POLAR TREC
Learning Resources

Details

- Arctic
- About a week (On-going)
- Download, Share, and Remix
- High School and Up

Using the IMOLD Interactive Model of Leaf Decomposition

Materials

- Computers, one per student is ideal, but the lesson can be done with fewer.
- Guided notes for each of the three animations, including student worksheets and answer keys.
- Lesson Plan for using the Interactive Model on the website.

Overview

IMOLD is a highly interactive website designed by Drs. Michael N. Weintraub and Daryl L. Moorhead in collaboration with the Center for Creative Instruction at the University of Toledo. Susan Steiner, PolarTREC teacher with Dr. Weintraub on the expedition, Tundra Nutrient Seasonality, collaborated on IMOLD's design. Other teachers have contributed wonderful classroom activities that can be found posted on the website. In this four part lesson, students learn from animations that teach them about the carbon cycle, leaf anatomy, and microbes, all in the context of plant litter decomposition. Students then apply their knowledge in a model of decomposition that uses real data that students can manipulate as they pose and answer questions about variables that affect rates of decomposition.

Objectives

Students will gain a better understanding of carbon cycling, especially in the context of litter decomposition. Students can manipulate climate types and litter types in the interactive model, and apply concepts they have learned about carbon cycling. Students will understand that studying the decomposition part of the carbon cycle is important for understanding factors that affect climate change.

Lessons Preparation

Students should have background knowledge of basic chemistry, as well as familiarity with biological processes such as photosynthesis and respiration. This lesson is perfect for inclusion in a unit about climate change, biogeochemical cycling, or ecology. The animations can be used for understanding topics such as microbes and enzymes or leaf anatomy in a different context than is normally covered in high school science classes.

Procedure

Students will view, take notes on and respond to the questions accompanying the three animations. Upon completion, they are ready to work with the interactive model. Part Four leads the students to ask testable questions and carry out their own investigation using the model.

Extension

Students can pursue further research about the litter materials and ecosystems used in the interactive model. From the Litter tab on the model page, information about each species of litter is provided with links to the climate range and growing information about each plant. Students can use this information to learn about different biomes and their key indicator plants. Additionally, the IMOLD site includes a variety of teacher submitted lab and classroom activities.

Resources

The Long-Term Inter-site Decomposition Experiment Team (LIDET) at:
http://andrewsforest.oregonstate.edu/research/intersite/lidet.htm

The Greenhouse Effect:
http://scied.ucar.edu/longcontent/greenhouse-effect

UCAR Center for Science Education

Assessment

Students will have completed the guided notes corresponding to the animations. Additionally, they will have completed an investigation using the interactive model and presented their findings through the medium of their choice.

Author/Credits

Lesson created by PolarTREC Teacher Susan Steiner at: ssteiner76@hotmail.com

The IMOLD Interactive Model of Leaf Decomposition is authored by Drs. Michael N. Weintraub and Daryl L. Moorhead in collaboration with the Center for Creative Instruction at the University of Toledo.

Many thanks go to Dr. Michael Weintraub of the University of Toledo for giving me the opportunity to provide input on the IMOLD project. I also so appreciate the work of Graduate Research Fellow Mallory Ladd at Oak Ridge National Laboratory. She worked with the Tundra Nutrient Seasonality Project at Toolik Field Station. Mallory's chemistry work inspired my lesson plan, as I learned firsthand how chemistry comes alive in the context of climate change fieldwork. Her assistance with the details is much appreciated!

Files

Lesson Plan
Animated Lessons from IMOLD http://imold.utoledo.edu/
Part One: The Carbon Cycle, Student Copy and Teacher Copy
Part Two: Leaf Anatomy, Student Copy and Teacher Copy
Part Three: Microbes and Enzymes, Student Copy and Teacher Copy
Part Four: Interactive Leaf Decomposition Activity

Standards

See PDF of applicable NGSS standards.

LESSON PLAN: **ANIMATED** LESSONS FROM I-MOLD
Part One: The Carbon Cycle http://imold.utoledo.edu/carbon.html

STUDENT WORKSHEET

Suggested vocabulary words/phrases:
atomic number, mass number, element symbol, greenhouse effect, climate, carbon cycle, photosynthesis, respiration, plant litter, decompose and decomposition, soil organic matter, global carbon cycle, land use change, greenhouse gas emissions, reservoir, infrared radiation, positive feedback loop

Turn on the captions. This will help you to slow down and pause the animation as needed to take notes and fill in the blanks in the following section.

I. Carbon, the Element
Pause as the animation begins: "Carbon is one of the most important elements on Earth"

1. What is the square that is pictured called?

2. Copy the symbol and label each bit of information given here (atomic number, atomic mass, element symbol, and name)

Resume the animation, answering the following questions as it runs:

3. What element is an important component of all living things?

4. Besides living things, what other things is carbon found in?

5. What gas made from Carbon plays an important role in regulating climate?

6. "Biological activity causes carbon to be constantly ____________ among different _____and________. These movements of carbon are referred to as the ________ ________."

II. The Carbon Cycle

1. Pause the animation at this point (~:27), and draw the Carbon cycle depicted here. Fill in the labels as you learn the material.

