How do small things make a big difference?

Microbes, ecology, and the tree of life

Lesson 4: What does a microbial ecosystem look like?

I. Overview

Students continue their exploration of microbes by looking at how microbes interact with each other to form ecosystems. Students first discuss traditional food webs and ecosystems and then transfer that discussion to a microbial ecosystem contained in a jar, a Winogradsky column. Students create a model of nutrient cycling in the Winogradsky column and use their model to predict and explain different aspects of the ecosystem such as how perturbations to the system influence microbial populations. The lesson strives to alter students' perception of what makes up an ecosystem, introduce metabolic diversity of microbes, and explore interdependence of populations.

Connections to the driving question

In order to answer "How do small microbes make a big difference?" students must understand the metabolic diversity of microbes and their ability to cycle nutrients. In this lesson students account for the metabolic needs and waste products of different microbes by constructing a model of nutrient cycling in a Winogradsky column. By building this model students gain an understanding of concepts of population interactions among microbes that can be applied to a multitude of microbial environments and ecosystems.

Connections to previous lessons

Previous lessons set the stage by covering the history of microbial classification, and highlighting the ubiquity and diversity of microbes. This lesson furthers these concepts by showcasing the metabolic diversity of microbes and illustrating how much is happening at the microbial scale in a simple jar of dirt.

II. Standards

National Science Education Standards

- The atoms and molecules on the earth cycle among the living and nonliving components of the biosphere. (Grades 9-12 The interdependence of organisms 4.1)
- Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years. (Grades 9-12 The interdependence of organisms 4.3)

- All matter tends toward more disorganized states. Living systems require a continuous input of energy to maintain their chemical and physical organizations. With death, and the cessation of energy input, living systems rapidly disintegrate. (Grades 9-12 Matter, energy, and organization in living systems 5.1)
- The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials. (Grades 9-12 Matter, energy, and organization in living systems 5.5)

Benchmarks for Science Literacy

Interdependence of Life

- Ecosystems can be reasonably stable over hundreds or thousands of years. As any population grows, its size is limited by one or more environmental factors: availability of food, availability of nesting sites, or number of predators. (5D/H1)
- If a disturbance such as flood, fire, or the addition or loss of species occurs, the affected ecosystem may return to a system similar to the original one, or it may take a new direction, leading to a very different type of ecosystem. Changes in climate can produce very large changes in ecosystems. (5D/H2)

Flow of Matter and Energy

- The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. At each link in a food web, some energy is stored in newly made structures but much is dissipated into the environment. Continual input of energy from sunlight keeps the process going. (5E/H3)

III. Learning Objectives

Learning Objective	**Assessment Criteria**	**Location in Lesson**
Define and use the terms organism, population, community, and ecosystem	• Organism – An individual living thing that shows all the characteristics of life. • Population – A group of organisms of one species that interbreed and live in the same place at the same time • Community – All populations living in the same space and time • Ecosystem – A system that includes all the living and non-living things in an area acting as a unit. • Students use these terms correctly within the context of microbes in the Winogradsky column.	Terms are defined in the opening and used throughout the lesson.

Describe the metabolic diversity of microbes	Student descriptions include: • Microbes have very diverse metabolic properties. • There are many different types of microbes using different sources of energy including: light, oxygen, carbon dioxide, sulfate, sulfide, methane, hydrogen, glucose, alcohols and water. • Different microbes produce a variety of molecules including oxygen, carbon dioxide, sulfate, hydrogen sulfide, alcohols, hydrogen, sugars, and methane that other microbes can use as energy. • To make new cells and grow, some microbes need to eat sugars while many others make sugars from carbon dioxide, much like plants.	Activities 1 & 2
Develop and explain a model of nutrient cycling among microbes in the Winogradsky column	Students develop a model that accurately represents cycling of nutrients by indicating where inputs come from and where outputs go. Students are able to articulate what the model shows as well as its limitations.	Activity 2
Explain the stratification of microbes in the Winogradsky column based on the availability of resources.	Student explanations include: • The gradients of available oxygen and other resources within the Winogradsky column. • How the availability of oxygen, light, and other resources and the requirements of different microbes determine which microbes can be found in different areas of the column. • How the inputs and outputs of microbes establish gradients and in doing so define which microbes are present in which locations.	Activities 1 & 2
Use the model of microbial nutrient cycling to predict impact of perturbations on the ecosystem.	Student explanations: • Accurately predict which organisms would be affected by a given disturbance. • Extend beyond one step of causality to show a chain of causality to discuss multiple indirect effects of a given case of disturbance.	Activity 2

