How do small things make a big difference?

Microbes, ecology, and the tree of life

Lesson 3: What are microbes?

I. Overview

This lesson defines the term “microbe” and introduces students to the diversity of microbes. Students first watch an engaging video that reviews some elements of the previous lessons about the place of microbes in the tree of life while making connections to what is to come as the unit continues to explore the different roles and ubiquity of microbes. The second activity scaffolds students’ concept of scale as they work with units and conversions to become more familiar with the microscopic scale. This concept of scale is then applied in the third activity where students make a “microbe mural”. To create the mural, students produce scaled up versions of different microbes and discuss aspects of microbial diversity such as their size, where they live, and their metabolic properties.

Connections to the driving question

This lesson provides students with essential background to answer the unit driving question. Students learn about how small microbes are (a defining characteristic), and how ubiquitous and diverse they are.

Connections to previous lessons

The previous two lessons tell the story of the tree of life and the role of microbes in that story. This lesson draws on this and shifts the focus entirely to the microbes they have been working to classify. Students discuss not only the domain-level classification of the microbes but also their size, where they live, and what they do.

II. Standards

National Science Education Standards

- Use technology and mathematics to improve investigations and communications. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results. (Grades 9-12 Abilities necessary to do scientific inquiry 1.3)

- Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results. (Grades 9-12 Understandings about scientific inquiry 2.4)

Benchmarks for Science Literacy

The Nature of Mathematics: Mathematics, Science, and Technology

- Mathematics provides a precise language to describe objects and events and the relationships among them. In addition, mathematics provides tools for solving problems, analyzing data, and making logical arguments. 2B/H3*

The Nature of Mathematics: Mathematical Inquiry

- To be able to use and interpret mathematics well, it is necessary to be concerned with more than the mathematical validity of abstract operations and to take into account how well they correspond to the properties of the things represented. 2C/H3** (SFAA)

The Mathematical World: Shapes

- Both shape and scale can have important consequences for the performance of systems. 9C/H6** (SFAA)

Habits of Mind: Computation and Estimation

- Use appropriate ratios and proportions, including constant rates, when needed to make calculations for solving real-world problems. 12B/H1*

III. Learning Objectives

Learning objective	**Assessment Criteria**	**Location in Lesson**
Students recognize the diversity of microbes	Students are able to identify the following elements of microbial diversity: • There is a range of sizes but all are microscopic • Microbes live in many different environments • Microbes can be found in all three of the domains • Microbes have many different metabolic properties (what they eat, breathe, and produce)	Activities 1 & 3

Students construct and use their own conversion tables to calculate measurements in different units.	Students' tables include: • The correct number of centimeters, millimeters and micrometers in **1 meter**, • The correct number of meters, millimeters and micrometers in **1 centimeter**, • The correct number of meters, centimeters and micrometers in **1 millimeter**, • The correct number of meters, centimeters and millimeters in **1 micrometer**.	Activities 2 & 3
Students identify the units that are used to measure different objects.	Students correctly identify the most appropriate units to measure several different objects.	Activity 2
Students use the concept of scale to calculate the new size of their microbes and to construct their microbes to scale.	Students correctly calculate the magnified size of their microbe using the assigned scale and accurately construct their microbes to scale.	Activity 3

IV. Adaptations/Accommodations

The video is critical for the first activity of this lesson. It is available online at http://neuron.illinois.edu/ and can be presented streaming online or downloaded for offline use if internet is not available in the classroom. A transcript of the video is also available in the lesson materials for those students who may need additional support in following the video.

This lesson requires students to use rulers in order to measure objects in different units and some students may not be familiar with using rulers. As a class, or in small groups, a discussion can be held to review how to properly use rulers, or the teacher can choose to perform the first measurement as an example for the class.

The lesson also involves converting from one unit to another, which can be challenging for students. A whole class or small group discussion or a teacher-led example on the board can help to show how conversions are calculated.

