

## At-A-Glance: Species Interactions (Mutualism)

Day 1		
Timing	Activity	Materials needed
5 min	<p>1. Hook interest in plants using seeds. Pass out clover and grass seeds to each lab group. Have students start discussing each prompt as a group then move to a class discussion to collect everyone's ideas. Have students make observations of the seeds. Before you tell students what type of seeds they are, have them make predictions. Use questioning to see what prior knowledge they have. Have you seen seeds before? Do they look like seeds you have planted before? What do you think will grow from these seeds? After giving them time to make predictions about the type of seeds, introduce the seed types. Start having them make comparisons using a question like: <b><i>How are the grass and clover seeds similar and different?</i></b></p>	<p>- Containers of grass &amp; legume seeds for each table/group. - Magnifying glasses <a href="#">Slide 2</a></p>
15 min	<p>What do plants need to grow, survive, and thrive?  First ask students: What does a plant need to grow? Individually think about the answer to the question Pair with one other person &amp; discuss your answers to the question. Share your ideas with the class. Record all the initial ideas on a large sheet of paper to look at during this lesson to help revise original ideas. First ask students: What does a plant need to thrive &amp; survive? Individually think about the answer to the question Pair with one other person &amp; discuss your answers to the question. Share your ideas with the class. Record all the initial ideas on a large sheet of paper to look at during this lesson to help revise original ideas.</p>	<p>- Large paper to document initial student ideas <a href="#">Slides 3 &amp; 4</a></p>
15 min	<p>Plant and experiment introduction - Planting Procedure  <i>Teacher Note: A mixture of soil &amp; sand is used to limit the nutrients available to the clover to promote better nodule formation.</i></p>	<p><b><i>Student Handout:</i></b> <a href="#">Procedure, Pre-Lab Questions &amp; Hypotheses.</a>  <a href="#">Slide 5</a></p>

	<p>As a class, read the lab introduction. In small groups, read procedure &amp; answer the pre-lab questions. After reading both the introduction &amp; procedure, have students discuss these questions with their group:</p> <ul style="list-style-type: none"> <li>-What is bacteria?</li> <li>-How will the bacteria affect the plants?</li> <li>-Is bacteria good or bad?</li> <li>-What does bacteria do?</li> </ul> <p>After discussing questions, students make hypotheses on their own. (Handout Pg 1)</p>	
10 min	<p>Preview the lab materials and demonstrate how to plant the seeds. After, have students label all their containers to be ready to plant on Day 2.</p> <p>Make sure you do NOT pack in the dirt, it should be loosely covered!</p> <p>Explain over watering and demonstrate how to water</p> <p>Students pre-label their containers to be ready for planting on Day 2</p>	<a href="#">Slide 6</a>
<b>Suggested End of Day 1</b>		

<b>Day 2</b>		
<b>Timing</b>	<b>Activity</b>	<b>Materials needed</b>
30 min	<p>Follow the procedure and plant all plants. Take initial observations of the seeds and soil.</p> <ul style="list-style-type: none"> <li>-Have each group collect the materials</li> <li>-Have students plant and ensure that students do not over-water their plants</li> </ul> <p>Decide as a class what information should be recorded on the observation sheet.</p> <p>For the next 3-5 weeks have students take observations daily and water the plants when the soil is beginning to dry out.</p>	<p><b>Student Handouts:</b></p> <ol style="list-style-type: none"> <li>1) <a href="#">Plant Observation Log</a></li> <li>2) <a href="#">Lab Procedure</a></li> </ol> <p><a href="#">Example Observations on Slide 9</a></p> <p><i>Teacher's Note:</i></p> <p><i>Plants take 3-5 weeks to grow.</i></p> <p><i>Once the clover has full clover leaves, you can harvest. The longer you wait to harvest, the better the nodules will be when harvested.</i></p>