LESSON PLAN: **ANIMATED** LESSONS FROM I-MOLD

Part One: The Carbon Cycle http://imold.utoledo.edu/carbon.html

2. Once you have drawn and labeled the Carbon cycle, study it for a minute or two to familiarize yourself with it. Think about such things as: Where does the Oxygen in the cycle come from? What are two pathways transforming the Carbon Dioxide? Write several sentences in the space below to answer these questions.

3. "The Global Carbon Cycle describes the __________of carbon between the atmosphere, __________ __________, _____and_______ ______, ______and______ ______. These exchanges are continually changing and ___ in perfect balance. ______ activities are converting___, ____, _______ ____, ____________________ _________ into ______ ________."

4. Describe the changes that have occurred in the images from the green field and mountains to the end image (at ~:55 seconds).

5. Using your resources, define the greenhouse effect and why it is a concern. An excellent reference resource for this information can be found at: "The Greenhouse Effect" **http://www.ucar.edu/learn/1_3_1.htm**

LESSON PLAN: **ANIMATED** LESSONS FROM I-MOLD
Part One: The Carbon Cycle http://imold.utoledo.edu/carbon.html

III. Atmospheric Carbon

1. "The atmosphere is a relatively small reservoir of carbon, containing less than ___ of the Earth's total carbon pool".
2. Write down or draw and label the analogy of the pool and glass of water and how it models the effect of increased atmospheric carbon dioxide.
3. The amount of carbon in terrestrial vegetation is __________to the amount of carbon in the atmosphere. Vegetation takes CO_2 out of the atmosphere through______________.

   What is the equation for photosynthesis? You may use words or symbols.

4. What do you notice about the two arrows in the image and what do they tell you?

IV. Carbon Dioxide cycling

1. What happens to the CO_2 that plants are able to use? Ultimately, where does it wind up and how does that happen?
2. How does carbon end up accumulating in soil carbon pools?
3. "Within the ____, there is more than _____as much carbon locked up in organic material than there is carbon in the__________".
4. What are two examples of human activities that accelerate the conversion of soil carbon to CO_2?
5. Give an example of land use change due to human activities, besides the example given here.

V. So What? Why is this important?

1. Explain the important role of carbon dioxide as a major greenhouse gas. Describe the process of how heat is retained by this gas using the words radiation, infrared radiation, absorb, and re-emit. You may draw and label a diagram if you wish.

2. What is the significance of the arrows in the drawing of this occurrence?

3. "This leads to _________temperatures in the _____ atmosphere, which in turn can ________the rate of decomposition, which _______ ________the amount of___." This creates a magnifying cycle of increased warming and increased atmospheric circulation. This is an example of a ________feedback loop.

As you review what you have learned, what can affect the balance of the overall exchanges of carbon? In a short paragraph, summarize what you have learned from this animation.

*During this presentation, what has the thermometer done? (beginning at time 2:33)

LESSON PLAN: **ANIMATED** LESSONS FROM I-MOLD
Part One: The Carbon Cycle http://imold.utoledo.edu/carbon.html

TEACHER LESSON KEY

The purpose of this lesson is to highlight the importance of the Carbon Cycle in the natural cycles of photosynthesis and respiration. It also models how human activity can alter the carbon cycle. The animation, which runs for 2:56 minutes total time, covers a large amount of information that students may or may not be familiar with. Here is one suggestion for working your students through the animation. By actively taking notes during the animations, students can engage in a dialogue with the model and better increase their understanding of the material. The instructions read as if each student has their own computer, but this can be modified for a whole class activity with one computer.

Suggested vocabulary words/phrases:
atomic number, mass number, element symbol, greenhouse effect, climate, carbon cycle, photosynthesis, respiration, plant litter, decompose and decomposition, soil organic matter, global carbon cycle, land use change, greenhouse gas emissions, reservoir, infrared radiation, positive feedback loop

Have the students turn on the captions. This will help address the different learning styles, and encourage them to slow down and pause the animation as needed to take notes and fill in the blanks in the following section.

I. Carbon , the Element

Pause as the animation begins: "Carbon is one of the most important elements on Earth"

1. What is the square that is pictured called?

   Element symbol

2. Copy the symbol and label each bit of information given here (atomic number, atomic mass, element symbol, and name)

   Atomic number: 6 **Atomic mass: 12.0107**

   Symbol: "C" **Name: Carbon**

Resume the animation, answering the following questions as it runs:

3. What element is an important component of all living things? **Carbon**
4. Besides living things, what other things is carbon found in?

   fuels that humans use for energy, food that humans

5. What gas made from Carbon plays an important role in regulating climate?
   CO_2 , Carbon Dioxide
6. "Biological activity causes carbon to be constantly **converted** among different **forms** and **locations**. These movements of carbon are referred to as the **carbon cycle**."