IV. Adaptations/Accommodations

Students develop a model of nutrient cycling among microbes in the Winogradsky column. This modeling activity can be simplified by decreasing the number of organisms and focusing only on specific cycles. The activity can also be adapted for more advanced classes by adding more robust information and student questions about the chemical reactions involved in the metabolic processes.

Safety

Soil samples used to build Winogradsky columns should generally only contain non-pathogenic microbes. However, it is always best to practice safe science. As such, students and teachers should be careful to not directly touch, consume, or inhale contents of the Winogradsky columns. When handling the Winogradsky columns, make sure lids are tightened and secure. However (and this is very important), make certain not to store the columns with lids tightened. **Columns must be stored with the lids loose. Gases produced by microorganisms can build up quickly and must be allowed to escape to avoid a build-up of pressure that may lead to column explosion.**

V. Timeframe for lesson

Opening of Lesson

- 10-15 minutes

Main Part of Lesson

- Activity 1: 20 minutes
- Activity 2: 30 minutes

Conclusion of Lesson

- 10 minutes

VI. Advance prep and materials

Opening

Materials:

- Organism cards (*U9_L1_Cards_TreeOfLifeActivty p. 1-3)*

Preparation:

- Have these cards ready from Lesson 1 of the unit or print and cut additional ones

Activity 1: Building and observing Winogradsky columns

Materials:

- Materials for building Winogradsky columns— refer to the "Winogradsky Column Protocol" resource *(U9_L4_Resource_WinogradskyColumnProtocol)*
    - Collect enough materials to pre-make one set of columns and also to have groups of students build their own columns in class
- Student Packet: Inside a Microbial Ecosystem (*U9_L4_StudentPacket_InsideAMicrobialEcosystem)*
- Resource: A Brief Microbial Field Guide *(U9_L4_Resource_BriefMicrobialFieldGuide)*

Preparation:

- Build the Winogradsky columns at least 4-6 weeks in advance. Refer to the "Winogradsky Column Protocol" resource.
- For students to build Winogradsky columns in class:
    - Prepare base mixture for Winograsky columns (Refer to "Winogradsky Column Protocol")
    - Bring in (or have students bring in) sediment samples
- Makes copies of the student packet "Inside a Microbial Ecosystem" - 1 copy per student
- Make copies of the Resource: A Brief Microbial Field Guide – 1 copy per group

Activity 2: Nutrient cycling in an ecosystem

Materials:

- Cards: Winogradsky Microbe Metabolism *(U9_L4_Cards_MicrobesMetabolism)*
- Template: Winogradsky Column *(U9_L4_Template_WinogradskyColumn)*
- Student Packet: Inside a Microbial Ecosystem (*U9_L4_StudentPacket_InsideAMicrobialEcosystem)* – students will continue to work on this packet from Activity 1
- Legal size laminate sheets
- Dry erase markers
- Microbe cards from Lesson 3 (*U9_L3_Cards_Microbes.pdf)*

Preparation:

- Make copies of the Winogradsky Microbes Metabolism cards. Each page is one set of cards. Print 1 set per every pair of students.
- Cut the cards as indicated by the dashed lines.
- Make copies of the Winogradsky Column Template on legal sized paper – 1 per every pair of students. (Be certain to select "Actual size" in the print options.)
- Laminate the Winogradsky Column Template copies so that students can write on them with dry erase markers.

- Check to see that students still have the packet "Inside a Microbial Ecosystem" that was given to them in Activity 1.
- Have copies of the Microbe cards from Lesson 3 (*U9_L3_Cards_Microbes.pdf)* available for students to reference (each group should have a set of 7 cards that correspond to the microbes in this activity).

VII. Resources and references

Teacher resources

- Dyer, B.D. (2003). A field guide to bacteria. Ithaca, NY: Cornell University Press.