	<p><b>Note:</b> Students have also enjoyed planting pinto beans along with the clover because they didn't have to harvest the pinto beans. Students were able to take home the pinto beans if they wanted. For students who do not want their pinto beans, you can harvest these beans to see the nodules and compare to what they saw on the clover. These nodules are a little easier to count/see so this could be helpful for some diverse learners.</p>	<p><i>Have students take daily observations on their worksheet. Decide as a class what information should be recorded on their observation sheets. (For instance: color, height, leave number, etc.) See an example on <a href="#">slide number 9</a>.</i></p> <p><i>Students should water the plants when they notice the soil is beginning to dry out. Record what days the plants were watered on the observation sheet.</i></p> <p><i>Note: If the weather forecast for the weekend is extreme and your building is not temperature controlled have a plan!</i></p>
20 min	Discuss - What is the nitrogen cycle? Review the process of nitrogen fixation.	<p><b>Video Introduction:</b>  <a href="#">The Nitrogen Cycle</a> (5.44 minutes)  <a href="#">Amoeba Sisters - Nitrogen Cycle</a> (begin at 3:57)</p>
<b>Suggested End of Day 2</b>		

<b>Day 3</b>		
<b>Timing</b>	<b>Activity</b>	<b>Materials needed</b>
30 min	<p>Start by showing the video - How does the nitrogen cycle work? As a review of yesterday's lab.</p> <p>Next, students will work in small groups to read the website information on the nitrogen cycle. Divide students into different groups to read the section and design a poster telling the class about their portion of the cycle. They should cover:</p> <ul style="list-style-type: none"> <li>-What is the nitrogen cycle?</li> <li>-Nitrogen fixation</li> <li>-Mineralization</li> <li>-Nitrification</li> <li>-Immobilization</li> <li>-Denitrification</li> <li>-Nitrogen is crucial for life</li> </ul> <p><i>As an option, students could make a small skit or act out each of their stages of the cycle to present to the class. They could also come up with a movement that represents their portion of the process that students have to do in order as they learn about each of the steps as a class.</i></p>	<p><b>Video:</b> <a href="#">How does the nitrogen cycle work?</a> (2.36 minutes)</p> <p><b>Reading:</b> <a href="#">What is the nitrogen cycle and why is it the key to life?</a></p>
20 min	Students work together to create scientific models of the nitrogen cycle in their science notebooks or on posters. Students should work together to draw the important factors in the nitrogen cycle, arrows showing how nitrogen travels, and how nitrogen is	<p><b>NSTA:</b> <a href="#">How to create a scientific model</a></p>

	transformed.	
10 min	Fill out plant observation guide	<b>Student Handouts:</b> 1) <a href="#">Plant Observation Log</a>
<b>Suggested End of Day 3</b>		

Day 4		
Timing	Activity	Materials needed
50 min	<p>Students work in groups to compare the nitrogen cycle to something else in their life. Examples of their comparisons could be a movie, a book, a sport, or a game.</p> <p>They should determine how their chosen item compares to the rhizoba’s role in nitrogen cycle in terms of:</p> <ul style="list-style-type: none"> <li>● <b>Specialization</b></li> <li>● <b>Nourishment</b></li> <li>● <b>Symbiotic Relationships</b></li> <li>● <b>Impact on their Environment</b></li> <li>● <b>Success Factors</b></li> </ul>	<p><b>Poster Paper, Markers</b></p> <p><u><a href="#">Poster Grading Rubric</a></u></p> <p><i>Example: The nitrogen cycle and a restaurant can be compared in several ways:</i></p> <ol style="list-style-type: none"> <li>1. <i>Specialization: Just like a restaurant specializes in a specific cuisine or type of food, rhizobia-fixing bacteria specialize in a specific symbiotic relationship with leguminous plants. They have the unique ability to form nodules on the roots of these plants and convert atmospheric nitrogen into a form that the plants can utilize.</i></li> <li>2. <i>Nourishment: A restaurant provides nourishment to its customers through the food it serves. Similarly, rhizobia-fixing bacteria play a crucial role in providing nitrogen nutrition to leguminous plants. By fixing nitrogen from the air, they help these plants grow and thrive, enhancing soil fertility.</i></li> <li>3. <i>Symbiotic relationship: A successful restaurant often relies on a symbiotic relationship with its customers. The customers provide the patronage and support that keep the restaurant running. Similarly, leguminous plants provide a home for rhizobia-fixing bacteria by forming nodules on their roots, while the bacteria provide essential nitrogen to the plants. It's a mutually beneficial partnership.</i></li> <li>4. <i>Environmental impact: Restaurants can have an impact on the environment through their sourcing practices, waste management, and sustainability efforts. Similarly, rhizobia-fixing bacteria contribute positively to the environment by reducing the need for synthetic fertilizers. This reduces the potential for water pollution and greenhouse gas emissions associated with nitrogen-based fertilizers.</i></li> <li>6. <i>Success factors: A successful restaurant often depends on factors like the quality of its food, service, ambiance,</i></li> </ol>

