**Unit Essential Question:** *How does energy and matter flow within natural and designed ecosystems?*

**Introduction**

In the last task, students modeled what happens at the molecular level in chemical reactions, including how atoms are rearranged and matter is conserved. They began to explore this within the context of a chemical reaction that happens in all environments—cellular respiration. By thinking about how matter enters organisms, is rearranged through chemical reactions, and released back into the environment, students began to form ideas about how matter cycles and energy flows through environments. This task builds on prior knowledge by introducing another critical chemical reaction that occurs in all environments—photosynthesis. Students conduct investigations that show how photosynthesis and cellular respiration interact to allow matter to cycle and energy to flow through living organisms. By the end of this task, students should have a clear model of this cycling, so they may apply this knowledge to the design of their aquaponics system.

**Alignment Table**

|  |  |  |  |
| --- | --- | --- | --- |
| **Performance Expectations** | **Science and Engineering Practices** | **Disciplinary Core Ideas** | **Crosscutting Concepts** |
| **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.** [Clarification Statement: Emphasis is on tracing movement of matter and flow of energy.] [Assessment Boundary: Assessment does not include the biochemical mechanisms of photosynthesis.] | **Constructing Explanations**   * Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students’ own experiments) 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. | **LS1.C: Organization for Matter and Energy Flow in Organisms**   * Plants, algae (including phytoplankton), and many microorganisms use the energy from light to make sugars (food) from carbon dioxide from the atmosphere and water through the process of photosynthesis, which also releases oxygen. These sugars can be used immediately or stored for growth or later use.   **PS3.D: Energy in Chemical Processes and Everyday Life**   * The chemical reaction by which plants produce complex food molecules (sugars) requires an energy input (ie. from sunlight) to occur. In this reaction, carbon dioxide and water combine to form carbon-based organic molecules and release oxygen (*secondary*). | **Energy and Matter**   * Within a natural system, the transfer of energy drives the motion and/or cycling of matter. |
| **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.** [Clarification Statement: Emphasis is on describing that molecules are broken apart and put back together and that in this process, energy is released.] [Assessment Boundary: Assessment does not include details of the chemical reactions for photosynthesis or respiration.]  \*\*Note: This PE is primarily addressed in Task 2, but many ideas and practices are reinforced throughout this task. | **Developing and Using Models**   * Develop a model to describe unobservable mechanisms. | **LS1.C: Organization for Matter and Energy Flow in Organisms**   * Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, and to release energy.   **PS3.D: Energy in Chemical Processes and Everyday Life**   * Cellular respiration in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials (*Secondary*). | **Energy and Matter**   * Matter is conserved because atoms are conserved in physical and chemical processes. |
| **Supplementary Science and Engineering Practices**   * **Planning and Carrying Out Investigations**   + Conduct an investigation […] to produce data to serve as the basis for evidence that meets the goals of the investigation. | | | |
| **Crosscutting Concepts**   * **Systems and System Models**   + Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. | | | |
| **Equity and Groupwork**   * Work within group roles to conduct investigations. | | | |
| **Language**   * Read a short article, using annotation strategies to analyze text. * Use evidence from an investigation and an article to support a written explanation. * Represent a concept visually and in text. | | | |

**Learning Goals**

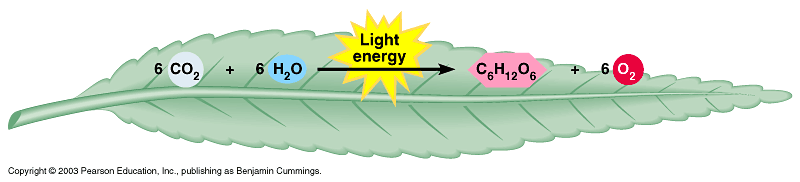
This learning task asks students to gather experimental evidence for the roles of cellular respiration and photosynthesis in the flow of energy and cycling of matter through living organisms. More specifically, the purpose is to:

* Engage prior knowledge of changes students noted in their river environment, specifically those pertaining to living organisms.
* Investigate the cycling of carbon dioxide through the processes of cellular respiration and photosynthesis, including the effects of light and dark conditions on those processes.
* Use information from an article about photosynthesis to explain what happened in the investigations.
* Model and explain how cellular respiration and photosynthesis interact to cycle energy and matter in ecosystems.
* Apply knowledge of photosynthesis to predict the role it will play in an aquaponics system design.