References

- Dyer, B.D. (2003). A field guide to bacteria. Ithaca, NY: Cornell University Press.
- Perkins, D.N., & Grotzer, T.A. (2005). Dimensions of Causal Understanding: the Role of Complex Causal Models in Students' Understanding of Science. *Studies in Science Education, 41*(1), 117-165.

VIII. Lesson Implementation

Opening of Lesson:

To start the lesson, tell students that the first two lessons focused on evolutionary relationships and in the last lesson they learned more about different kinds of microbes. By understanding this information about microbes we can learn more about individual organisms and how they interact with other organisms in their environment. Next, show students the organism cards from the first lessons and ask them to draw any interactions between organisms that they can think of. To provide additional instructional support, start by holding up the lion card and the gazelle card. Ask “how do these two organisms interact?” Next show the gazelle card and the grass card, asking the same question. Finally show the lion and the grass and ask how these two organisms interact in the environment. Where do they get their energy?

Allow students to work on this in groups of 2-3 for several minutes. Facilitate and support students’ thinking as they work through this activity. For example, some students may not immediately recognize the lion and grass are connected through the gazelle. Encourage students to identify and discuss these important indirect interactions as well. Ask students “If the grass population started to flourish, would this affect the lion population size?”

When students have drawn their ideas of the different connections between organisms, ask some groups to share their drawings with the class. As a class, discuss the similarities and differences in the organisms the students used, the connections they made and the levels of complexity they indicated in their drawings. Ask them to note the inputs (what organisms take in) and outputs (what organisms produce) necessary to keep this ecosystem running. This discussion works to bring forth student preconceptions on what an ecosystem is and how organisms interact within that ecosystem.

Next, ask students to define the following words in the context of their drawing: Organism, Population, Community, and Ecosystem. For example, students could say that a cheetah and a piece of grass are single organisms, while all the cheetahs are a population. Students will likely not know the difference between population, community, and ecosystem but can be guided in the right direction. The purpose is to introduce these terms in a familiar context so that they can be used for discussion in unfamiliar ecosystems. Conclude this part of the lesson by agreeing as a class on the working definitions they will use in this unit.

- Organism – An individual living thing that shows all the characteristics of life.
- Population – A group of organisms of one species that interbreed and live in the same place at the same time
- Community – All populations living in the same space and time
- Ecosystem – A system that includes all the living and non-living things in an area acting as a unit.

Make connections back to previous lessons by asking:

- Do you think that microbes are part of an ecosystem?
- Do you think that microbes can be their own ecosystem?
- How big is an ecosystem?

Explain to the students that today they will be investigating what an ecosystem at the microbial level might look like.

Hand out the student packet *Inside a Microbial Ecosystem* and give students time to complete the first two questions before continuing to Activity 1.

Crosscutting Concepts: Scale, proportion, and quantity

When studying systems and processes in science, it is important for students to recognize the size and scale at which they are working and to realize that systems can be studied at different scales. The opening of this lesson facilitates student understanding of scale in ecosystems by first beginning with the larger, more familiar scale of animals such as lions, vultures, zebras, and plants and then moving to an ecosystem at a microscopic scale—a microbial ecosystem.

Main Part of Lesson

Safety

Soil samples used to build Winogradsky columns should generally only contain non-pathogenic microbes. However, it is always best to practice safe science. As such, students and teachers should be careful to not directly touch, consume, or inhale contents of the Winogradsky columns. When handling the Winogradsky columns, make sure lids are tightened and secure. However (and this is very important), make certain not to store the columns with lids tightened. **Columns must be stored with the lids loose. Gases produced by microorganisms can build up quickly and must be allowed to escape to avoid a build-up of pressure that may lead to column explosion.**

Activity 1: Building and observing Winogradsky columns

Show students a Winogradsky column and explain that it is a way for scientists to study microbes in a more natural setting. Another popular technique in microbiology is for scientists to culture and study a single microbe species at once in a petri dish. Ask students to come up with pros and cons of studying a single species of microbe versus studying an ecosystem of microbes. After this discussion students should see that the Winogradsky column is a way to study microbes in a setting that is similar to their natural environment and ecosystem. In the lesson, the column is used to aid the discussion of how microbes interact with each other.