Safety

This activity requires students to use scissors. Students should be reminded to handle scissors carefully.

V. Timeframe for lesson

Opening of Lesson
- Discuss previous lessons and introduce today's topic – 5 minutes

Main Part of Lesson
- Activity 1: Microbes video and discussion – 20 minutes
- Activity 2: Microbial scale – 20 minutes
- Activity 3: Microbe mural – 40 minutes

Conclusion of Lesson
- Class discussion – 15 minutes

VI. Advance prep and materials

Activity 1: Microbes video

Materials:
- Microbes video (neuron.illinois.edu/videos/video-microbes)
- Microbes video transcript (U9_L3_Resource_MicrobesVideoTranscript)

Preparation:
- Set up a way for the class to view the video. It may be helpful to download the video prior to class so as not to rely on the internet connection. Be prepared to pause the video at different points to have discussions with the students (these pause times are indicated in the Lesson Implementation section below).
- (Optional) Print video transcript for students to read and follow.

Activity 2: Microbial scale

Materials:
- Student Sheet: Putting Microbial Scale in Context *(U9_L3_StudentSheet_PuttingMicrobialScaleinContext.docx)*
    - One copy per student
- Four customized rulers *(U9_L3_Rulers.pdf)*
    - One copy per group
- (Optional) YouTube video by NASA on measurement systems: http://www.youtube.com/watch?v=DQPQ_q59xyw
- YouTube video of how objects look under a microscope: http://www.youtube.com/watch?v=P-n5TbifUIQ

Preparation:

- Make copies of the student sheet, “Putting Microbial Scale in Context” – 1 copy per student.
- Print the rulers-1 set per group or pair of students. Each set contains one meter ruler, one centimeter ruler, one millimeter ruler and one micrometer ruler. Printing each ruler type on a different colored paper will help to easily distinguish rulers and ruler sets.
- Laminate and cut out the rulers. Prepare one set per group or pair of students.
- Set up a way for the class to view the videos. It may be helpful to download the videos prior to class so as not to rely on the internet connection.

Activity 3: Microbe mural

Materials:

- Magnified period
  - Piece of paper that is at least 250cm x 250cm (this is equivalent to approximately 8.5 ft x 8.5 ft).
  - Scissors, marker, tape
- Microbe cards (*U9_L3_Cards_Microbes.pdf)* – 1 card per student or pair of students
- Students’ microbes
  - Colored paper– 1-3 sheets per pair
  - Scissors – 1 per pair
  - Tape – can be shared
  - Marker – 1-2 per pair

Preparation:

- For the magnified period:
  - On the 250cm x 250cm piece of paper, draw and cut out a circle with a diameter of 250cm.
  - Place on floor or tape onto board/wall so that students can add their microbes to it later on in the lesson. If drawing an entire circle takes up too much space, brackets can be drawn or taped to simply indicate the edges of the circles.
- Microbe cards:
  - This document must be printed double-sided. The image and microbe name will appear on one side and the informational text will appear on the reverse.
  - Cut out the cards
- For students’ microbes:
  - Have materials ready to distribute so students can use the markers to draw their microbes to scale on their colored paper. Microbes can also be color-coded by domain, so that each eukaryote is one color, archaea another color, and bacteria a third color.
  - Students will cut their microbes and tape them onto the magnified period.

VII. Resources and references

Teacher resources

- Moreno, N.P., Tharp, B.Z., Erdmann, D.B., Clayton, S.R. & Denk, J.P. (2012). The science of microbes: Activity comparing sizes of microorganisms. Baylor College of Medicine. Retrieved from: http://www.bioedonline.org/tasks/render/file/index.cfm?fileID=A1289E74-BBD5-07E2-3BC4E155304E18D9
- Video by NASA explaining measuring in the ancient world and the advantages of our current metric and US standard systems for doing science. http://www.youtube.com/watch?v=DQPQ_q59xyw.
- YouTube video on how objects look under a microscope: http://www.youtube.com/watch?v=P-n5TbifUIQ
- Cell Size and Scale: http://learn.genetics.utah.edu/content/cells/scale/ (A simulation to visualize cellular scale. Developed by the Genetic Science Learning Center at University of Utah.)

