OVERVIEW

This hands-on activity serves to reinforce concepts of scientific discovery and the diversity of organisms as presented in the short video *Animated Life: Seeing the Invisible*. Students will review metric units and how to convert between them. They will then apply that knowledge to build scale models of different cells and microorganisms and compare their relative sizes.

KEY CONCEPTS

- Most of life on Earth is invisible to the naked eye.
- The microbial world is diverse.
- Scale bars allow us to determine the relative sizes of cells and microorganisms.

STUDENT LEARNING TARGETS

- Calculate the sizes of organisms for comparison using ratios and conversions.
- Create scale models to demonstrate and compare the sizes of organisms.

CURRICULUM CONNECTIONS

Standards	Curriculum Connection
NGSS (2013)	MS-LS1-1, HS-LS2-2
AP Bio (2015)	SP1, SP2
IB Bio (2016)	4.1
IB Env Systems and Societies (2017)	1.2
Common Core (2010) Math	HS.A-SSE.A.1, HS.A-SSE.B.3, HS.N-Q.A.1, HS.N-Q.A.2, MP2, MP4

KEY TERMS

conversions, magnification factors, microbes, ratios, scale models

TIME REQUIREMENTS

One to three 45-min class periods, depending on student math proficiency. Alternatively, sections of the Student Handout can be assigned as homework.

SUGGESTED AUDIENCE

- Middle school life science
- High school biology

PRIOR KNOWLEDGE

- Familiarity with ratios and basic mathematical calculations
- Basic understanding of microbes

MATERIALS

- 1 set of Cells and Microorganisms cards: each student or group of students should have at least one card
- Video of *Animated Life: Seeing the Invisible* and video player

- Butcher or flip chart paper, large sheets of newsprint/poster board, and card stock or construction paper. (Some of the models will require several sheets of paper taped together. Most of the models will easily fit on a single sheet of card stock/construction paper.)
- Tape
- Metric rulers
- Scissors
- Calculators
- Colored pencils or markers for creating scale models of organisms (optional)
- String and yarn for making cilia and flagella (optional)

BACKGROUND

In 1674, Antonie van Leeuwenhoek looked at a drop of lake water through his homemade microscope and discovered an invisible world that no one knew existed. His work inspired countless microbiology researchers, including HHMI investigator Bonnie Bassler, one of the narrators of this animated feature. Leeuwenhoek was a haberdasher (fabric merchant) and city official in Delft, The Netherlands. He started making simple microscopes and using them to observe the world around him. He was the first to discover bacteria, protists, sperm cells, blood cells, rotifers, and much more.

TEACHING TIPS

- Cut out the Cells and Microorganisms cards ahead of time, or have students cut them out. You can laminate the cards and reuse them.
- Students can work individually or in groups of 2 or 4; it's important to distribute all the cards for the comparisons of the scale models to be effective.
- The scaled student model should illustrate the general shape of the cell/microorganism (rough circle or oval) using the maximum length and width measurements. For more advanced or proficient students, the model should be more detailed, illustrating the general shape of the cell/microorganism along with structures such as cilia, flagella, and antennae.
- Depending on how your printer/copier scales the images, measurements will vary from those provided in this document, but the relative sizes should be the same.
- When making the model of the magnified period, students can tape one end of a piece of string where they want the center of the period to be. They can then measure 250 mm from that point, hold a pencil at the 250-mm mark, and use the string/pencil combination as they would a compass to draw the outline of the circle.
- Students will need to make several calculations to build their models. You may instruct them to show their calculations on a separate sheet of paper and submit them with their handouts.
- Following this activity, you may give students an opportunity to prepare microscope slides and observe some of the organisms used in this activity. Cultures of many of these organisms can be purchased from science supply houses such as Carolina Biological Supply Company or Wards Science. Alternatively, students can bring in samples of pond water to view under a microscope. Ask students to record observations of the organisms, including the magnification used to make these observations. Was the magnification used for observing the behavior of the organisms the best for observing their anatomical details?

PROCEDURE

Part 1: Cells and Microorganisms cards

Note that van Leeuwenhoek observed each of the cells and microorganisms depicted on these cards.