II. The Carbon Cycle

1. Pause the animation at this point (~:27), and draw the Carbon cycle depicted here. Fill in the labels as you learn the material. **Students should draw the picture; labeling trees, oxygen, plants and other living organisms, leaf section image, decomposing microbes, carbon dioxide, and the factory. They also should include the arrows.**

2. Once you have drawn and labeled the Carbon cycle, study it for a minute or two to familiarize yourself with it. Think about such things as: Where does the Oxygen in the cycle come from? What are two pathways transforming the Carbon Dioxide? Write several sentences in the space below to answer these questions.

The oxygen in the cycle comes from the photosynthesis process of plants, represented here by the trees. Fossil fuels, from once living material, burned in the factory results in CO_2 emissions. Oxygen is taken up by living things and as they live and decay they release CO_2 through the processes of respiration. These biological activities are constantly converting carbon in the cycle into different forms and locations.

3. The Global Carbon Cycle describes the **exchanges** of carbon between the atmosphere, **terrestrial vegetation**, **soils** and **organic matter**, **oceans** and **fossil fuels**. These exchanges are continually changing and **not** in perfect balance. **Human** activities are converting **oil, coal, natural gas, plant and soil organic carbon** into **carbon dioxide**.

4. Describe the changes that have occurred in the images from the green field and mountains to the end image (at ~:55 seconds).

The image of the meadows and mountains transforms with added images of clouds representing the atmosphere, trees representing terrestrial vegetation, soils and organic matter of the field, the blue water of an ocean, and roots and underground layers representing fossil fuels. Next, a car and road, house with landscaping and a swimming pool, a factory, and a tractor plowing the field are added to represent human activities which convert various forms of carbon into carbon dioxide, which is accumulating in the atmosphere, enhancing the greenhouse effect.

5. Using your resources, define the greenhouse effect and why it is a concern.

The greenhouse effect results from gases in the atmosphere trapping heat as it re-radiates off of Earth. This keeps Earth at a habitable temperature. However, too much greenhouse gas can cause the atmosphere to retain too much heat and get too warm. An excellent reference resource for this information can be found at The Greenhouse Effect, http://www.ucar.edu/learn/1_3_1.htm

III. Atmospheric Carbon

1. "The atmosphere is a relatively small reservoir of carbon, containing less than **1%** of the Earth's total carbon pool".

2. Write down or draw and label the analogy of the pool and glass of water and how it models the effect of increased atmospheric carbon dioxide.

For equal size portions of carbon, the added carbon makes a bigger difference in the glass of water than it does the larger swimming pool. This is analogous to the addition of CO_2 into the atmosphere; although it is a relatively small reservoir of carbon, a little extra added to it can make a significant difference.

3. The amount of carbon in terrestrial vegetation is **comparable** to the amount of carbon in the atmosphere. Vegetation takes CO_2 out of the atmosphere through **photosynthesis.**

What is the equation for photosynthesis? You may use words or symbols.

$6CO_2 + 6H_2O$ (with light)-------→ $C_6H_{12}O_6 + 6O_2$

Carbon dioxide plus water react (with light) to form sugars and oxygen.

4. What do you notice about the two arrows in the image and what do they tell you?

The arrow is larger for the emissions one…showing an imbalance of carbon dioxide emissions to the atmosphere due to human activity. This adds more carbon than plants can use, causing carbon in the atmosphere to increase.

IV. Carbon Dioxide cycling

1. What happens to the CO_2 that plants are able to use? Ultimately, where does it wind up and how does that happen? **It becomes new plant tissue which will die and fall to the ground, eventually to decompose or be transformed into soil organic matter. It can then be stored in the soil carbon pools.**

2. How does carbon end up accumulating in soil carbon pools? **It accumulates faster than it decomposes, adding to soil carbon pools.**

3. "Within the **soil**, there is more than **twice** as much carbon locked up in organic material than there is carbon in the **atmosphere**".

4. What are two examples of human activities that accelerate the conversion of soil carbon to CO_2? **Land use changes and greenhouse gas emissions.**

5. Give an example of land use change due to human activities, besides the example given here. **Deforestation**

V. So What? Why is this important?

1. Explain the important role of carbon dioxide as a major greenhouse gas. Describe the process of how heat is retained by this gas using the words radiation, infrared radiation, absorb, and re-emit. You may draw and label a diagram if you wish.

   Carbon dioxide in the atmosphere causes heat to be retained between the Earth and the atmosphere. Some radiation leaving the earth is trapped by the greenhouse gases, causing heat to be retained. The carbon dioxide radiates the escaping heat in all directions, including back down toward Earth.

2. What is the significance of the arrows in the drawing of this occurrence?

   The arrows show the direction of heat radiation.

3. "This leads to **increased** temperatures in the **lower** atmosphere, which in turn can **increase** the rate of decomposition, which **further increases** the amount of **CO_2**." This creates a magnifying cycle of increased warming and increased atmospheric circulation. This is an example of a **positive** feedback loop.

As you review what you have learned, what can affect the balance of the overall exchanges of carbon? In a short paragraph, summarize what you have learned from this animation.

Emissions from human activity including energy uses, releasing soil carbon from stored pools, and changes in decomposition rates are factors that can affect the balance of the overall exchanges of carbon.