Teacher Pedagogical Content Knowledge

Winogradsky columns take about 4-8 weeks to develop visible microbial growth. Students can either prepare their Winogradsky columns well in advance of doing this lesson or they can prepare the columns as a part of this lesson. If students prepare the columns during the lesson, have some columns (ideally one per group of students) pre-prepared and ready for students to observe microbial growth for this lesson. The Winogradsky Column Protocol document contains additional information on this topic.

No matter when students build their own columns, have them make weekly observations of how the microbial colonies develop in the column over time. In addition to weekly observations, a neat way to track and visualize changes to the Winogradsky columns over time is to create a time lapse video. Using a digital camera or webcam plugged into a computer, students and/or teachers can collect a daily photo of the column. At the end of a few weeks to months, these images can be strung together to make a time lapse movie of how the microbial populations in the column developed and changed over time. Be sure to always take the photo at the same distance and angle from the column. (It is likely best to set up the column and the camera and not move the setup until the time frame of recording is finished.) Additionally, a ruler can be taped into the frame in order to facilitate even more precise observations. Creating a time lapse video helps students to visualize development of the Winogradsky columns and is also a way for them to experience and think about long-term data collection in science.

To begin this portion of the lesson, if students did not participate in making the columns they will observe for this lesson, provide them with a description and photos of the source from which the sediment was collected. Also give them information about how the column was constructed and what ingredients were used. If students were involved in collecting the samples and building the Winogradsky columns, ask them to recall this information. This will help students to identify and understand the microbial community that is growing in the columns.

Ask students to work in groups of 2-4 to examine the Winogradsky columns and write down 5 observations about what they see in the column. There is a space on the student sheet for them to record these observations. The goal with these initial observations is for students to begin thinking about what they are looking at in the column and asking questions about microbial communities. Discuss students' initial observations and questions as a class. Address questions such as the following:

- What do you think is happening in the column?
- What are the different colors?
- Microbes are microscopic, but even without a microscope, how can we tell there is microbial growth?
    - When microbial populations are at a high density of cells, they, as a group, can be seen without the aid of a microscope. For example, the colors in the Winogradsky column represent dense populations of microbes that were always in that sample of sediment. However, at the site of collection, they were likely not visible due to the relative sparseness of the cells.

After discussing students' initial observations as a class, continue on to the identification of different microbial populations. Tell students that the "A Brief Microbial Field Guide" packet has information on microbes that are likely in the Winogradsky column in front of them. Using the field guide, ask students to identify 3-5 types of microbes they think might be in their Winogradsky column and explain why they think so. Also, ask students if there are any microbes mentioned in the field guide that are highly unlikely to be in their columns? For example, Halophiles only live in saltwater environments and therefore would likely not be found in a sample of fresh water sediment.

Activity 2: Nutrient cycling in an ecosystem
Explain to students that they just identified some of the types of microbes that might be in the Winogradsky column. Next, they will look at how microorganisms interact with each other and how those interactions allow them to exist together in an ecosystem. Additionally, one of the most important characteristics that allow for differentiating and grouping microbes is their metabolic properties; that is, what they breathe and eat, to get the energy they need to live and build new cells. In this activity, students will look at the metabolic aspect of microbial diversity and the types of ecosystems this can lead microbes to form.

Teacher Content Knowledge

We eat plants or animals for sugars and breathe oxygen for energy. And, as a result of making energy in this way, we produce carbon dioxide. We get the building blocks to make new cells and proteins from the sugars, amino acids, lipids and other carbohydrates in the food we eat (i.e. plants and animals). Some microbes do this too, savaging and consuming the components (like sugars and other amino acids) from dead cells to have the building blocks for new cells. Microbes can have very diverse sources of energy including different types of chemicals. For example, some can eat hydrogen sulfide and breathe oxygen, or eat hydrogen and breathe iron. Some microbes make energy from light + H_20 or light + H_2S. Most microbes that get their energy from chemicals or from light make their own building blocks and sugars from

	carbon dioxide, just like plants.

