HOLDEN FORESTS & GARDENS

TEACHER RESOURCES

Deadly Messengers

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These educational materials were designed to accompany the video seminar "" by Jade Bleau, presented on June 9th, 2021 as part of a virtual Holden Forests & Gardens Scientist Lecture Series, Growing Black Roots: the Black Botanical Legacy.

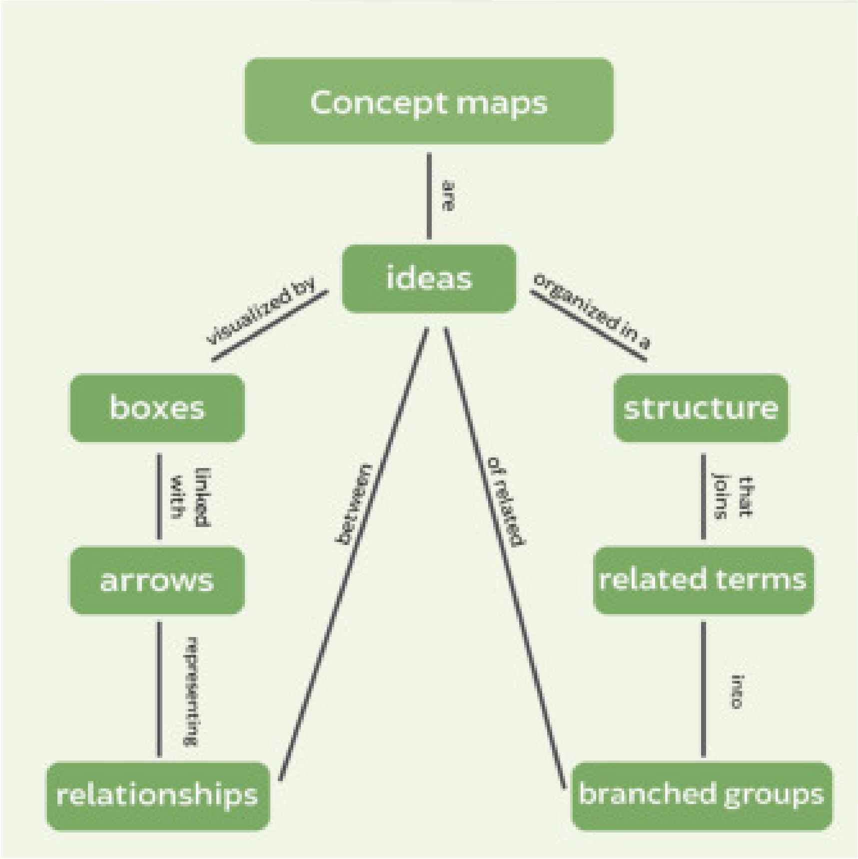
Learn more about the lecture series here: holdenfg.org/resources/the-deadly-messengers-how-plants-harness-highly-reactive-products-of-stress/

Comprehend and Connect: Find out how Ms. Bleau's work on the Deadly Messengers relates to your daily life.

1. Listen to the talk to find out: What plant does Ms. Bleau work on, and what is the real-world application of Ms. Bleau's research?
2. To what plant family does Ms. Bleau's study organism belong? What other plants are in this plant family? Are there any human uses for plants in this family? Have you ever used a plant from this family in your daily life?
3. Think about any plant that you yourself have interacted with in the real-world. This could be a plant that you know about growing in your neighborhood, such as a tree in your yard, or a plant that you use for food, like corn. What types of stress does this plant face? Consider the following: heat, freezing, drought, pollution, water logging, lack of sunlight, or even infrequent stresses like fire or hurricanes. Use the internet to find information about how you might be able to help alleviate the stress the plant is facing.

To Do: Create a concept map to understand how electrons move through the electron transport chain in the absence of stress, during the plant's daily life.

1. Listen to the talk to find out: What role does normal cellular metabolism play in creating the Deadly Messengers? What role do electrons play in the daily metabolism of the plant?