**Content Background for Teachers**

In this task, students look at two processes that are happening in parallel in living organisms in an environment—photosynthesis and cellular respiration. By exploring this activity through readings, investigations, and models, students will be able to conceive of these not as separate processes, but as processes that are constantly interacting and exchanging matter and energy. Not only do these processes both happen in some living organisms at the same time, but they can also exchange matter *between* organisms.

As described in the last task, cellular respiration happens in all living organisms—plants and animals alike. Cellular respiration takes glucose from the food organisms eat and together with oxygen creates the energy living organisms need to grow and function. As dictated by the conservation of matter, cellular respiration also creates byproducts in the form of carbon dioxide and water. Coincidentally, these molecular byproducts are exactly what plants need to do photosynthesis. Photosynthesis requires carbon dioxide and water, as well as energy from the sun, in order to make glucose. The byproduct of this process is oxygen. Ultimately, the equations for photosynthesis and cellular respiration are mirror images of each other. The only difference is the type of energy involved—sunlight vs. ATP.



Students may notice this relationship on their own just by looking at the chemical equations in the reading. However, this will soon be reinforced through the lab investigations. The lab investigation involves Elodea and BTB solution placed in different light conditions. This serves as evidence for the cycling of one essential molecule in both processes—carbon dioxide. Under light conditions, Elodea is able to do photosynthesis, thus using up carbon dioxide and turning the BTB solution from yellow to blue. In the dark, no photosynthesis takes place, so the BTB solution remains yellow.

By the end of this task, students will be able to form a holistic picture of the role of chemical reactions in the cycling of matter and flow of energy through living organisms. Rather than seeing photosynthesis and cellular respiration as two separate processes, students should in the end be able to model how matter like carbon dioxide, water, oxygen, and glucose is cycled through living organisms, using energy from the sun and producing energy in the form of ATP. This cycling will help them think about the needs of their Aquaponics System.

\*\*For more background information, see the article in the Student Version as well as the TedEd video provided in the Explore.

**Academic Vocabulary**

* Indicator
* Bromothymol Blue (BTB)
* Photosynthesis
* Cellular Respiration
* Carbon Dioxide
* Oxygen
* Water
* Energy
* Matter
* Glucose
* ATP

**Time Needed (Based on 45-Minute Periods)**

4.5 Days

* Engage: 0.5 period
* Explore: 1 period (also requires 24 hours for experiment to run)
* Explain: 1 period
* Elaborate: 1 period
* Evaluate and Reflection: 1 period

**Materials**

* Unit 3, Task 3 Student Version

Explore

* Per Lab Group
  + Small Beaker 1/3 filled with Bromothyml Blue Solution
  + Straw
  + Investigation Card in sheet protectors for each table group
  + 2 Test Tubes or Baby Food Jars
    - If using test tubes, need test tube racks
  + Small Graduated Cylinder (to retrieve BTB solution from teacher)
  + 1-2 Sprigs Elodea Plant (available at most local aquariums)
  + Straw
  + Masking Tape
  + Pen
* For Class
* Empty Oatmeal Containers or Large Cardboard Box (For dark environment)
* 2 Sun Lamps
* Bromothyol blue solution
  + 1 g bromothymol blue
  + 1 L distilled water
  + 18 drops of 1M sodium hydroxide (Optional: makes it more blue)

Elaborate

* Optional: If students actually want to run the experiment described, follow the same instructions as the other jars, except add a sea snail or small fish. Be sure to use distilled water or the snail/fish will likely die before data can be collected.

Evaluate

* Project Organizer Handout

**Instructions**

**Engage**

1. Introduce Task 3: Through previous tasks, you have recorded all the different changes you observed in the river environment over time. In the last task, for example, you examined the role of cellular respiration in some of these changes. Think about what you were still wondering about at the end of the last task (look back if you need to). What questions do you still have?
   * Before you pass out their Student Guide, give students time to reflect individually or with a partner about the questions they recorded at the end of the last task. Share a few of these out as a class, using facilitating questions to guide students toward questions that relate to this task.
2. Transition to Task 3: You may remember that some off these changes in the river environment involved plants and animals that seem to have grown. Why do you think this is the case? In this task, you will explore different processes that lead to these kinds of changes in ecosystems.
   * Now pass out the Task 3 Student Guide.
3. To begin this task, students are asked to engage their prior knowledge to consider how animals and plants are able to grow and make energy. In pairs, ask students to discuss the questions on their Student Guides.
   * This begins to lay the foundation for the crosscutting concept emphasized in this task—**Energy and Matter**. As students engage their prior knowledge, they will likely begin to make connections between the matter needed to create energy, which will set the stage for them to later consider how energy transfer drives the cycling of matter.
   * Potential responses:
     + Question 1: Food and water are needed for animals to grow.
     + Question 2: Sunlight, water, and nutrients are necessary for plant growth. (Note: Students may say soil, instead of nutrients, but it is really the nutrients and water in the soil that plants need).
   * After pairs discuss, use equity sticks to share out ideas in a class-wide discussion (See “How to Use This Curriculum” for more details on how and why to use equity sticks).