		<i>and location. Similarly, the success of rhizobia-fixing bacteria depends on factors such as their compatibility with specific legume plants, the efficiency of nitrogen fixation, and the presence of suitable environmental conditions.</i>
10 min	Fill out plant observation guide	<b>Student Handouts:</b> 1) <a href="#">Plant Observation Log</a>
<b>Suggested End of Day 4</b>		

<b>Day 5</b>		
<b>Timing</b>	<b>Activity</b>	<b>Materials needed</b>
30 min	<p>Discuss - Besides nitrogen, what do plants need to grow? What other nutrients are important for plant growth?</p> <p>Let students know that two other ways gardeners and scientists can measure what is in our soil is with pH and NPK balance. NPK levels are referring to the nitrogen, phosphorus, and potassium levels in the soil. All are important for plant growth.</p> <p>Have students go outside and find a small cup of soil. They will add ~ 1 tablespoon of soil and mix it with half a cup of water. Let the soil material settle overnight for testing.</p>	<p><b>Cups (clear if possible) - 1 per group</b></p> <p><b>Marker to label cup location and group number</b></p> <p><b>Small shovels to collect soil sample</b></p>
20 min	<p>In their science notebooks, have students watch the following videos. Take notes for each of the different elements—what happens if they are missing in any of the plants?</p> <p>Discuss as a class - What do they think they could be added to the soil to help balance these elements?</p>	<p><b>Videos:</b></p> <p><b>Nitrogen Importance:</b> <a href="#">Understanding Our Soil</a> (4 minutes)</p> <p><b>Phosphorus Importance:</b> <a href="#">Soil Nutrients and Phosphorus</a> (3 minutes)</p> <p><b>Potassium Importance:</b> <a href="#">Potassium Requirements for your plants</a> (3 minutes)</p>
10 min	Fill out plant observation guide	<b>Student Handouts:</b> 1) <a href="#">Plant Observation Log</a>
<b>Suggested End of Day 5</b>		

Day 6		
Timing	Activity	Materials needed
30 min	<p>Using the NPK and pH test strips, determine if there is an element we would need to add to our garden to enrich the soil, or if they are all at healthy levels. Some of the materials that they could use to organically help balance the soil could include:</p> <ul style="list-style-type: none"> <li>● <b>Nitrogen:</b> coffee grounds, manure, fresh cut greens, cover crops</li> <li>● <b>Potassium:</b> Banana peels, citrus rinds, wood ash</li> <li>● <b>Phosphorus:</b> Fresh compost, bone meal</li> </ul>	<p><a href="#">NPK Test Strips</a></p> <p><b>Worksheet - <a href="#">NPK Testing</a></b></p> <p><i>Examples of some of the materials that they could use to organically help balance the soil could include:</i></p> <ul style="list-style-type: none"> <li>● <b>Nitrogen:</b> coffee grounds, manure, fresh cut greens, cover crops</li> <li>● <b>Potassium:</b> Banana peels, citrus rinds, wood ash</li> <li>● <b>Phosphorus:</b> Fresh compost, bone meal</li> </ul>
10 min	<p>Discuss as a class: What NPK and pH levels were the soil samples? Did everyone's soil type have the same results? Are there any trends in what levels were found in different areas? What could lead to this?</p>	
10 mi	<p>Fill out plant observation guide</p>	<p><b>Student Handouts:</b></p> <p>1) <a href="#">Plant Observation Log</a></p>
<b>Suggested End of Day 6</b>		