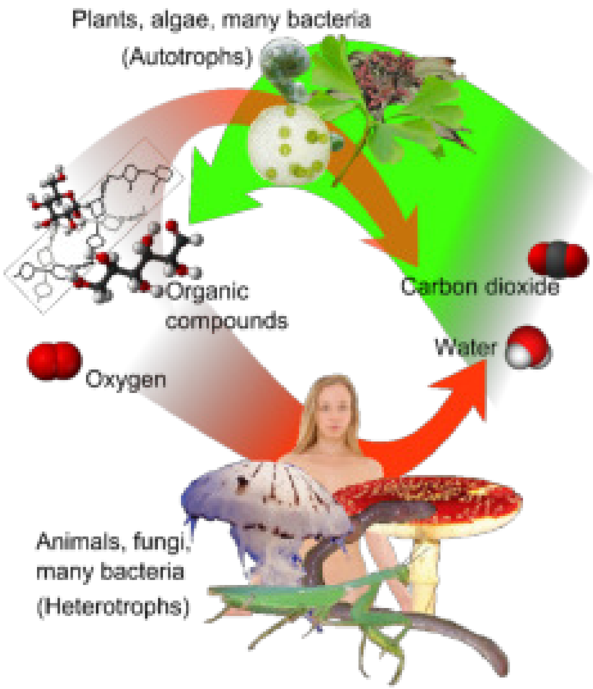


2. Create a concept map to help you understand normal cellular respiration, or metabolism and the roll electrons play in this process. Concept maps come in many forms, such as diagrams, figures, or flow charts. We will be creating a concept map that is a combination of drawings representing the chemical components of cellular respiration and arrows showing the relationships between them, similar to the one shown here.
3. Convert a text description of cellular respiration to a visual representation (any text description will work, but a text specifically designed for this activity is shown at the end of this lesson). Make sure to place all the processes in the correct cellular compartment (cytoplasm or mitochondria). Also make sure that processes that occur in the mitochondria are placed correctly with respect to the mitochondrial membrane and the inter-membrane space. For components that are transformed from one form to another (e.g., ATP is converted to ADP + Pi), use arrows like the one shown here to indicate that the products enter and then leave the process.
4. **CAUTION: IT IS RECOMMENDED THAT YOU PRACTICE PLACING ALL OF THE ITEMS IN THEIR CORRECT POSITIONS BEFORE DRAWING ARROWS AND GLUING THEM!**
5. Use one of the cell images to place the processes that occur under aerobic conditions and the other to place the processes that occur under anaerobic conditions.

Follow-up Work: Conduct a role-playing game to show how the Deadly Messengers are produced and how they can send a signal for help.

1. Listen to the talk to find out: How does stress impact production of the Deadly Messengers? Can you name one of the deadly messengers mentioned by Ms. Bleau?
2. Conduct a role play to review what you learned about electron transport in normal cellular metabolism https://online.ucpress.edu/abt/article/82/5/338/110287/Role-Playing-Activity-to-Demonstrate-the-Electron.
3. Now that you have a good idea of the normal process of cellular respiration, it is time to consider the process by which the Deadly Messengers are produced under stress. Use the information you learned in the talk to modify the role-playing game to include the following:
    a. The role of an electron which “escapes” the electron transport chain and combines with oxygen to produce free radicals.
    b. The role of the enzyme superoxide dismutase in reducing free radicals to produce hydrogen peroxide.
    c. The role of catalase in converting hydrogen peroxide to water and oxygen.
    d. The role of hydrogen peroxide in signaling response to stress.

CELLULAR RESPIRATION AND ELECTRON TRANSPORT TEXT FOR TO-DO SECTION



Cellular respiration is the process by which the energy rich molecules ATP and NADH are made from an organic compound, glucose. ATP and NADPH are then used to fuel all types of cellular processes, from muscle movement to digestion to brain function. Cellular respiration occurs in both Autotrophs and Heterotrophs. Heterotrophs must get glucose from the food they eat, while plants obtain their glucose from photosynthesis. How glucose is ultimately used differs depending on whether or not oxygen is present in the cell. It is also important to note that the byproducts of cellular respiration are carbon dioxide, which we breathe out through our lungs, and water.

Glycolysis is the first step of cellular respiration, whether oxygen is present or not. Glycolysis takes place in the cell cytoplasm. First, glucose is converted into fructose diphosphate, which requires the conversion of two ATP molecules into ADP and inorganic phosphate. This is an unstable molecule that breaks down further into two pyruvate molecules. As the pyruvate is produced, four ATP molecules, two NADH molecules and water are also produced. Because two ATP are used to start the process of glycolysis, the net gain is two ATP and two NADH molecules. What happens next depends on whether or not oxygen is present in the cell.