**Explore**

1. In this part of the task, students conduct investigations in order to figure out what animals and plants need to survive and grow, and how they must interact with their environments to get what they need.

* This *Explore* gives students practice at the supplementary Science and Engineering Practice, **Planning and Carrying Out Investigations**, as students conduct an investigation to produce data that serves as evidence for the roles of cellular respiration and photosynthesis in the cycling of matter and flow of energy.

1. Assign roles to each group. You may use whatever roles you prefer. We recommend the use of the Materials Manager, Facilitator, Harmonizer, and Recorder.
   * Ask the Facilitator to read the directions and to make sure everyone understands the investigations.
   * Ask the Materials Manager to handle any resources needed to complete the investigations.
   * Ask the Harmonizer to make sure that everyone contributes their ideas and that everyone’s voice is heard.
   * Ask the Recorder to make sure the group is recording their data in their Student Guides.
2. The first investigation serves two purposes: 1) to introduce students to the indicator they will be using in the more complex second investigation, and 2) to find evidence for the production of carbon dioxide by cellular respiration.
   * In both investigations, students use an indicator called bromothymol blue (BTB) to see the effects of photosynthesis or cellular respiration. BTB is an indicator that turns from blue to yellow when in the presence of CO2.
3. Because humans do cellular respiration like all other organisms, students are going to use themselves to investigate cellular respiration using bromothymol blue (BTB).

* We recommend first reviewing the cellular respiration equation on their Student Guide (Optional: project on the board and review).
  + Distribute materials to each group. Then have students follow the procedure on their student handout and record observations in their data table. \*Safety: Make sure students do not suck in on the straw, but rather only blow out.
  + Once students have completed this short investigation, have them discuss and answer the analysis question in their Student Guide. Review the results and analysis in a brief class-wide discussion.
    - Students should find that the BTB solution turns yellow, which they will likely hypothesize means that BTB is an indicator for the carbon dioxide created during cellular respiration.

1. Transition students to Investigation 2 by reading the introduction on their Student Guide aloud. This confirms that BTB is indeed an indicator for carbon dioxide, which turns yellow when carbon dioxide is present and back to blue when it is absent. Students will use this same indicator for this investigation.

* This investigation is intended to provide evidence for how photosynthesis helps to cycle matter, such as carbon dioxide. By comparing light vs. dark conditions, it also provides evidence that the transfer of energy drives the cycling of this matter; this explicitly emphasizes the CCC for this task, **Energy and Matter**.

1. Distribute the investigation card and prepare all materials. You may choose to keep students in the same group roles or re-assign the roles for this investigation.

* Student groups follow the procedure on the investigation card to set up their experiment. To ensure the experiments are successful, check that all student set-ups have yellow BTB solution to begin with; this provides the carbon dioxide plants will need to do photosynthesis.
* After setting up their experiment, students should record initial observations, including labeled and colored sketches of both set-ups, so they can compare these to their observations after 24 hours. Space is also provided in their data tables to record predictions of what color they think the BTB solution will be after 24 hours in both light and dark settings.

1. The two lab set-ups will remain in light and in dark for 24 hours, so students will need to check them the same time the next day.
   * Again, students should make observations and draw colored and labeled sketches in their Student Guides.
   * An example is shown to the right: Students should find that the set-up left in the light turned blue (on left). This is because all of the carbon dioxide was used up for photosynthesis. The set-up left in the dark remained more yellow (on right). This is because photosynthesis does not happen in the dark (on right). Students will read a text in the next section of this task that describes this result.