Day 7		
Timing	Activity	Materials needed
10 mins	<p>Discuss as a class: Yesterday they may have seen that NPK levels were depleted in some of their soil samples. While we are able to add things like coffee grounds, banana peels, and compost on a small scale, how would this look in larger agriculture settings?</p> <p>What are some methods that farmers currently use to increase their crop yields?</p>	
30 mins	<p>Assign students one of the three articles (jigsaw w/group) &amp; class discussion about the inoculating legume plants with nitrogen and the role of mycorrhizal fungus in plant growth.</p>	<p><b>Article:</b></p> <ol style="list-style-type: none"> <li>1. <a href="#">Inoculating legume plants with nitrogen</a></li> <li>2. <a href="#">Introduction to Mycorrhizal Symbiosis</a></li> <li>3. <a href="#">What Are the Benefits of Growing Multiple Crop Species Together?</a></li> </ol>

		<a href="#">What is a jigsaw?</a> <a href="#">Jigsaw Template</a>
10 min	Time for students to apply what they have learned - have them take the Nitrogen Cycle challenge. They are able to choose where they would like to look at the nitrogen cycle as it is used in agriculture, and answer questions based on how nitrogen is fixed through the process. If students answer incorrectly, the challenge will tell them the correct answer and why.	<a href="#">Nitrogen Cycle Challenge</a>
10 min	Fill out plant observation guide	<b>Student Handouts:</b> 1) <a href="#">Plant Observation Log</a>
<b>Suggested end of Day 7</b>		

<b>Day 8</b>		
<b>Timing</b>	<b>Activity</b>	<b>Materials needed</b>
30 min	<p>Students will analyze a DataNugget showing the scientific research featuring clover and rhizobia growth when fertilizer is added as variable to the soil.</p> <p>Begin by reading the background information about Iniyān's research and discuss as a class the connections students have to the lab they are currently completing. How do they think Iniyān's research will be similar to theirs? How is it different? What do they think is going to be the outcome of the experiment?</p> <p>Looking at the initial graph, students should discuss with their groups the independent and dependent variables for this data.</p>	<p><b>Data Nugget Link:</b> <a href="#">Cheaters in Nature</a></p> <p><i>There is a teacher's guide to accompany this lesson with answers, tips, and additional information you can use in your class. In order to access that material so it is not widely distributed online, you can submit a request located at the top of the page. You should be approved within 3 days.</i></p> <p><i>**Note, the difference in student versions refers to the graphs supplied in the DataNugget. Graph type A contains a graph already completed for students to analyze, Graph type B has students graph some of the data, and Graph type C has students graph all of the data. It is recommended for this lab that you use Graph type A.</i></p>
20 min	<p>Discuss the data Iniyān found as a class. What do they notice about the rhizobia levels in the soil that had fertilizer vs soil that did not have fertilizer? Students should mark the graphs with as many statements about the data as they can see.</p> <p>For example - the hybrid clover had an average of 9.04 cms as a stem height, and the white clover had an average stem height of 9.98 cm in the low nitrogen environment</p>	

	End DataNugget for the day, complete the second portion in the next class period.	
10 mi	Fill out plant observation guide	Student Handouts: 1) <a href="#">Plant Observation Log</a>
<b>Suggested End of Day 8</b>		

<b>Day 9</b>		
<b>Timing</b>	<b>Activity</b>	<b>Materials needed</b>
50 min	<p>Students will analyze a DataNugget showing the scientific research featuring clover and rhizobia growth when fertilizer is added as variable to the soil.</p> <p>Discuss the data Iniyon found as a class. Using the data that students found yesterday, they will work with their groups to make a scientific claim, explain the evidence that was important throughout the lab to answer Iniyon's question, and write their reasoning using the data. If this is the first time your class has written a CER response, more time may need to be spent on this process.</p> <p>Students will work together in their groups to complete the second portion of the DataNugget lab.</p> <p>If you have extra time, students can write their CER response on posters and the class can complete a gallery walk to see the CER response other groups concluded from the data.</p>	<p><b>Video to share:</b> <a href="#">Plant Microbe Interactions</a>  <b>Data Nugget Link:</b> <a href="#">Cheaters in Nature</a></p> <p><b>Link to teachers guide - <a href="#">click here</a></b></p> <p><a href="#">CER Explanation</a> - High School  <a href="#">CER Explanation</a> - Middle School  (although these are suggested grade levels, please use the video explanation that you feel works best for your classroom)</p> <p><a href="#">CER Template</a></p>
10 mi	Fill out plant observation guide	Student Handouts: 1) <a href="#">Plant Observation Log</a>
<b>Suggested End of Day 9</b>		