The students' task in this activity is to create a model of how the microbes in the column make up a web of nutrient cycling. Hand out the student materials which include the Winogradsky Column Template and a set of microbe cards with the inputs and outputs indicated. Begin by having students look at the Winogradsky Column Template. Explain that this is a simplified representation of their Winogradsky column. Each different colored layer in this drawing represents a different level of oxygen along an oxygen gradient and different sets of microbes living in that layer. Have students compare this illustration to their actual columns asking questions such as:

- How does this illustration look similar or different from your column?
- Are the layers as clear and distinct in the real column?
- How might illustrating the column in this simplified, clear-cut way help us to understand the ecosystem inside the column?

Next, have students look at the organism cards. Each card shows an image and name of a microbial species or genus that is commonly found in most Winogradsky column sample sites. The cards also indicate each microbe group's metabolic properties: what they take in through breathing and eating (the inputs) and what they produce (the outputs, what they breathe out). Again, have students reflect on how the organism cards compare to the real column by asking questions such as:

- How might the microbes shown on these cards be similar and different from what is in your column?
- Do you think there are exactly this many (referring to number of cards) microbes in the actual column? Are there more or less?
- What information might this model help us to learn? What information might it leave out?

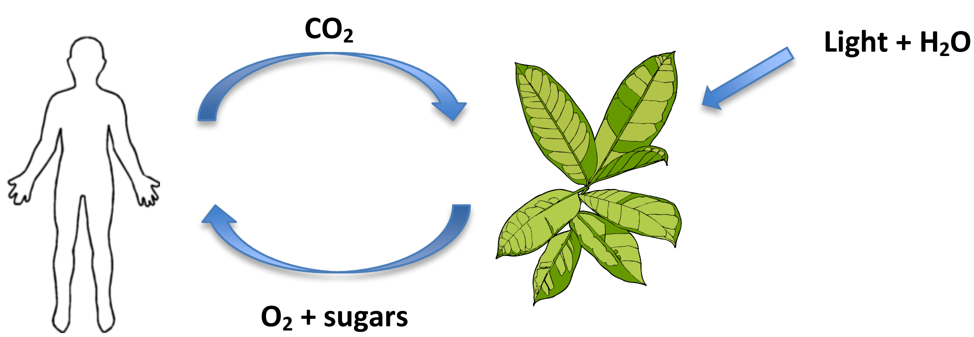
Through the discussion, explain that the organisms that are included in the activity are microbes that can be found in most sediment environments. While there are most likely more than just these species of microbes in the Winogradsky column, the activity is used as a simple model to understand the complex interactions of populations of microbes and the abiotic factors in their environment.

	Teacher Pedagogical Content Knowledge The instructional goal of this activity is to have students work with a simplified model of nutrient cycling in order to learn about the types of molecules that are cycled between organisms and the diversity of life's metabolism. The lesson also teaches larger ecological concepts such as: there is a complex web of interdependence between organisms in an ecosystem and nutrients cycle between organisms in an ecosystem. In order to support this bigger picture understanding, some of the details about the nutrients were simplified for the student materials. The organism cards, for

	example, indicate the basics of the different microbes' metabolic properties but do not always show all inputs and outputs of that organism. They also often show only one of several metabolic modes of organisms that can switch between different modes of metabolism. Also, the compound "sugars" represent different sugars such as glucose, but also several different types of carbon compounds including biomass, polymers, lipids, and amino acids.

Explain that the goal of this activity is to develop a model of the nutrients being cycled within the Winogradsky column. Each colored layer on the column template represents a group of organisms that live at different oxygen levels. Oxygen is the key component defining this system. Some organisms need to breathe oxygen to get energy. However, to many other organisms, oxygen is toxic and they will die if they come into contact with it. Each output molecule is used by another microbe (sometimes more than one) as its input. This task is similar to putting together a puzzle. The goal is to arrange the organisms in the correct part of the column and draw arrows indicating the movement of the nutrients throughout the system. Nutrients (inputs and outputs) can move between layers but organisms only grow where they have the resources they need. Remind students that this is similar to their previous food web drawing, but many microbes use molecules as their food sources rather than whole organisms. Some microbes rely on sugars scavenged from other microbes (similar to us eating plants and animals). These sugars are not listed as products because they took energy to build and are part of the living cell, not a by-product of metabolism. These sugars become available to other heterotrophic microbes when the cell dies or leaks its contents into the environment.