Divide your class into groups of two or three students. Each group will be examining a set of the same five Cells and Microorganisms cards. In advance of this activity, make enough sets to supply all of the groups in your class. There are two options for this part of the activity:

Option A: Students View a Subset of Cards and Make Claims About Relative Sizes
1. Select organisms that differ widely in size from each other—for example, *E. coli*, hydra, euglena, *Cyclidium glaucoma*, *Giardia intestinalis*.
2. Have each group of students examine the cards and arrange the cells and microorganisms from smallest to largest. If they ask how they are to know this, tell them to do their best and that you know it is difficult. Some students might know about scale bars and how to use them; others will not. This is a good formative assessment that will reveal what students know about interpreting and using micrographs.
3. Have several groups share their arrangements and the reasoning behind their size sequences. Be supportive of all of their ideas. After a general discussion of students' sequencing strategies, ask them why it is important to have a uniform method for determining magnification and the size of cells/microorganisms.

Option B: Students View a Subset of Cards and Make Observations About Their Appearance
1. Cut the cards so that students only have the illustration and not the information on the back. Include no more than one diatom in this set of cards. Select organisms with some similarities and differences, such as *E. coli*, hydra, euglena, paramecium, and *Asterionella*. Do not use the cards that show human red blood cells or sperm.
2. Ask the student groups to examine the cards and list the traits the organisms appear to have in common and their differences.
3. After approximately five minutes, ask several groups to share some of their observations with the class.

Part 2: Metric Units and Conversions
Your students may already be familiar with metric unit conversions, and you may assign the Metric Units and Conversions handout as an optional homework activity. If students are not familiar with the topic, allow approximately 20 minutes for them to complete it in class with your guidance. After you review and explain the ratios and conversion process, students should complete the table individually or in groups of two.
- Point out that the example calculations on the student sheet flip the positions of the numerators and denominators, and that this does not affect the answers to those calculations.

1 m =	100 cm =	1,000 mm =	1,000,000 µm
0.01 m =	*1* cm =	10 mm =	*10,000* µm
0.001 m =	0.1 cm =	*1* mm =	1,000 µm
0.000001 m =	*0.0001* cm =	0.001 mm =	*1* µm

- Students should next complete the Practice Problems either individually or in groups, and check their work.

Practice Problems Answer Key

1. Use a ruler to measure the width of your index finger in centimeters (cm).

Record the measurement here: *1.5 cm (answers will vary depending on the size of the individual)*

    a) How wide is your index finger in meters (m)? *0.015 m*

    b) In millimeters (mm)? *15 mm*

    c) In micrometers (μm)? *15000 μm*

2. An average human skin cell measures 30 μm in diameter.

    a) What is the diameter in millimeters (mm)? *0.03 mm*

    b) In centimeters (cm)? *0.003 cm*

    c) In meters (m)? *0.00003 m*

3. If you lined up human skin cells side-by-side, how many would fit across the width of your index finger? Explain your reasoning.

        finger is 15 mm across.

        1 skin cell is 0.03 mm across

        15 mm/0.03 mm = *500 skin cells*

Part 3: Watch the Video and Discuss the Importance of Microbial Life

After the students watch *Animated Life: Seeing the Invisible* in class or as homework, lead a discussion about the significance of the fact that most of the organisms on Earth are invisible. How did knowledge of microscopic life change scientists' understanding of the world?

Ask students to imagine that they can ask van Leeuwenhoek about the organisms he saw or that the students examined on the cards in Part 1. Working in their original groups, have students make a list of questions they would ask him. Have students share some of these questions with the entire class. Guide the discussion so that students become curious about the actual size of each organism and the significance of the scale bars. Ask students why it is important to have a uniform method for determining magnification and the size of cells/microorganisms.

Part 4: Calculating Magnification and Scale

1. Discuss the importance of measuring microorganisms and the use of scale, pointing out the scale model of the *Daphnia ambigua* on the Student Sheet. Ask students why a scale model of this organism is useful.

3. Have students work individually or in small groups to complete the calculations in the analysis questions about *Daphnia*. They should check their work before proceeding to Part 5.

ANSWER KEY

1. Use your ruler to measure the dimensions of the *Daphnia* in Figure 1.

        Daphnia's width at its widest point: *33 mm*

        Daphnia's body length (without the tail): *54 mm*

2. To determine the actual dimensions of the *Daphnia*, you will divide the measurements above by the conversion factor.

        Daphnia's actual width: scaled dimension/50 = 33 mm/50 = *0.66 mm* = *660 μm*

        Daphnia's actual length: scaled dimension/50 = 54 mm/50 = *1.08 mm* = *1,080 μm*

3. How big would the *Daphnia* be if it were magnified 1000×? Calculate the magnified size in mm, showing your work:

        Daphnia's width at its widest point, magnified 1,000×: *660 mm*

        Daphnia's length, magnified 1,000×: *1,080 mm*

4. Create a model of *Daphnia* magnified 1,000× with paper, cutting the paper to approximate the shape using your maximum length and width calculations.