### **3-4 weeks later for harvesting**

<b>Harvesting Day 1</b>
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Timing	Activity	Materials needed
5 mins	<p>Ask students “What do you expect to see when we harvest the plants?”</p> <p>If students do not mention anything about the roots, prompt them to also look under the soil.</p>	<p>Slides - <a href="#">Page 7</a></p>
5 mins	<p>Revisit initial hypothesis Have students look back on their initial hypothesis worksheet.</p> <p>Next, take a poll by raising hands to the following questions:</p> <p>What group did you think would grow best? What group did you think would not grow the best?</p> <p>Share within groups:</p> <p>Why did you make these hypotheses?</p>	<p>Slides - <a href="#">Page 8</a></p>
20 min	<p>Following the harvesting procedure, have each group harvest their 2 plants.</p>	<p>Slides - <a href="#">Page 9, 10 and 11</a></p>
10 min	<p>Measure &amp; Record Observations of the harvested plants. Next, discuss as a class what information should be recorded.</p>	<p><b>Student Handout:</b> <a href="#">Plant Harvest Data Collection</a></p> <p><i>On this worksheet: Record observations, both qualitative and quantitative. Decide as a class what information should be recorded on their observation sheets. (For instance, height, nodule #s, mass, color, etc.) Students make a drawing of their plant. Explain this can be the entire plant and a zoomed in section if you see something that looks interesting or you feel should be documented.</i></p>
5 mins	<p>Instruct students to find at least one other group to compare plants with &amp; discuss if any data trends they found were shared between the groups.</p>	<p>Slides – <a href="#">Page 13</a></p>
10 mins	<p>Individually, students should reflect on their hypotheses and determine if their guesses were supported or unsupported using the data. They should stop when they get to the post lab questions.</p>	<p><b>Student Handout:</b> <a href="#">Reflecting on your hypothesis</a></p>
<p><b>Suggested end of Harvesting Day 1</b></p>		

Harvesting Day 2		
Timing	Activity	Materials needed
10 mins	<p>Generate and record new questions and ideas that students have about the results from their lab. Examples: Why do the legumes have bumps and the grass does not? Why do some plants grow better with bacteria?</p> <p>Prompt students to move away from “What” questions to “How” &amp; “Why” questions</p> <p><i>Ex: “How do the bumps form?” “Why don’t the bumps kill the clover?”</i></p> <p>Have students share their questions in small groups and write two questions on a post and stick them on the board.</p>	Slides - <a href="#">13 and 14</a>
25 mins	<p>Read article (jigsaw w/group) &amp; class discussion about the bacteria impact on the clover plants</p> <p>Students can work independently, read as a class or do a jigsaw with their group.</p> <p><i>Note: The questions on the document are optional but could be a good supplement.</i></p> <p>Go over student questions: -Which questions were answered? -What questions do we still have?</p>	<p><b>Article:</b> <a href="#">What makes some species successful Invaders?</a></p> <p><a href="#">What is a jigsaw?</a> <a href="#">Jigsaw Template</a></p>
15 mins	Using information from the lab and the jigsaw reading, students should complete their student handout and post lab questions.	<b>Student Handout:</b> <a href="#">Post-Lab Questions</a>
<b>Suggested end of Harvesting Day 2</b>		

Harvesting Day 3 - Assessment		
Timing	Activity	Materials needed
15 mins	Review concept mapping and modeling of interactions.	<a href="#">How to create a scientific model in your classroom</a>
35 mins	Using provided images for the processes that take	<a href="#">Scientific Model</a> template and grading rubric

place in the clover, students create a concept map to act as their summative assessment to illustrate and explain the beneficial species Interactions that take place between legumes and rhizobia.	
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**Suggested end of Harvesting Day 3**