References

- Ideas for Activity 3 were drawn from: Moreno, N.P., Tharp, B.Z., Erdmann, D.B., Clayton, S.R. & Denk, J.P. (2012). The science of microbes: Activity comparing sizes of microorganisms. Baylor College of Medicine. Retrieved from: http://www.bioedonline.org/tasks/render/file/index.cfm?fileID=A1289E74-BBD5-07E2-3BC4E155304E18D9
- Microbe Cards for Activity 3
  - MicrobeWiki (https://microbewiki.kenyon.edu/index.php/MicrobeWiki)
  - Stockner, J.D. (1988) Phototrophic picoplankton: an overview from marine and freshwater ecosystems. *Limnol Oceanogr.*, 33, 765–775.
  - Farquhar J, Bao H, Thiemens M. Atmospheric influence of Earth's earliest sulfur cycle. Science. 2000 Aug 4; 289(5480):756-9. PubMed PMID: 10926533.

VIII. Lesson Implementation

Opening of Lesson:

Begin the lesson by reviewing some of what students have learned thus far in the unit and bringing microbes into focus. Ask students questions such as the following:

- What have you learned so far about the tree of life model?
- Why did it change throughout history?
- What led to the more recent major shift?
- What does the current tree of life look like?
- What did microbes have to do with why the new model was developed?
- What does the new model tell us about microbes?

Explain to students that today they are going to delve into the rest of the unit which is all about microbes—some of the smallest members of the tree of life (depending on whether you include viruses or not!). By the end of this lesson, they should be able to answer the question "What are microbes?" What kinds of answers do they have to this question already?

Main Part of Lesson

Activity 1: Microbes Video

Explain to students that they will be watching a video about the roles and characteristics of microbes in each of the three domains of life (archaea, bacteria, and eukarya) that they have learned about.

As the video plays, pause it at different points to engage the class in brief whole-class discussions. The following are some suggested pause points and discussion questions.

- Pause at: 1:37 (right after the narration: "…to help synthesize proteins from their DNA code.")
    - What are microbes?
    - What do all microbes have in common?
    - What did the video say about how many microbes can fit on a tiny period?

- Pause at 3:05 (right after narration: "…oxygen in our atmosphere by photosynthesis.")
    - What did you learn about Bacteria?
    - Was there anything you did/didn't know before?
    - What did you find interesting?

- Pause at 3:40 (right after narration: "and most other places that you will find microbes.")
    - What did you learn about Archaea?
    - Was there anything you did/didn't know before?
    - What did you find interesting?
- Pause at 4:40 (…and can be transmitted by mosquitoes.")

  - What did you learn about Eukarya?
  - Was there anything you did/didn't know before?
  - What did you find interesting?

- Pause at 5:16 (right after: "…and animals fall into this category too.")
  - How are microbes in the domains eukarya, archaea, and bacteria similar?
  - How are they different?
  - What makes eukaryotic microbes different from archaea and bacteria?

After watching the whole video, lead a discussion about microbes by asking questions such as the following:

- If I told you what a particular microbe eats and excretes, would you know what domain it belongs to?
  - Have students expand on this by giving examples of energy sources for each group.
- If I told you where a particular microbe lived, would you know what domain it belongs to?
  - Ask students for specific examples.
- Before the three domain model, bacteria and archaea were classified together in the same kingdom. Why do you think biologists put them in the same group?
- How do the answers to these questions make molecular methods so important?
- What are some examples of how the different types of microbes are important for human health? Are all microbes good? Bad?
- What are some examples of how microbes are important in ecosystems?

After discussing the video, tell students that they will be focusing on a particular and defining characteristic of microbes for the next part of the lesson– their size. Tell them that they will start working with a unit of measurement that is essential for understanding the size of microbes and for studying them.