Students might discuss the importance of carbon as a greenhouse gas, the effects of added human emissions due to energy uses, the effects of land use change on releasing soil carbon locked in the organic material, the natural flux of carbon among the different pools, the effect of adding excess carbon to the atmospheric pool of carbon, the effects of photosynthesis or respiration on the carbon cycle, or the important role of decomposition of plant material in the carbon cycle.

*During this animation, what has the thermometer done? (beginning at time 2:33)

It increased.

LESSON PLAN: ANIMATED LESSONS FROM I-MOLD
Part Two: **Leaf Anatomy** http://imold.utoledo.edu/anatomy.html

STUDENT WORKSHEET

Suggested vocabulary words/phrases. These are found in the context of the animation, and can be defined as the student works through the lesson.

decomposition, specialized cells, interstitial space, cell wall, intracellular, leached, extracellular, cellulose, hemicellulose, lignin, polymer, microbes (more information about them during their own animation), microfibril, phenol

Turn on the captions. This helps you to slow down and pause the animation as needed to take notes and answer the questions as you work through the animation.

I. Understanding plant litter decomposition by understanding leaf anatomy
    1. Look at the image of leaves drifting down from the trees. What does plant litter decomposition have to do with the carbon cycle?

    2. Why is it important to learn about the anatomy of a leaf?

    3. "Leaves are made of many __________ cells, which determine_____, ____, and________.

II. Leaf Anatomy
    1. Interstitial space. Where is interstitial space found in a leaf?

    2. What do you think is important about this space? (you will learn more about the role of the interstitial space in lesson 3, about Microbes)

III. Cell Wall
    1. What is the function of the cell wall? Where is it located? What happens to intracellular components after leaf fall?

    2. In the image of the plant cell, the thick grayish colored layer with multiple pathways represents the waxy cuticle on the outside of the leaf. Next is the cell wall. What is the layer inside the cell wall called?

    3. What is the main target of decomposition?

IV. Leaf image and anatomy
    1. Draw and label a representation of the images shown. Be sure to include the plasma membrane, hemicellulose, cellulose, lignin, and cell wall.

2. What are the three main components of the primary cell wall?

V. Cellulose

1. "Cellulose consists of sugars known as________. Each individual sugar molecule, the_______, is linked together, forming a long ______ _______." These long polymers _____ ________ to form a ____________________. Since cellulose consists of______, it is a high energy fuel. ________ attack it first in______________."

2. Draw the long linear polymer that groups together to form the crystalline structure of cellulose. What molecule is represented by each individual green colored sphere?

VI. Hemicellulose

1. What is hemicellulose? It is a ________ made of long chains of_____ _________, primarily xylose and arabinose. These are ____ _______ _____. Hemicellulose consists of short chains and has a ________ structure.

2. What does hemicellulose do? It encases the cellulose to form a ___________ and plays an important role in holding everything together. Roots of the word microfibril are: micro _____________, and fibril_____________,

3. Draw another cellulose polymer, and this time add the branched hemicellulose. What is this entire unit now called?

VII. Lignin

1. Lignin is a complex compound made of different kinds of______ ______ ___________, which are arranged in random patterns to form__________.

2. Lignin _________ the spaces between cellulose bundles. It is a___ ______ ______, which requires a ____of work (energy) to break down, and thus shields the high energy foods of cellulose and hemicellulose. You will learn more about lignin and how it is broken down in the Lesson 3, about Microbes.

VIII. SUMMARIZE

1. Pick up, or imagine, a decaying leaf and write a paragraph about the process of decomposition using the terms intracellular components, polymer, cellulose, glucose, hemicellulose, lignin, and energy

2. What questions does this information lead you to?

TEACHER LESSON KEY

Suggested vocabulary words/phrases. These are found in the context of the animation, and can be defined as the student works through the lesson.

decomposition, specialized cells, interstitial space, cell wall, intracellular, leached, extracellular, cellulose, hemicellulose, lignin, polymer, microbes (more information about them during their own animation), microfibril, phenol

Have the students turn on the captions. This helps address different learning styles, as well as encourages the student to slow down and pause the animation as needed to take notes and answer the questions as they work through the animation.

I. Understanding plant litter decomposition by understanding leaf anatomy

1. Look at the image of leaves drifting down from the trees. What does plant litter decomposition have to do with the carbon cycle?
   Decomposing plant litter adds carbon to the soil organic carbon pool.

2. Why is it important to learn about the anatomy of a leaf?
   It is important to learn about leaf anatomy to better understand the process of plant litter decomposition.

3. Leaves are made of many **specialized** cells, which determine **shape**, **size** and **function**.

II. Leaf Anatomy

1. Interstitial space. Where is interstitial space found in a leaf?
   Between each of the plant cells

2. Predict: what is important about this space?
   Student prediction might correctly point to it being an opening for decomposers to enter. During the Microbes lesson, this information comes into play.

III. Cell Wall

1. What is the function of the cell wall? Where is it located? What happens to intracellular components after leaf fall?
   The cell wall supports the leaf structure, protects the cell, and separates the intracellular components from the extracellular environment.

2. In the image of the plant cell, the thick grayish colored layer with multiple pathways represents the waxy cuticle on the outside of the leaf. Next is the cell wall. What is the layer inside the cell wall called?
   The plasma membrane is inside the cell wall.

