and decomposers within an ecosystem.
- Identification Exercise:
    - Before labeling their model, conduct a quick identification exercise. Ask students to point out elements in their model that represent producers, consumers, and decomposers. Discuss their choices as a group.
- Clear Labeling:
    - Provide labels for each trophic level (e.g., "Producer," "Primary Consumer," "Decomposer"). Instruct students to place these labels strategically within their model, ensuring clarity and visibility.
- Discuss Placement and Roles:
    - Facilitate a group discussion on the placement of trophic levels. For example, discuss why certain animals or plants are positioned where they are based on their roles in the ecosystem.
    - Use of Arrows or Lines:
    - Consider using arrows or lines to visually represent the flow of energy between trophic levels. This can help convey the concept of energy transfer more effectively.
    - Attention to Detail:
        - Encourage students to be precise in their labeling. Discuss the

importance of accuracy in representing the ecosystem's structure and trophic interactions.

- Review and Adjust:
    - After labeling, review the entire model as a group. Ask each group to explain their choices in labeling and make adjustments if needed.

- Incorporate Trophic Level Discussions:
    - As students label their models, engage them in discussions about the trophic interactions within their ecosystem. Encourage them to explain the relationships between producers, consumers, and decomposers based on their model.
        - Begin by revisiting key vocabulary terms related to ecosystems. Ask students to recall and define terms such as trophic levels, producers, consumers, and decomposers.
        - Engage students in an interactive discussion about the importance of these terms in understanding ecosystem dynamics. Pose questions like:
            - How do trophic levels contribute to the balance of an ecosystem?
            - Why are producers essential for energy flow in ecosystems?
            - Discuss the roles of consumers and decomposers in maintaining biodiversity.
    - Presentation Structure:
        - Guide students on how to structure their presentations. Discuss the importance of starting with a brief explanation of their model's overall concept and the chosen ecosystem.
            - Highlight Key Features:
                - Emphasize the significance of highlighting key features in their presentations. Encourage students to point out specific elements in their models that represent trophic levels, energy flow, and notable adaptations.
            - Connection to Vocabulary:

            - Remind students to consciously connect their presented information to relevant vocabulary terms. For example, when discussing a predator-prey interaction, ask them to use the terms "predator" and "prey" in their explanations.
        - Visual Aids:
            - Discuss the effective use of visual aids, such as the whiteboard, to illustrate trophic levels and energy flow. Encourage students to draw arrows or diagrams that represent the movement of energy within their ecosystems.
- Allow each group to present their model to the class. Encourage students to use the whiteboard to illustrate trophic levels, energy flow, and any unique adaptations or interactions within their ecosystems.
- Foster an interactive Q&A session after each presentation. Encourage classmates to ask questions about specific features or trophic interactions. This promotes engagement and deeper understanding.
    - Pose discussion questions to the class:
        - What stood out to you in the presentations regarding energy flow and trophic interactions?
        - Did any group showcase a particularly interesting adaptation or interaction?
        - How did the use of vocabulary terms enhance your understanding during the presentations?
- Individual Reflection:
    - Conclude the lesson with a brief reflection. Ask students to individually reflect on what they learned from both creating and observing the models.
- Challenges and Solutions Discussion:
    - Engage the class in a discussion about any challenges faced during the activity and the solutions discovered. Encourage students to share strategies used to overcome difficulties.

- Connection to Real-world Ecosystems:
    - Discuss how the lessons learned from this activity can be applied to real-world ecosystems. Encourage students to draw parallels between their models and actual ecological scenarios.