Give students the following example as a way to help them think through this activity. Humans need the inputs O_2 and sugars to survive and produce the output CO_2. Plants need the inputs light and water for energy and CO_2 to produce sugars. They use this energy and CO_2 to build sugars and release O_2 in the process (therefore, outputs are O_2 and sugars). Other organisms, like humans, who cannot make sugars can consume these sugars to build their own cells. Therefore, to show the cycling of nutrients between humans and plants, an arrow labeled “O_2 & sugars” would be drawn from plants to humans and an arrow labeled “CO_2” would be drawn from humans to plants. There would also be an arrow indicating that plants need light and water.



Teacher Pedagogical Content Knowledge

The nutrient cycling modeling activity can be adapted for different levels. To make the activity simpler, the number of organisms can be reduced and the focus can be drawn to particular cycles (i.e. sulfur cycling between Rhodopseudomonas and Desulfovibrio). To modify the activity for a higher level class or for a chemistry class, the inputs/outputs information can be made more robust, so students can work with complete chemical equations.

When completing the nutrient cycling modeling activity, it is important to understand that while microbes may be found in a specific zone (ex: the anaerobic zone), that within that zone, microbes will not be found in specific layers. For example, in the student modeling activity, the three anaerobic species: methanogens, clostridia, and desulfovibrio should be in the bottom anaerobic zone of the column. Within the column, these 3 species can be found in any order. The important thing for students to show is the nutrient cycling that occurs among these three species and between these microbes and microbes in other zones.

Ask students to work in groups of 2-3 to use the information provided to develop a model of the nutrients cycled within the Winogradsky column. After some time, if students are struggling, guide them to use additional information from the Lesson 3 Microbe Cards and A Brief Microbial Field Guide to help them develop their model of nutrient cycling. To determine where the different organisms fit within the column template, students need to be aware of the availability of inputs in various parts of the column. The oxygen gradient is the primary driver of the arrangement of microbes in this column. Lead a discussion to draw students' attention to this important factor in their model.

- Where is oxygen highest and lowest in the column?
    - More oxygen is available at the top of the column and the availability decreases as you go deeper down into the column. (This is due to the fact that the oxygen produced at the top of the column is consumed before it can reach the bottom.)
- So, what types of organisms might you see near the top?
    - Students will likely say that organisms that need oxygen will be near the top. However, remind students that the gradient is also because of which organisms are producing oxygen. Oxygen producers would likely also be found near the top.
- Ask students to think about their microbe cards from the previous lesson: Do you remember talking about the words "aerobic" and "anaerobic"? Knowing about the oxygen gradient, where would you expect to find organisms that live in an aerobic environment? An anaerobic environment?

Another factor of the model students may be struggling with is the input sugar. As some students may already have observed and asked about, sugar is listed as an input for two of the microbes, but none of the microbes are shown to be producing sugars. To help students with this, ask them to think about what they know from previous biology classes or even from the microbe cards in the previous lesson. Do organisms make sugars? Which ones? Some students may pick out that cyanobacteria (a primary producer and autotroph, like plants) produces glucose. They are correct, but all organisms make some form of sugars. These sugars then become available in the environment as organisms die and leak out the sugars. Therefore, students can think of the Clostridium and Vibrio as getting sugars from all of the other microorganisms.

Student Misconceptions

Some students may not realize that the column contains a very large quantity of these molecules. Be prepared to address this possible misconception by explaining that each microbe does not produce only a single molecule at a time, but rather the cards represent a population of microbes that are producing lots of molecules as they grow that then exist in the environment. The molecules do not always immediately travel from one microbe to another, they can be present in the environment or can be used by different populations of microbes simultaneously.

Once students have constructed their models, stop them for a class discussion about their models. Have students compare their model to the group next to them. Do their models look the same or different? How and why?

Ask students to consider the explanatory power as well as the limitations of the model. Have them discuss questions such as:

- What can we learn from this model?
- What are the limitations of this model?
    - In what ways is the actual ecosystem more complex than the model?
    - What additional kind of information would you want to know or add to this model?