3. What is the main target of decomposition?

The primary cell wall

IV. Leaf image and anatomy

1. Draw and label a representation of the images shown. Be sure to include the plasma membrane, hemicellulose, cellulose, lignin, and cell wall.

   Students should copy the drawing and label, from the waxy cuticle working inward: the plasma membrane, the bundles of cellulose, the hemicellulose branches wrapping around the cellulose, and the brown lignin in between the bundles.

2. What are the three main components of the primary cell wall?
   Cellulose, hemicellulose, and lignin

V. Cellulose

1. Cellulose consists of sugars known as **glucose**. Each individual sugar molecule, the **monomer**, is linked together, forming a long **linear polymer**." These long polymers **group together** to form a **crystalline structure**. Since cellulose consists of **sugars**, it is a high energy fuel. **Microbes** attack it first in **decomposition**.

2. Draw the long linear polymer that groups together to form the crystalline structure of cellulose. What is the molecule represented by each individual green sphere? **Glucose**

VI. Hemicellulose

1. What is hemicellulose? It is a **polymer** made of long chains of **sugar molecules**, primarily xylose and arabinose. These are **high energy fuels**. Hemicellulose consists of short chains and has a **branched** structure.

2. What does hemicellulose do? It encases the cellulose to form a **microfibril** and plays an important role in holding everything together. Roots of the word microfibril are: micro: **small** and fibril: **fiber**

3. Draw another cellulose polymer, and this time add the branched hemicellulose. What is this entire unit now called? **A microfibril**

VII. Lignin

1. Lignin is a complex compound made of different kinds of **phenol based molecules**, which are arranged in random patterns to form **polymers**.
2. Lignin **traverses** the spaces between cellulose bundles. It is a **low energy food**, which requires a **lot** of work (energy) to break down, and thus shields the high energy foods of cellulose and hemicellulose. You will learn more about lignin and how it is broken down in the Lesson 3, about Microbes.

VIII. SUMMARIZE

1. Pick up, or imagine, a decaying leaf and write a paragraph about the process of decomposition using the terms intracellular components, polymer, cellulose, glucose, hemicellulose, lignin, and energy
   As a leaf decomposes, the first things to leach out are the intracellular components. Next, the primary cell wall is the main target of decomposition. It is made up of cellulose, hemicellulose, and lignin. The high energy glucose molecules of cellulose are attacked first, as hemicellulose molecules wrapping the glucose polymers are also attacked. Lignin is a big blocky molecule filling in the spaces between the bundles of cellulose and hemicellulose. Lignin requires a lot of energy to break down, and it shields the cellulose and hemicellulose.

2. What questions does this information lead you to? **Students might predict a need to know how lignin is broken down, which is addressed in the Microbes animation.**

LESSON PLAN: ANIMATED LESSONS FROM I-MOLD
Part Three: **MICROBES AND ENZYMES** http://imold.utoledo.edu/microbes.html

STUDENT WORKSHEET

Suggested vocabulary words/phrases. These are found in the context of the animation, and can be defined as the student works through the lesson. Some words are used in previous lessons and may already be defined.

Microbes, leaf cuticle, interstitial space, cellulose, hemicellulose, lignin, enzymes, lock and key method, scaffold, oxidation, free radicals, respiration, cellular respiration

Turn on the captions. This helps you to slow down and pause the animation as needed to take notes and answer the questions as they work through the animation.

I. Microbes
1. Microbes are ___________ __________that belong to groups such as _____and________. They are the _____ _________organisms on Earth and are sometimes referred to as germs.
2. Microbes can live__________, including___, ____, ___________, ______and the ______ ______. Microbes play an important role in almost everything, including _____ _____ _____________.

II. Process of decomposition
1. During decomposition of leaf litter, microbes break through the _____ _______and ________the _________ ______on their way to the___ _____.

   Draw and label the close-up of the leaf cells pictured, labeling the interstitial space and the cuticle. What is the function of the leaf cuticle?

2. Microbes find food by releasing a small number of _______ which break down their food; _______ ____________like ___________, into _________ ones, such as_______, so that they can be consumed. An _________ in the concentration of these simple compounds (the__________), tells the _________ to produce _____ of the needed ___________to release.

III. Structural components of a leaf important to microbes
1. The three main structural components of a leaf the microbes break down are____________, _______________, and________. Write a brief sentence summarizing the relationship among these leaf components.
2. Microbes *(using their enzymes*) attack the_____ ________ _______, such as ____________ and_______________, first. Why does this make sense in the context of energy used by an organism?
3. ________is a___ _______ _______, which ______ __________and___________________. Microbes only attack lignin as a last resort to get at the protected _____ _______foods.
4. *Predict* what you think happens to the lignin, how does it get decomposed and by what processes? Do you think it has much nutritional value; why or why not?