In the Presence of Oxygen

Under aerobic conditions (e.g. when oxygen is present), each pyruvate produced in glycolysis is combined with coenzyme A, creating an acetyl Co-A molecule. During this process, two NAD+, are converted into NADH molecules, and one of the carbon atoms is removed from each pyruvate molecule. The carbon that is removed is combined with two oxygen atoms, creating two carbon dioxide molecules, which is released as a byproduct of cellular respiration. Acetyl Co-A is then transported into the mitochondria where it begins the Krebs cycle.

The Krebs Cycle

To start the Krebs cycle, oxaloacetate (a four carbon molecule) binds to one of the acetyl Co-A molecules produced in glycolysis to produce citric acid (a six carbon molecule). Citric acid then donates high energy electrons to NAD+ to form one NADH. During this process two of the carbons are released from citric acid, each combining with two oxygen molecules to produce two molecules of carbon dioxide. This results in the production of a four carbon molecule, which is converted back into oxaloacetate. During this process, one ATP is formed and electrons are passed to NAD+ to create one NADH. Because each glucose molecule creates two molecules of acetyl Co-A, it takes two turns of the Krebs cycle to process one molecule of glucose. The NADH produced in glycolysis and the Krebs cycle goes on to be used in the electron transport chain.

The Electron Transport Chain

The electron transport chain is made up of protein complexes embedded in the mitochondrial membrane. The protein complexes include: NADH dehydrogenase, cytochrome b-c1, cytochrome oxidase, and the complex that makes ATP, ATP synthase. Two mobile carriers are also involved: ubiquinone, and cytochrome c. Electrons from NADH (made in the Krebs cycle) are passed down this chain to pump hydrogen ions into the mitochondrial inter-membrane space.

First, two electrons are passed from NADH to NADH dehydrogenase. One hydrogen ion is pumped across the mitochondrial membrane for each electron that is passed.

Next, the two electrons are transferred to the mobile carrier ubiquinone, which moves the electrons to the cytochrome b-c complex.

Next, cytochrome c accepts each electron from cytochrome b-c one at a time, coupled with the pumping of two hydrogen ions.

Finally, four electrons are passed to cytochrome oxidase, which forms two water molecules using these four electrons, two oxygen molecules and four hydrogen ions. During this process four additional hydrogen ions are pumped across the membrane.

The pumping of hydrogen ions sets up a concentration gradient across the membrane, known as a proton motive force. The proton motive force is used by ATP synthase to make ATP from ADP and inorganic phosphate, a process known as oxidative phosphorylation. Up to 34 ATP can be produced through the electron transport chain from each glucose molecule. Though the process of electron transport is described here as occurring a few electrons at a time, in reality many electrons are being transferred simultaneously, which maintains a constant proton gradient.

In the Absence of Oxygen

Fermentation

Under anaerobic conditions (e.g. in the absence of oxygen) many cells use a process called fermentation to produce ATP. Fermentation takes place in the cell cytoplasm. Fermentation has two disadvantages compared to aerobic respiration. First, it produces much less ATP, and second, it produces a toxic byproduct. This toxic byproduct must be broken down by the cells, with the help of enzymes. However, fermentation is very useful if oxygen is not available.

There are two types of fermentation. The first type occurs in animals, the second type occurs in yeast. In both types of fermentation, glycolysis, the first step in energy production, still takes place, resulting in the production of two ATP molecules. But, the pyruvate produced in this step does not go on to the Krebs cycle. Instead, pyruvate goes on to produce either lactate or ethanol, depending on whether it occurs in animals or in yeast. The steps in fermentation following glycolysis do not produce any further ATP or NADH, and in fact they require NADH to complete. For this reason the energy gained from one molecule of glucose is far less in the absence of oxygen (net 2 ATP and one NADH) compared to when oxygen is present (net 34 ATP).

In Animals

Lactate fermentation occurs in anaerobic animals cells. For example, in muscles when an animal exercises hard, all of the oxygen in the muscle cells gets used up faster than it can be supplied by the blood stream. In this process each pyruvate produced during glycolysis is converted to a lactate molecule. This process requires one of the NADH molecules produced in glycolysis.

In Yeast

Alcoholic fermentation occurs in yeast, for example, in the process of making wine and beer. First, each pyruvate made during glycolysis is converted to acetaldehyde, a process which produces a molecule of CO_2 (hence the bubbles found in beer!). Next, each acetaldehyde is converted to an ethanol. This process requires one of the NADH molecules produced in glycolysis.