Activity 2: Microbial Scale

To begin the activity, ask students:

- What types of units of measurements have you used before? (Expect answers like feet, inches, centimeters, etc.)
- Do you know how big that unit is? (For example, if a student answered that they have used the unit of feet before, can he/she tell you how big a foot is?)

Explain to students that some units are bigger or smaller than others, which is why we need to convert units (for example, instead of saying that something measures 0.001 kilometers, you can simply say that it measures 1 meter). Ask students if they remember converting from one unit to another. (Example, from inches to feet, meters to kilometers, etc.) Tell students that today, they will review how to do this using several different units of measurement.

Ask students the following questions to get their concept of microscopic measurements:

- What units do you think microbes are measured in?
- What is the smallest unit of measurement you can think of?
- Can you see this unit? Can you see microbes?

After the discussion, explain that there are some units that are so small you can't see them with the naked eye. Show them the micron ruler. Explain that they are going practice converting between units they are familiar with, the meter, centimeter and millimeter, and then they will start using the unit used to measure microbe, the micrometer. In the first part of the activity, "Let's Measure!", they will measure several objects and will come up with their own conversion tables between these units which they will use later on in the lesson.

Arrange students into groups of 2-3 and hand out the 4 customized rulers to each group *(U9_L3_Rulers.pdf)*: one meter ruler, one centimeter ruler, one millimeter ruler and one micrometer ruler. Also give each student a copy of the "Putting Microbial Scale in Context" student sheet *(U9_L3_StudentSheet_PuttingMicrobialScaleinContext.docx)*.

Instruct students to follow the student sheet to measure several objects using all four rulers. Using their measurements, they will then construct their own conversion tables.

As students work in groups to complete the student sheet, walk around the room to assist students in their measurements and conversion tables. Some students might be confused with the rulers and the conversion units, therefore it is important to monitor student conversations and guide students who may struggle with the activity. Also, clarify to students that "micrometers", "microns", and the symbol "µm" are all the same things. They may see all three of these and should keep in mind, they are all different ways of referring to the same unit of measurement.

The following video may also be shown: http://www.youtube.com/watch?v=DQPQ_q59xyw. This video by NASA explains measuring in the ancient world and the advantages of our current metric and US standard systems for doing science.

After students complete Part 1 of the student sheet, discuss the questions out loud. To reflect on the different units and conversions, ask students additional questions such as:

- What do you find difficult about converting between units?
- Why is it useful to have different units of measurements?

Tell students that for the next section of the student sheet (Part 2: Using Units), they will be looking at how several different units of length are used to measure different objects. There is a list of objects that are measured in various units and they must write down what units they believe should be used to measure that object.

Have students work on Part 2 of the activity where they work in groups to determine what units are the most appropriate for measuring certain objects. This activity intends to help students better visualize the relative sizes of each unit.

After students have completed Part 2 of the student sheet, discuss out loud the confusions they might have about the units covered on it. If students need extra help visualizing the size of the units, these references might be helpful:

- One meter = the size of a meter stick, or approximately the size of a baseball bat
- One centimeter = approximately the width of an adult's fingernail
- One millimeter = approximately the thickness of a dime
- One micrometer = although very hard to reference, a human hair is between approximately 30-180 µm. Therefore, one micron would be between $1/30^{th}$ - $1/180^{th}$ parts of a single human hair.

In the discussion, make sure to reference item #3 on Part 2 of the student sheet. Verify that all students agree that microbes are measured in micrometers, since it is the main focus of the lesson. After discussing the main points of Part 2, take a few minutes to summarize the concepts covered in the student sheet:

- The differences between meters, centimeters, millimeters and micrometers
- The importance of conversion tables
- The importance of knowing which units to use to measure certain objects

Have students reflect on all the units they just reviewed (meters, centimeters, millimeters and micrometers). Ask them questions such as:

- Was there a unit in particular that was hard for you to visualize?
- What unit do you think is the most commonly used? Why?
- What unit do you think is the least used? Why?