**Explain**

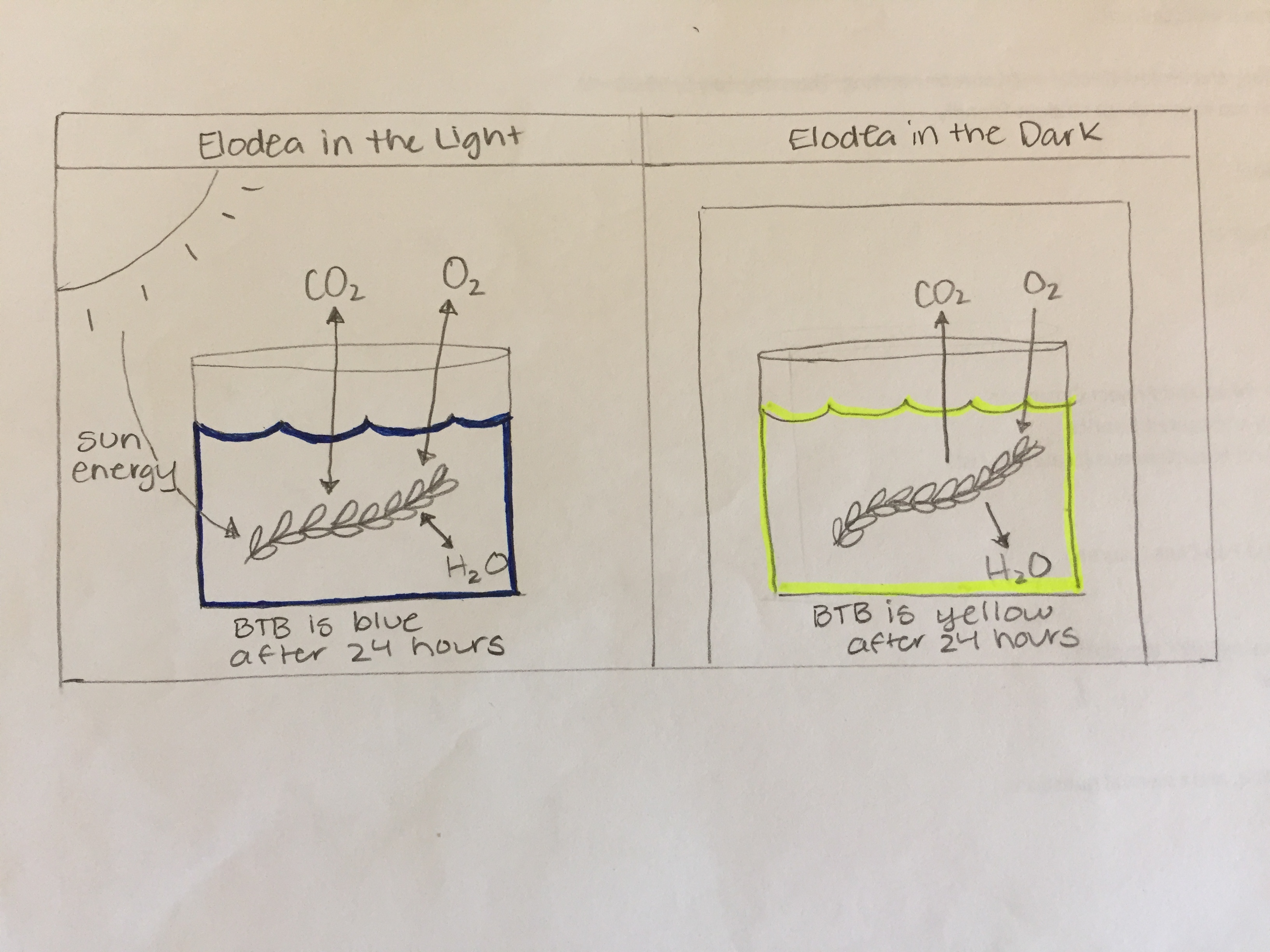
1. While the first investigation dealt with a process they were familiar with—cellular respiration—students are likely not sure at this point what was happening in Investigation 2. To understand more, students read an article about cellular respiration and photosynthesis and use this new knowledge to explain and model Investigation 2.
   * This section of the task continues to emphasize the crosscutting concept of **Energy and Matter** as students explain and model how photosynthesis cycles matter through plants. This supports two elements of this CCC as students explore how energy transfer drives this cycling of matter and also how matter is conserved as the molecules are rearranged and released as different molecules.
2. First have students read and annotate the article independently, using an annotation strategy of your choice.

* Optional resource to further tie photosynthesis and cellular respiration together: http://ed.ted.com/lessons/the-simple-but-fascinating-story-of-photosynthesis-and-food-amanda-ooten#review

1. Students then work in pairs to complete the explanation and model of Investigation 2. This allows students to practice two Science and Engineering Practices: **Constructing Explanations**, using evidence from both the article and experiment; and **Developing and Using Models** to describe the role of photosynthesis in the cycling of matter and flow of energy through the Elodea plant.