> *Model shapes will vary; the max height and width is of most importance.*

5. How does it compare to the models that were cut out by your classmates?

> *Answers will vary.*

6. The period at the end of this sentence is a circle measuring 0.5 mm in diameter, which is 500 µm (0.5 mm × 1,000 µm/1 mm). If the period is magnified 1,000×, calculate the diameter of the period in mm.

> Diameter of period, magnified 1,000×: *500 mm*

7. Cut out a paper model of the period multiplied 1,000×. Is it bigger or smaller than the *Daphnia*?

> *The* Daphnia *is larger.*

8. The magnification factor for a scale bar that is 2 mm long and represents a length of 8 µm would be calculated as follows:

> Scaled dimension/actual dimension = magnification factor
>
> 2000 µm/8 µm = 250

Determine how large you would make a model microorganism magnified 1000× if its image at the maximum width is 40 mm and at its maximum length is 80 mm.

	Measurement in mm	Magnification Factor	Actual measurement (in µm)	Measurement when magnified 1,000× (in mm)
Length	80 mm	250	*320 µm*	*320 mm*
Width	40 mm	250	*160 µm*	*160 mm*

> **Note:** You can convert 80 mm to 80,000 µm and divide by 250 or leave the measurement as 80 mm, divide by 250 and multiply the answer by 1000 since there are 1000 µm in a mm.

Part 5: Build Your Own Scale Model

Some of the models can be done in a short amount of time while other models require more time. To balance this, you may want to assign each group two models, one that is easy to make and another that is more involved. This will also be a good way to check the accuracy of the models and provide a basis for discussing various types of error.

1. Distribute the Cells and Microorganisms cards; be sure that all cards are used so that students can see the range of sizes of the different cells and microorganisms. Give students time to read through the cards and to ask any questions.

2. Have students calculate the actual size of their cell or microorganism and then determine the size of the cell/microorganism if it were magnified 1,000×.

3. Here, you can have students measure (a) just the main body of the cell/microorganism, or (b) the main body and the flagella, arms, and other extensions. They can either just cut out a shape of the right dimensions or illustrate their assigned cells/microorganisms using the paper, rulers, and other materials provided. Instruct them to display all of the models from smallest to largest.

4. Allow discussion time concerning the relative sizes of the different organisms.

5. Sample measurements and magnifications for the model organisms are provided in the table that follows. Measurements will vary depending on the accuracy of the ruler and the printer or copier used.

Organism		Measurement in mm	Magnification factor	Actual size (in µm or mm)	Size when magnified 1,000× (in mm)
Amoeba proteus	Length	70 mm	(13 mm/50 µm) × 1000 = **260**	269 µm	269 mm
	Width	68 mm		262 µm	262 mm
Asterionella formosa Diatom	Length	total = 75 mm individual cell = 36 mm	(18 mm/30 µm) × 1000 = **600**	total = 125 µm individual cell = 60 µm	total = 125 mm individual cell = 60 mm
	Width	body = 18 mm flagellum = 1 mm		body = 18 µm flagellum = 1 µm	body = 18 mm flagellum = 1 mm
Cyclidium glaucoma	Length	59 mm	(17 mm/5 µm) × 1000 = **3400**	17 µm	17 mm
	Width	39 mm		11 µm	11 mm
Euglena viridis	Length	body = 57 mm flagellum = 90 mm	(10 mm/10 µm) × 1000 = **1000**	body = 57 µm flagellum = 90 µm	body = 57 mm flagellum = 90 mm
	Width	body = 18 mm flagellum = 1 mm		body = 18 µm flagellum = 1 µm	body = 18 mm flagellum = 1 mm
Escherichia coli	Length	labeled cell body = 25 mm flagellum = 52 mm	(20 mm/2 µm) × 1000 = **10,000**	labeled cell body = 3 µm flagellum = 5 µm	labeled cell body = 3 mm flagellum = 5 mm
	Width	labeled cell body = 7 mm flagellum = 1 mm		labeled cell body = 1 µm flagellum = 0.1 µm	labeled cell body = 1 mm flagellum = 0.1 mm