LESSON PLAN: ANIMATED LESSONS FROM I-MOLD
Part Three: **MICROBES AND ENZYMES** http://imold.utoledo.edu/microbes.html

IV. Break it down!

1. There are two methods __________use to break down large __________compounds into _______ _________ones that they can eat. Do the enzymes really eat the compounds they break down? What organism are they really breaking down these compounds for?
2. One method is the _____ ____ ______method, which is used to break down _____________and_________________________, which are chains of sugars, into single sugars that can be consumed (*by the microbes*). So, they are breaking down _________into ___________.
3. In the lock and key process, the ________ acts as a____. This key fits the lock on the ___________ __________molecule and causes a break in the chain.

   Draw and label the enzyme lock and key model, labeling the enzyme, the substrate, the chain of sugars, and the active site for the reaction to occur.

   Some enzymes use this method to break a long chain in the middle to create shorter chains. Other enzymes chip off ends to release individual sugars.

   Typically, multiple enzymes are packaged together onto a complex_________.
   The scaffold organizes the enzymes that break________on both the ends and the center of the chain.
   To completely break down the chain, the scaffold slides up and down the chain and takes it apart.

   Where is the microbe in this image?

4. The other method enzymes break down complex compounds is by __________.
   This is the process used to break down _______.
   Lignin has a _______ structure, every molecule is different, and so the ____________ method does not work. Also, it takes a lot of _______ to break down lignin, which is a very _______ ___________. Because of this, enzymes do not have enough energy to attack lignin directly. Instead, enzymes attack other molecules that create ______ ___________, which are _______ ___________ compounds.
   These free radicals then react with the lignin and break it down. Describe what is occurring in the dramatic image you are seeing...

   Once the _______ is removed in this way, the __________ and ______________ that was encased by the lignin is available for _______________.

V. Release of Carbon

1. As microbes consume these foods, they are releasing carbon dioxide into the atmosphere through the process of _____________.
2. Write the equation for cellular respiration.

VI. So what?

Scientists need to understand how leaves decay, and what influences how fast the process occurs, so that they can predict how much carbon dioxide will be produced during decomposition.

1. After working through this animation, what are your thoughts about the science of studying carbon cycles and its relevance to the release of carbon dioxide into the atmosphere? What are sources of carbon dioxide being released into the atmosphere?

LESSON PLAN: ANIMATED LESSONS FROM I-MOLD
Part Three: **MICROBES AND ENYZMES:** http://imold.utoledo.edu/microbes.html

TEACHER LESSON KEY

Suggested vocabulary words/phrases. These are found in the context of the animation, and can be defined as the student works through the lesson. Some words are used in previous lessons and may already be defined.

Microbes, leaf cuticle, interstitial space, cellulose, hemicellulose, lignin, enzymes, lock and key method, scaffold, oxidation, free radicals, respiration, cellular respiration

Have the students turn on the captions. This helps address different learning styles, as well as encourages the student to slow down and pause the animation as needed to take notes and answer the questions as they work through the animation.

I. Microbes
   1. Microbes are **microscopic organisms** that belong to groups such as **fungi** and **bacteria**. They are the **most numerous** organisms on Earth and are sometimes referred to as germs.
   2. Microbes can live **everywhere**, including **air**, **soil**, **vegetation**, **water**, and the **human body**. Microbes play an important role in almost everything, including **leaf decomposition**.

II. Process of decomposition
   1. During decomposition of leaf litter, microbes break through the **leaf cuticle** and **traverse** the **interstitial space** on their way to the **cell wall**.

Draw and label the close-up of the leaf cells pictured, labeling the interstitial space and the cuticle. What is the function of the leaf cuticle?

   2. Microbes find food by releasing a small number of **enzymes** which break down their food; **complex compounds** like **cellulose**, into **simpler** ones, such as **glucose**, so that they can be consumed. An **increase** in the concentration of these simple compounds (the **glucose**), tells the **microbes** to produce **more** of the needed **enzymes** to release.

III. Structural components of a leaf important to microbes
   1. The three main structural components of a leaf the microbes break down are **cellulose**, **hemicellulose**, and **lignin**. Write a brief paragraph summarizing the relationship among these leaf components. **Cellulose is composed of chains of simple sugars (glucose). Hemicellulose wraps around cellulose for structure and is composed of sugars including arabinose and xylose. Lignin is a blocky molecule that fills in the spaces between and around the cellulose and hemicellulose structures.**

   2. Microbes *(using their enzymes*) attack the **high energy foods**, such as **cellulose** and **hemicellulose**, first.

3. **Lignin** is a **low energy food**, which **shields cellulose** and **hemicellulose**. Microbes only attack lignin as a last resort to get at the protected **high energy** foods.

4. *Predict* what you think happens to the lignin, how does it get decomposed and by what processes? Do you think it has much nutritional value; why or why not?

   The lignin will need to be broken down in order for decomposers to get to the cellulose and hemicellulose. The lignin is considered a low energy food, so it likely doesn't have much nutritional value to the microbe.

IV. Break it down!

1. There are two methods **enzymes** use to break down large **complex** compounds into **simpler smaller** ones that they can eat. Do the enzymes really eat the compounds they break down? What organism are they really breaking down these compounds for? **The enzymes are not eating the cellulose and hemicellulose molecules…they are breaking them down for the microbes to digest.**

2. One method is the **lock and key** method, which is used to break down **cellulose** and **hemicellulose molecules**, which are chains of sugars, into single sugars that can be consumed by the microbes. So, they are breaking down **polymers** into **monomers**. In the lock and key process, the **enzyme** acts as a **key**. This key fits the lock on the **matching substrate** molecule and causes a break in the chain.