* Sample sentence frames you may want to provide are:
  + “In Investigation 2, \_\_\_\_\_ happened.”
  + “ According to the article,…”
  + “Photosynthesis requires…”
  + “Without \_\_\_\_, \_\_\_\_\_ couldn’t happen.”
  + “This was shown in the experiment by…”
  + “In the dark setting…”
  + “In the light setting…”
  + “This means that…”
  + “…which means that…”

1. Sample Student Explanation: *In Investigation 2,* *photosynthesis happened in the Elodea plant in the light setting, but not in the dark setting. According to the article, the chemical reaction of photosynthesis needs energy from sunlight and matter from carbon dioxide and water in order to happen. We provided the water and carbon dioxide by blowing into the water, but in the dark setting, there was no sunlight, so the reaction couldn’t happen. This was shown in the experiment by the BTB solution staying yellow in the dark setting. This means that the carbon dioxide was not used for photosynthesis. In the light setting, the BTB solution changed from yellow to blue, which means that carbon dioxide was used up for photosynthesis.*



1. Sample models:

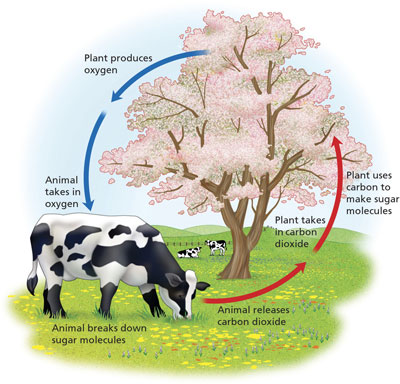
* Elodea in the Light: Notice that the sample shows both cellular respiration and photosynthesis are happening. However, at this point, students may just show the process of photosynthesis: sunlight, carbon dioxide, and water entering the plant (turning BTB blue) and oxygen leaving the plant.
* Elodea in the Dark: Notice that the sample shows cellular respiration with oxygen entering the plant and carbon dioxide and water leaving the plant (keeping BTB yellow). However, at this point, students may just show the lack of photosynthesis by showing no inputs and outputs.

1. After pairs of students have drafted their explanations and models, we recommend facilitating a class discussion to co-construct these models and explain what happened in their experiment. Students can then go back and revise based on the classroom discussion.

**Elaborate**

1. In this activity, students take their understanding of photosynthesis and think about how that process interacts with cellular respiration to make ecosystems function properly. To do so, they imagine that a fish has been added to their original experimental set-up and placed in a light setting.

* Students individually make a prediction about what would happen, drawing a new model, and explaining how cellular respiration and photosynthesis interact to cycle matter and energy through ecosystems.
  + This gives students more practice at **Developing and Using Models** and continues to emphasize the crosscutting concept of **Energy and Matter.** However, students are also beginning to look at these concepts through the lens of the supplementary crosscutting concept, **Systems and System Models,** as they show the interactions between two sub-systems (plant and animal, or cellular respiration and photosynthesis) as part of the functioning of the larger ecosystem.
  + Optional: Students can also set up an additional jar/test-tube to test their hypothesis. Have students follow the same instructions as the other jars, except add a sea snail or small fish.

1. Sample Student Responses
   * 1: If we left a fish and elodea in yellow BTB overnight, the BTB would likely stay the same color because both the fish and plant do cellular respiration, which produces carbon dioxide, but the plant also does photosynthesis, which uses up some of the carbon dioxide.
   * 2: Student should draw a light source and a jar with yellow BTB solution, a fish, and an elodea plant. Arrows and labels should show sunlight, water, and carbon dioxide entering the plant and oxygen leaving the plant. Arrows and labels should also show oxygen and the plant itself entering the fish, and carbon dioxide and water leaving the fish. This carbon dioxide and water can then be linked back to the plant as it is using these molecules for photosynthesis.
     1. 2a: During cellular respiration, animals use the molecules originally made by plants during photosynthesis. Plants can then recycle the carbon dioxide and water made during this process as they do photosynthesis. This is how the two processes interact to cycle matter in ecosystems. These processes also facilitate flow of energy by taking energy from the sun, which flows into plants for photosynthesis, and is then eaten by animals for cellular respiration, providing the energy they need.
   * 3: The sun drives this process.
2. This model and the corresponding explanations are a good opportunity for formative assessment. Collect student work to identify trends in students’ ability to develop models of the two chemical processes responsible for cycling of matter and flow of energy in ecosystems. See “How to Use This Curriculum” for strategies on utilizing formative assessment data to provide feedback to students and inform classroom instruction.
3. Return to the whole-class concept map from the Lift-Off Task.