Organism		Measurement in mm	Magnification factor	Actual size (in μm or mm)	Size when magnified 1,000× (in mm)
Euglypha brachiata	Length	body = 70 mm spine = 43 mm	(34 mm/50 μm) × 1000 = **680**	body = 103 μm spine = 63 μm	body = 103 mm spine = 63 mm
	Width	body = 29 mm spine = 2 mm		body = 43 μm spine = 3 μm	body = 43 mm spine = 3 mm
Filinia longiseta	Length	body = 24 mm long bristle = 95 mm short bristle = 40 mm	(16 mm/100 μm) × 1000 = **160**	body = 150 μm long bristle = 594 μm short bristle = 250 μm	body = 150 mm long bristle = 594 mm short bristle = 250 mm
	Width	body = 11 mm bristle = 1 mm		body = 69 μm bristle = 6.25 μm	body = 69 mm bristle = 6.25 mm
Fragilaria crotonensis Diatom	Length	colony = 95 mm individual cell = 9 mm	(40 mm/30 μm) × 1000 = **1333**	colony = 71 μm individual cell = 7 μm	colony = 71 mm individual cell = 7 mm
	Width	colony = 52 mm individual cell = 8 mm		colony = 39 μm individual cell = 6 μm	colony = 39 mm individual cell = 6 mm
Giardia intestinalis	Length	body = 30 mm flagella = 17 mm	(40 mm/10 μm) × 1000 = **4000**	body = 8 μm flagella = 4 μm	body = 8 mm flagella = 4 mm
	Width	body = 20 mm flagella = 0.5 mm		body = 5 μm flagella = 0.1 μm	body = 5 mm flagella = 0.1 mm
Homo sapiens Erythrocyte	Length	36 mm	(25 mm/5 μm) × 1000 = **5000**	7 μm	7 mm
	Width	36 mm		7 μm	7 mm

What Leeuwenhoek Saw

Organism		Measurement in mm	Magnification factor	Actual size (in µm or mm)	Size when magnified 1,000× (in mm)
Homo sapiens spermatozoan	Length	head = 7 mm tail = 81 mm	(15 mm/10 µm) × 1000 = **1500**	head = 5 µm tail = 54 µm	head = 5 mm tail = 54 mm
	Width	head = 5 mm tail = 1 mm		head = 3 µm tail = 1 µm	head = 3 mm tail = 1 mm
Hydra vulgaris Hydra	Length	body = 58 mm tentacle = 25 mm	(7 mm/1 mm) = **7 ***	body = 8 mm tentacle = 4 mm	body = 8,000 mm tentacle = 4,000 mm
	Width	near foot = 8 mm tentacle = 1 mm		near foot = 1 mm tentacle = 0.1 mm	near foot = 1,000 mm tentacle = 143 mm
Meridion circulare Diatom	Length	total = 68 mm individual cell = 22 mm	(22 mm/30 µm) × 1000 = **733**	total = 93 µm individual cell = 30 µm	total = 93 mm individual cell = 30 mm
	Width	total = 22 mm individual cell = 8 mm		total = 30 µm individual cell = 11 µm	total = 30 mm individual cell = 11 mm
Paramecium aurelia Paramecium	Length	62 mm	(13 mm/50 µm) × 1000 = **260**	238 µm	238 mm
	Width	25 mm		96 µm	96 mm
Philodina roseola	Length	97 mm	(14 mm/50 µm) × 1000 = **280**	346 µm	346 mm
	Width	20 mm		71 µm	

* The scale bar and measurements are in mm, so the ratio is not multiplied by 1,000 for the magnification factor calculation