   Draw and label the enzyme lock and key model, labeling the enzyme, the substrate, the chain of sugars, and the active site for the reaction to occur.

   Some enzymes use this method to break a long chain in the middle to create shorter chains. Other enzymes chip off ends to release individual sugars.

   Typically, multiple enzymes are packaged together onto a complex **scaffold**. The scaffold organizes the enzymes that break **bonds** on both the ends and the center of the chain.
   To completely break down the chain, the scaffold slides up and down the chain and takes it apart.
   Where is the microbe in this image? **Attached to the scaffold structure the enzymes are packaged together on.**

3. The other method enzymes break down complex compounds is by **oxidation**. This is the process used to break down **lignin**.

Lignin has a **random** structure, every molecule is different, and so the **lock and key** method does not work. Also, it takes a lot of **energy** to break down lignin, which is a very **stable molecule**. Because of this, enzymes do not have enough energy to attack lignin directly. Instead, enzymes attack other molecules that create **free radicals**, which are **highly reactive** compounds.

These free radicals then react with the lignin and break it down. Describe what is occurring in the dramatic image you are seeing.

As the microbe hovers nearby, the enzyme leaves it to attack another molecule, releasing blue structures representing free radicals. These free radicals attack the lignin and end up breaking it away from the cellulose and hemicellulose.

Once the **lignin** is removed in this way, the **cellulose** and **hemicellulose** that was encased by the lignin is available for **decomposition**.

V. Release of Carbon

1. As microbes consume these foods, they are releasing carbon dioxide into the atmosphere through the process of **respiration**.

2. Write the equation for cellular respiration.

Oxygen + glucose react to form carbon dioxide + water + energy

$6O_2 + C_6H_{12}O_6 \text{ ------}\rightarrow 6CO_2 + 6H_2O$ + energy

VI. So what?

Scientists need to understand how leaves decay, and what influences how fast the process occurs, so that they can predict how much carbon dioxide will be produced during decomposition.

1. After working through this animation, what are your thoughts about the science of studying carbon cycles and its relevance to the release of carbon dioxide into the atmosphere? What are sources of carbon dioxide being released into the atmosphere?

One part of the carbon cycle involves decomposition, and these animations explain the process of decomposition. An important point was that due to the enzymes that microbes release during decomposition, different phases of decomposition can be identified. Burning of fossil fuels, decomposition of leaves and other once living material, release of carbon dioxide stored in permafrost and other soils worldwide are all sources of carbon dioxide being released into the atmosphere.

Students might discuss the complexity of understanding the various contributors to the carbon cycle, and express a new knowledge of how many parts work together to affect an outcome.

LESSON PLAN: Interactive Model of Leaf Decomposition
Part Four: **Interactive Leaf Decomposition Activity** **http://imold.utoledo.edu/model.html**

Models are great to use to make a concept easier to understand, to visualize a process or outcome, and also to allow a scientist to test selected variables. IMOLD is a great model of leaf decomposition, because it allows the students to interact with two variables affecting decomposition rates, and test those variables in many more ways than they could at their own local research site. The fact that IMOLD uses real data collected over many years to populate the data points of the graphing activity highlights the fact that data collected for one experiment has uses to other groups in different ways. It is important that students design and carry out their own hands-on experiments with litter decomposition, but this model will help them understand the concepts behind decomposition better, and also give them ideas for multiple questions they can pursue on their own.

Plant litter decomposes at different rates depending upon many factors. Two such variables are the chemical composition of the litter itself, and the type of climate it is in. IMOLD applies knowledge learned in three animations and then allows the student to test the decomposition rates of various litter types with different chemical compositions in different environments, or test rates of decomposition of different litter types in one environment.

In this model, students can decide upon a question to investigate, choose the variables they are testing, and learn very directly how chemical composition of the litter and climate can affect decomposition rates. They can also choose to look at the effects of soil temperature and soil moisture on the decomposition rates. Finally, students can choose among 25 different types of vegetation, and seven different ecosystems. In the process, they will be learning about different climate regions in the US, and also about the representative plant species from these ecosystems.

The chemical compositions of the leaf litters in this model come from the NSF-sponsored program called LIDET (Long-Term Inter-site Decomposition Experiment Team) of the Oregon State University and the Andrews Forest LTER (Long Term Ecological Research) Site. http://andrewsforest.oregonstate.edu/research/intersite/lidet.htm The LIDET project itself is worthy of study; a painstaking, 10 year, 28 site experiment to gather data about factors affecting long term decomposition and nitrogen accumulation of leaf litters. The information about their methods, the biomes involved, and the plant species themselves, all available through the IMOLD website, are a treasure trove of data that an inquisitive student could use to pose further questions of their own.