Scientific Practices: Developing and using models

Models are an important tool that scientists use to represent, study, and manipulate scientific phenomena. Here students have developed a model to begin describing what microbial communities look like, how nutrients are cycled between them, and interdependency of organisms. In addition to developing models, it is also important for students to evaluate the explanatory power and the limitations of their model. Like all scientists, they must recognize that although this model serves a valuable purpose

	in helping to explain and understand a scientific phenomenon, it does not perfectly represent what happens in nature. Therefore, when developing and using models, it is important for students to stop and consider the advantages and shortcomings of their model and to work within those limits.

Following the class discussion about the nutrient cycling model, students can move on to the additional questions in their student packet. Students should continue to work in their groups to discuss and answer the questions.

The questions after students build their model encourage students to think about how disturbances in the ecosystem not only affect the one or two organisms directly involved, but can affect the entire ecosystem. While students often understand the direct effects that a disturbance on an ecosystem can cause, there can be many more indirect effects that may not be immediately apparent to students. Even scientists have trouble predicting what effects changes to an ecosystem will have on the ecosystem as a whole. Since all of the populations of organisms in the students' model of the Winogradsky column are linked, removing one will destabilize the community as a whole. (An understanding of these concepts will be important later in Lesson 6.) Students should recognize that ecosystems are complex; actions do not always lead to definitive consequences, but by knowing about the ecosystem we can come up with reasonable hypotheses.

	Student Misconceptions Research in science education shows that students have difficulty thinking about complex causal patterns in science. In the case of ecosystems, students may be able to acknowledge a direct effect of a particular disturbance (or cause). However, without scaffolding, students will likely not recognize multi-step causality or multiple effects caused by a single disturbance. However, when provided with explicit scaffolds for recognizing complex causal patterns, students can begin to explain the extended effects of a disturbance on an ecosystem. (Perkins & Grotzer, 2005)

For the questions in the packet about manipulating the Winogradsky column, the focus is more on students' abilities to provide answers that consider more than only direct effects and include sound reasoning based on the information contained in their model. Below are some examples of possible answers.

- Question: If you blocked light from the Winogradsky column, how would the Cyanobacteria and Rhodopseudomonas be affected? Would this affect the other bacteria in the column? Explain your answer.

  - *Example answer: The Cyanobacteria and Rhodopseudomonas would not be able to survive for an extended period of time because they would not be getting energy from light. After they die out, less oxygen will be available for Vibrio and Methylococcus, so they will also eventually die out as well. Also, sulfate won't be available for Desulfovibrio which will also be eliminated. Without Methylococcus, the Methanogens will not get enough carbon dioxide and will also die out. Without any other organisms in the column, Clostridium would also soon be gone because it won't have any sugars available.*

- Question: If you were able to remove Clostridium from the column without disturbing anything else, how would the other microbe species respond to this change in environment?
  - *Example answer: If Clostridium was removed, Methanogens and Desulfovibrio would not get the nutrients they need and their populations would decline. As a consequence, Methylococcus and Rhodopseudomonas would not have the inputs they need and their populations would decline as well.Cyanobacteria and Vibrio would still have everything they need and would survive.*

The student packet also guides students to think about metabolic niches in the Winogradsky column to explain the stratification of different types of microbes in the column. The availability of light, oxygen, and sulfide changes throughout the column. These gradients of available resources are critical to where microbes of different metabolic properties can be found in the column.

Conclusion of Lesson

To conclude this lesson and lead into the next, lead a class discussion about the last two questions from the student packet:

- Do you consider the Winogradsky column to be an organism, population, community, or ecosystem? Explain your answer.
- Do you consider yourself to be an organism, population, community, or ecosystem? Explain your answer.

Based on the working definitions established at the beginning of the lesson, students should be able to see that the Winogradsky column is a snapshot of the ecosystem that existed in the collected sample of sediment.

When discussing the second question of what a human could be considered, allow students to share different ideas and their thinking behind them. Students need not be correct or be led to any particular response to this question. The topic of the human microbiome, which this question begins to lead into, will be the focus of the next lesson. For now, gather the students' preconceptions and give them time to think about this question in preparation for the next lesson.