* In small groups, have students brainstorm new concepts and new connections that they have learned in this task, as well as any new questions that have come up for them. Then have groups share these aloud in a class-wide discussion and add to the class concept map. The use of equity sticks is encouraged for more equitable participation in class-wide discussions (See “How To Use This Curriculum” for more details).
  + Some possible facilitating prompts to ask students are: What new ideas/concepts do you want to add to the map? What connections do you want to add or change? What is your reason for that addition/revision? What connections can we make between the questions/ideas already on the map? What new questions do you have about the phenomenon?
  + Draw circles around each question and boxes around each concept.
  + Write connector words to describe connections between the concept boxes.
  + For this task, students may begin to connect some of their previous question circles to concept boxes about the following: the cycling of matter and flow of energy in ecosystems, specifically relating to cellular respiration and photosynthesis.
* Have students analyze the additions to the class concept map for as many examples of this task’s crosscutting concept as they can find. Once a student has identified the crosscutting concept, you can trace the circle in the corresponding color (decided on in the Lift-Off task). We recommend asking students to share key words that helped them identify the crosscutting concept for that concept or question. Some identifying words students might look for are:
  + **Energy and Matter**: These could be phrases such as, “is made by,” “is put into,” “is added to,” “is cycled within,” “is taken out by,” “is extracted for,” “is conserved,” “is changed into,” etc.
* Once again, the purpose of this concept map is to facilitate the generation of student questions, promote language development, and support understanding of the science content throughout the unit. Allowing students to ask their own questions and use their own words to make meaning of the concepts will not only help them make deep connections about science content, but will also help their oral and written language development.

**Evaluate: Connecting to the Culminating Project**

1. Students independently complete the Task 3 section of the Unit 3 Project Organizer in class. Revisions can be done for homework, depending upon student’s needs and/or class scheduling.
2. Students have been tasked with creating a sustainable aquaponics system that mimics the properties of the river environment, including any chemical reactions that may occur. Their prompt is as follows: Identify or add an organism to your aquaponics system that does photosynthesis.
   * Identify what molecules it will need to have in order to do photosynthesis. How will your system provide what the organism needs?
   * Identify what molecules it will create through this process. How will the system use up the products that it creates?
   * Draw a picture of your organism and the molecules identified, using arrows to show whether the molecules enter or leave the organism.
   * Make connections to the organism you chose after Task 2: How do the plant and animal work together to cycle matter and keep energy flowing through the system?

**Reflection**

1. At the end of the task, ask students to reflect on what they have learned over the course of this task by answering the following three questions in their Student Guide:

* At the beginning of this task, you were asked to use your prior knowledge to explain why you think plants and animals grow over time. Look back at your explanations: after exploring photosynthesis and cellular respiration today, how would you change or add to your explanations? Use evidence from the task to justify your changes or additions and record below.
* In this task, we focused on the crosscutting concept of **Energy and Matter**: The transfer of energy can be tracked as it flows through a system, is conserved, and drives the cycling of matter. Where did you see examples of **Energy and Matter** in this task?
* Now that you have learned more about how cellular respiration and photosynthesis cycle matter and energy amongst living things in an ecosystem, what questions do you still have?

1. There are no right answers, but encourage students to look back at their Student Guides and their class concept map. They should not change their initial responses, but rather use this reflection space to add to their ideas and questions based on what they have learned through this task. By generating more of their own questions, students continue to engage in sense-making of the phenomenon and gathering knowledge and skills for their final projects.

**Assessment**

1. You may collect students’ Project Organizer and assess using:

* *Criteria of your choice.* We recommend using the 3-Dimensional Assessment matrix at the beginning of this document to inform your criteria.
* This can be a formative tool to periodically look for trends in student understanding after the completion of a task. You can then use this formative data to inform any re-teaching as necessary.

1. You may also give students time to make revisions with one of the two options:

* Students may make changes to their Project Organizer according to your comments OR
* Ask students to exchange Project Organizers with a partner and give partners 5 minutes to give written feedback. Then allow students time to make changes to their work according to the feedback.