If no one mentions the micrometer during this discussion, encourage students to think about how small this unit is by asking them:

- If a microbe is 1µm (like many of them are) how many would fit across the tip of their finger if they were lined up? Students can perform these calculations on the student sheet, on the 'Additional Calculations' section. After giving students time to calculate this and report out, emphasize this concept by telling them that microbes can measure between 1 and 200µm which means that 125-25,000 could be lined up across the tip of an average finger.
- To provide another example in order to emphasize the smallness of a micron, tell students that the average size (length) of a grain of salt (or the size of a period, which is what will be used later on) is 0.5mm. Ask them to calculate how many microns this would be using their

conversion tables from their student sheets (the answer is 500µm). Students can perform these calculations on the student sheet as well, on the 'Additional Calculations' section.

After students have calculated the size (length) of a grain of salt in microns, discuss out loud what this means. Some questions that could be asked are:

- Can you imagine how tiny a micrometer is if 500 of them fit into a grain of salt?
- Knowing that a grain of salt measures 500µm, can you think of other things that might be convenient to be measured in micrometers? (Some examples could be thickness of hair, thickness of a coat of paint, diameter of wool fibers, MICROBES, etc.)

After discussing the topic of microns for a few minutes, this would be a good opportunity to reinforce the idea that microbes are measured in microns, due to their microscopic size. Although students have already covered the topic of microbes in the previous lessons, some concepts may be reviewed before moving on.

Teacher Pedagogical Content Knowledge

To help students further visualize the cellular scale, have them explore the "Cell Size and Scale" simulation developed by University of Utah's Genetic Science Learning Center. The simulation allows students to zoom in and out from a coffee bean down to a carbon atom to see how different objects relate to each other in terms of scale. It can be accessed at the following web link:
http://learn.genetics.utah.edu/content/cells/scale/

Ask students how they think scientists are able to see and study microbes and other objects that are measured in microns, even though they are so small (expect students to say microscopes). After students mention microscopes, have a short discussion about what microscopes are and what they are used for. Ask students:

- What are microscopes?
- What are they used for?
- Is there only one type of microscope? If not, why do you think we need different types of microscopes?

During the discussion, use visuals/images of microscopes to promote student understanding of microscopes. If a microscope is available in the classroom, show students how they look and how they are used by scientists.

After the short discussion, show this video which illustrates how everyday items, like salt and pepper, sand, etc. are seen under a microscope: http://www.youtube.com/watch?v=P-n5TbifUIQ. The video may help students understand how powerful microscopes are. After the video, have students comment on what they saw. Potential discussion questions are:

- Are all small things the same size? (Answer: no)
- If we were as small as a grain of salt, what would sand look like? (Answer: giant boulders)
- What was the most surprising picture?
- Have you looked at very small things with a microscope? What did they look like?

To make additional connections between this activity and the instruments scientists use to see and study microbes, facilitate a discussion about how different types of microscopes can be used to observe different-sized objects.

The first invented and perhaps most common is the optical microscope (though the first version of this microscope looked very different than it does today). If students have used microscopes before, it was likely an optical microscope. If students have used them before, ask what they were able to see in this microscope. Do they remember how much it was able to magnify what they were looking at? Explain that optical microscopes typically magnify up to approximately 1500X. Many microbes are only 1µm in size. Ask students if they can calculate how big a microbe measuring 1µm would appear when magnified 1500X. Would that be big enough for us to be able to see it? Students should realize that while they may be able to see these smallest of microbes, an individual microbe would only appear as a tiny speck measuring about 1.5mm.

Therefore, a more powerful microscope is necessary. Scanning electron microscopes (SEM) are much more powerful. They can magnify up to 1,000,000X! How big would a 1µm microbe appear under maximum magnification using an SEM? Guide students to convert 1,000,000µm to 1,000mm or 100cm or 1m. That is powerful magnification capacity!