Organism		Measurement in mm	Magnification Factor	Actual size (in µm or mm)	Size when magnified 1,000× (in mm)
Saccharomyces cerevisiae	Length	labeled parent cell = 25 mm labeled daughter cell = 11 mm	(23 mm/5 µm) × 1000 = **4600**	labeled parent cell = 5 µm labeled daughter cell = 2 µm	labeled parent cell = 5 mm labeled daughter cell = 2 mm
	Width	labeled parent cell = 20 mm labeled daughter cell = 11 mm		labeled parent cell = 4 µm labeled daughter cell = 2 µm	labeled parent cell = 4 mm labeled daughter cell = 2 mm
Stentor roeseli Stentor	Length	81 mm	(17 mm/100 µm) × 1000 = **170**	476 µm	476 mm
	Width	widest = 35 mm narrowest = 3 mm		widest = 206 µm narrowest = 18 µm	widest = 206 mm narrowest = 18 mm
Vibrio harveyi	Length	rod = 18 mm flagellum = 35 mm	(18 mm/2 µm) × 1000 = **9,000**	rod = 2 µm flagellum = 4 µm	2 mm 4 mm
	Width	rod = 6 mm flagellum = 1 mm		rod = 1 µm flagellum = 0.1 µm	1 mm 0.1 mm
Volvox aureus Volvox	Length	54 mm	(10 mm/50 µm) × 1000 = **200**	270 µm	270 mm
	Width	54 mm		270 µm	270 mm
Vorticella campanula	Length	cilia base region = 5 mm body = 29 mm stalk = 40 mm	(20 mm/50 µm) × 1000 = **400**	cilia base region = 13 µm body = 73 µm stalk = 100 µm	cilia base region = 13 mm body = 73 mm stalk = 100 mm
	Width	cilia base region = 30 mm body = 27 mm stalk = 3 mm		cilia base region = 75 µm body = 68 µm stalk = 8 µm	cilia base region = 75 mm body = 68 mm stalk = 8 mm
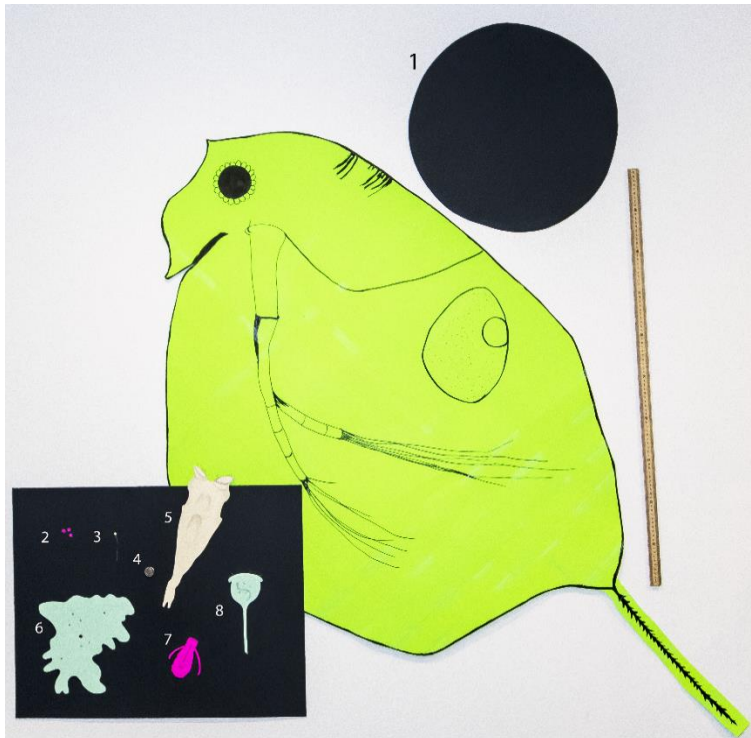
Examples of students' work: Each cell/microorganism included in this photograph has been scaled 1000× its actual size. The figures are (1) Period; (2) Erythrocyte – human red blood cell; (3) Spermatozoan – human sperm cell; (4) quarter for scale (5) *Philodina roseola* – Rotifer; (6) *Amoeba proteus* – Amoeba; (7) *Euglypha brachiate* – Euglypha; (8) *Vorticella campanula* – Vorticella, and the largest organism is the *Daphnia*.

Analysis Questions:

1. Which of the cells or microorganisms that you and your classmates modeled are larger than a 0.5-mm period?
   Daphnia pulex is larger than a period. If you include the bristles, *Filinia longiseta* is longer.
   Smaller than a period?
   All of the other cells/microorganisms are smaller.

2. Van Leeuenhoek's microscope was only capable of 200× magnification. Microscopes today, such as scanning electron (SEM) and transmission electron (TEM) microscopes, are far more powerful, up to 10,000,000×!

   a. What would the diameter of a 500-µm period be when magnified 10,000,000×? **0.0005 m**
   b. Why do you think scientists would need such strong magnification?
   Greater magnification enables scientists to observe whether microorganisms are present. It also provides information about cellular structure and microorganism anatomy. It also allows scientists to determine the actual size of the specimens they are observing.
   Note: You might want to discuss the difference between light microscopes and scanning electron and transmission microscopes and when it would be desirable to use one or the other.

REFERENCES

The activity is adapted from an activity developed by Project Neuron.

AUTHOR

Laura Bonetta, HHMI; Ann Brokaw, Rocky River High School, Ohio; Mary Colvard, consultant
Edited by Aleeza Oshry
Illustrator: Heather McDonald