LESSON PLAN: Interactive Model of Leaf Decomposition
Part Four: **Interactive Leaf Decomposition Activity http://imold.utoledo.edu/model.html**

Using the model:

I. Open the front page of the Interactive Leaf Decomposition Activity
   http://imold.utoledo.edu/model.html
   Look at the graph as pictured. Note what information is on the x-axis, the y-axis, what each different colored line represents, and what the default variable is (litter carbon)
   1. x-axis:

   2. y-axis:

   3. Blue line, default litter and site:

   4. Orange line, default litter and site:

   5. Green line, default litter and site:

   Using the litter carbon tab, run the default model a few times. Which litter has the least carbon left at the end? Which litter decomposed the fastest? When during the time period are decomposition rates the highest? Does the season seem to make a difference? Given the measurement of the carbon left over in the leaf litter after 1 year has passed, and your knowledge about the carbon cycle from the animations, where do you think the rest of the carbon has gone?

II. Possible questions for investigation:
   1. What happens to decomposition rates when you move a plant litter from one type of ecosystem to another?
   2. How does the composition of different plant litters affect how fast they can decompose?
   3. What are the decomposition rates when temperatures are the highest for a given litter? The lowest?
   4. Which litter contains the most lignin? Predict how that might affect its decomposition rate.
   5. How do different ecosystems affect how fast a particular type of litter decomposes?
   6. How does season affect the rate of decomposition for different litter types? In different ecosystems?
   7. Do you think climate change will affect litter decomposition rates? For all types of litter? For all ecosystems? How?

III. Conducting your investigation
   1. Complete a lab report about your investigation. Be sure to include:
      a. An introduction…what information has led you to your question. Also, explain how what you learn from your model will relate to a natural world phenomenon.
      b. The question you wish to answer and the variables you are testing
      c. Your hypothesis or prediction of outcome
      d. Your methods…what were the constants in your experiment? How did you set up your model to test your question(s)?
      e. Your outcome
      f. Your analysis of the results…did the results support or refute your hypothesis?

g. Your conclusion: what have you learned from your experiment? What does the information tell you about a possible scenario in the natural environment?
h. Knowing what you know now, what further question can you think of to investigate?
i. Include reference material that you used for background information.

2. Share your results! Prepare a poster or electronic presentation of your experiment. Include relevant background information that led you to this investigation, and explanation of your experiment, and connections to the natural world cycles that you have learned about.

HS.Matter and Energy in Organisms and Ecosystems

HS.Matter and Energy in Organisms and Ecosystems

Students who demonstrate understanding can:

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy. [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.]

HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.]

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.]

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.]

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. [Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen and nitrogen being conserved as they move through an ecosystem.] [Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.]

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. [Clarification Statement: Examples of models could include simulations and mathematical models.] [Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-5),(HS-LS1-7)
- Develop a model based on evidence to illustrate the relationships between systems or components of a system. (HS-LS2-5)

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to support claims. (HS-LS2-4)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS1-6),(HS-LS2-3)

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-3)

Disciplinary Core Ideas

LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6)
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7)
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.(HS-LS1-7)

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. (HS-LS2-3)
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. (HS-LS2-4)
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-5)

PS3.D: Energy in Chemical Processes

- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-LS2-5)

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-LS1-5), (HS-LS1-6)
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.(HS-LS1-7),(HS-LS2-4)
- Energy drives the cycling of matter within and between systems. (HS-LS2-3)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

	photosynthesis. *(secondary to HS-LS2-5)*	

Connections to other DCIs in this grade-band: **HS.PS1.B** (HS-LS1-5),(HS-LS1-6),(HS-LS1-7),(HS-LS2-3),(HS-LS2-5); **HS.PS2.B** (HS-LS1-7); **HS.PS3.B** (HS-LS1-5),(HS-LS1-7),(HS-LS2-3),(HS-LS2-4); **HS.PS3.D** (HS-LS2-3),(HS-LS2-4); **HS.ESS2.A** (HS-LS2-3); **HS.ESS2.D** (HS-LS2-5)

Articulation across grade-bands: **MS.PS1.A** (HS-LS1-6); **MS.PS1.B** (HS-LS1-5),(HS-LS1-6),(HS-LS1-7),(HS-LS2-3); **MS.PS3.D** (HS-LS1-5),(HS-LS1-6),(HS-LS1-7),(HS-LS2-3),(HS-LS2-4),(HS-LS2-5); **MS.LS1.C** (HS-LS1-5),(HS-LS1-6),(HS-LS1-7),(HS-LS2-3),(HS-LS2-4),(HS-LS2-5); **MS.LS2.B** (HS-LS1-5),(HS-LS1-7),(HS-LS2-3),(HS-LS2-4),(HS-LS2-5); **MS.ESS2.A** (HS-LS2-5); **MS.ESS2.E** (HS-LS1-6)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS1-6),(HS-LS2-3)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-LS1-6),(HS-LS2-3)
WHST.9-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-LS1-6),(HS-LS2-3)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. (HS-LS1-6)
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-LS1-5),(HS-LS1-7)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-LS2-4)
MP.4	Model with mathematics. *(HS-LS2-4)*
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-LS2-4)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. *(HS-LS2-4)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-LS2-4)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.
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