If students are interested, one more microscope can be discussed. The scanning-tunneling electron microscope (STEM) is very powerful, magnifying up to 10,000,000X or more! These microscopes can even image individual atoms!

To lead into the next activity, explain to students that they will be doing an activity that will be similar to using a microscope. Clarify that they will not use actual microscopes, but the activity will involve magnifying microbes, like microscopes do. Of the three different microscopes just discussed, optical, SEM and STEM, which one would they use to look at microbes, keeping in mind that the smallest are about 1µm? (Remind students that they only discussed the microscopes' highest magnification but the microscopes can be set on lower magnifications also.) Guide students to choose the SEM. The optical microscope is not powerful enough to show a clear image of the tiniest 1micron microbes. The STEM will clearly magnify microbes, but a microscope that powerful is not necessary. Students will "use" the SEM to magnify microbes in the next activity.

Activity 3: Microbe Mural

(This activity was adapted from: Moreno, Tharp, Erdmann, Clayton & Denk. (2012). The science of microbes: Activity comparing sizes of microorganisms. Baylor College of Medicine.)

In this activity, students can work individually or in pairs. They will construct scaled up versions of different microbes and compare their sizes with each other and their size relative to an object that is visible to the naked eye. For this activity, a magnified period with a diameter of 250cm should be prepared beforehand. To construct the magnified period:

1. Obtain a piece of paper that is at least 250cm x 250cm (this is equivalent to approximately 8.5ft x 8.5ft).
2. On this piece of paper, draw and cut out a circle with a diameter of 250cm.

Alternatively, the border of the magnified period can be outlined on a wall or floor using non-permanent writing or tape. If drawing an entire circle takes up too much space, brackets can be drawn or taped to simply indicate the edges of the circles.

Ask students what they would see if a period, which measures 0.5mm, was placed under a microscope? (Expect students to say that it would become really big, but they don't know exactly how big). Tell students to imagine that they will use a scanning electron microscope to magnify the period 5,000 times.

Have students calculate how big the period would be after magnifying it 5,000 times. Students can perform these calculations on the "Putting Microbial Scale in Context" student sheet, on the 'Additional Calculations' section. (When magnified, the period goes from measuring 0.5mm to 0.5*5,000 = 2,500mm). Ask students: "How much would this be in cm, mm and µm?" and have them perform these calculations on the student sheet as well. Tell them that they can use the conversion tables they constructed previously. (The period went from 0.5mm/0.05cm/500µm to 2,500mm/250cm/2,500,000µm).

After students have completed their calculations, show them the magnified period you constructed or outlined. Place the magnified period on the wall or floor, so students can place their microbes on it. (Placing the period on the floor or another flat surface is preferable so that students can place their microbes on the period but also move them around during the follow-up discussion.) Explain to students that this is how a period would look if it were magnified 5,000 times. Tell students that each group (or student) will be assigned a microbe and that they must: 1) magnify their microbe by 5,000 times, 2) construct their magnified microbe using the rulers and materials provided, and 3) place it on top of the magnified period in order to compare the size of their magnified microbe to the size of the magnified period.

Pass out the microbe cards (*U9_L3_Cards_Microbes.pdf)* one per student or per pair of students. Orient students to the type of information the cards provide about each of the microbes: domain, size, shape, where it lives, its metabolic properties, and an interesting fact about it. Students should review this information (they will later be asked to present and use this information) and begin their task of constructing a scaled-up version of their microbe.

Students will first need to calculate the new, magnified size of the microbe they have been assigned. They should first multiply by 5000 and then convert to units that will make it easier for them to make their drawings. Some students will have no trouble with this while others may need additional support.

The microbes students construct can be color-coded by domain, so that each eukaryote is one color, archaea another color, and bacteria a third color. Color-coding the microbes by domain will make the discussion questions that follow easier for students to visualize.

After all the groups have constructed their microbes and have placed them on top of the magnified period, discuss the microbe mural with the students. First, ask questions about the size and scale of microbes:

- How would you compare the size of microbes with the size of a period?
- Are most microbes bigger or smaller than the period you would see on a piece of paper?

Then lead students through a series of questions that allow them to explore and discuss the information they have about the microbes.

Ask students to group the microbes by domain. (Tape can be used to designate sections within the magnified period where students can place their microbes by category.)

- Are all microbes in the same domain? *Microbes are in all three domains.*
- Do you see any trends in the size of the microbes as compared to the domain they are in? *For example, eukaryotic protists are significantly larger.*
- Do you see any trends in their shape based on the domain they are in? *Many microbes are rod-shaped, spherical, or spiral-shaped. It is hard to distinguish the domain of a microbe based on its shape and size. This is one of the reasons Archaea were not separated out into their own evolutionary group until genetic sequencing technology became available.*

Ask students to group microbes by where they live. (Guide students to look at the “Lives” and “Fun Fact” categories for information about environments.)

- What kinds of places do microbes live in? *A variety of environments. Have some or all students share with the class where their microbe lives.*
- What domain are the microbes that live in extreme environments? *Archaea*
- Are there archaea that live in more typical environments? *Yes. For example, Methanobrevibacter smithii lives in our guts.*

Lead from the conversation about environments to a conversation about microbes' diverse metabolic properties by first addressing the terms "aerobic" and "anaerobic". Students will see one of these terms on each of the microbe cards but may not have a clear idea of what they mean. Ask students questions such as the following to establish definitions for these terms:

- Has anyone seen the words "aerobic" or "anaerobic" before? *Students may have seen these in previous science classes or maybe they have heard them in gym class in relation to different types of exercise.*
- Does anyone know what they mean? What does the prefix "an-" indicate?

Guide student responses or explain to students that aerobic and anaerobic refer to the amount of oxygen available in an environment. Aerobic indicates environments with oxygen and *an*aerobic indicates environments without oxygen. Ask: Which of these types of environments do we live in?

Lead a conversation about what microbes eat, breathe, and produce (i.e. their metabolic properties) which questions such as the following:

- Looking at your cards, what types of things do microbes eat, breathe and produce? *By asking students to share this information with the class, they should recognize the microbes are diverse in what they can take in and produce.*
- Can some microbes switch what they eat and breathe? *For example, Rhodopseudomonas can take use light and hydrogen sulfide but can also eat sugars and breathe oxygen depending on what is available in its environment.* Can students imagine what would happen if we were able to change how we get energy?!
- Do you notice that some microbes make their own food (called sugars) from CO_2 and others have to take in sugars? Does anyone know what these different types of organisms are called? *The organisms that make their own food are called "autotrophs" or "primary producers". The organisms that need to take in sugars are called "heterotrophs".*
- Where do you think the heterotrophs get their sugars? Humans are heterotrophs—where do you get our sugars? *All organisms make sugars and heterotrophs get sugars from other organisms. For example, humans eat plants and animals to get the sugars they need to build cells.*

Tell students that this will be important in the next lesson where they will look at nutrient cycling in a microbial ecosystem.

Based on the "Fun Facts" category, ask students to also discuss what kinds of different things microbes do. Finally, have students share out what they found really interesting either about their microbe (i.e. from the "Fun Facts" category of the card) or from the class discussions about the microbe mural.

Conclusion of Lesson

Conclude by asking students some big picture questions about what they just discussed.

- What did you learn about microbes today?
- How big are they? What unit is used to measure them?
- Where do microbes live?
- What do they eat and breathe?
- What kinds of things do microbes do?

This broad discussion about microbes should help students realize the ubiquity, diversity, and valuable roles of microbes.

To prepare students for the next lesson, ask students to think about microbial habitats and ecosystems and to consider the following questions:

- What is an ecosystem?
- What is the scale of an ecosystem?
- Can ecosystems be made up of microbes alone?

Students will explore these questions in the next lesson.