Lesson 1 – Does Size Matter? Comparing Viruses, Bacteria, and Human Cells

LESSON QUESTIONS

- What are the similarities and differences in size between viruses, bacteria and human cells?
- How does the size of viruses, bacteria and human cells relate to their functions?

LESSON OBJECTIVES

- Compare the sizes of viruses, bacteria and human cells.
- Relate the size of viruses, bacteria and human cells to their functions.

DOK 2 - 3

OVERVIEW

In this lesson, students investigate the relative sizes of viruses, bacteria and human cells. As a class, students generate a list of diseases. Working in groups, students conduct online research to determine the cause of each disease. Once they determine which diseases are caused by viruses and which are caused by bacteria, they research the relative sizes of each. Students create a graphic to show the relative scales of the organisms. They calculate ratios to compare relative sizes of viruses, bacteria, and human cells. Comparison of information allows students to identify patterns. (DOK2) One such pattern is the size trend: most viruses are smaller than most bacteria, which are smaller than most eukaryotic cells. As a class, information is compiled to identify and explain phenomena in terms of concepts. (DOK3) For example, students could choose to explain that smaller size is a structural characteristic that enables viruses to infect bacteria or eukaryotic cells. In a hands-on activity, student groups design a model of a virus particle, bacterium or eukaryotic cell. 3D model instructions from the NIH are included with the lesson to print a representative model of flu virus, *Streptococcus pyogenes*, and a dendritic cell.

LENGTH

Up to three 45-minute sessions

GLOSSARY TERMS

bacteria, eukaryote, prokaryote, virus

STANDARDS

Next Generation Science Standards

- Disciplinary Core Ideas in Life Sciences
  - Structure and Function
    - All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular).
    - In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions.
  - Growth and Development of Organisms
    - Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring.
  - Interdependent Relationships in Ecosystems
    - Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors.
- Science and Engineering Practices
  - Asking Questions and Defining Problems
    - Ask questions that require sufficient and appropriate empirical evidence to answer.
    - Ask questions that arise from careful observation of phenomena, models, or unexpected results to clarity and/or seek additional information.
    - Ask questions to determine relationships between independent and dependent variables and relationships in models.
    - Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.
  - Developing and Using Models
    - Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
    - Develop a model to describe unobservable mechanisms.

- Planning and Carrying out Investigations
  - Collect data to produce data to serve as the basis for evidence to answer scientific questions or test design solutions under a range of conditions.

- Analyzing and Interpreting Data
  - Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
  - Analyze and interpret data to determine similarities and differences in findings.

- Using Mathematics and Computational Thinking
  - Use mathematical representations to describe and/or support scientific conclusions and design solutions.
  - Apply mathematical concepts and/or processes (such as ratio, rate, percent, basic operations, and simple algebra) to scientific and engineering questions and problems.

- Constructing Explanations and Designing Solutions
  - Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.
  - Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

- Crosscutting Concepts

  - Patterns: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.
    - Macroscopic patterns are related to the nature of microscopic and atomic-level structure.
    - Patterns can be used to identify cause-and-effect relationships.
    - Graphs, charts, and images can be used to identify patterns in data.

  - Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
    - Relationships can be classified as causal or correlational, and correlation does not necessarily imply causation.

- Scale, Proportion, and Quantity
  - Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
  - Proportional relationships (e.g. speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes.
  - Phenomena that can be observed at one scale may not be observable at another scale.

- Systems and System Models
  - Systems may interact with other systems; they may have sub-systems and be a part of larger complex systems.

- Structure and Function
  - Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the relationships among its parts, therefore complex natural structures/systems can be analyzed to determine how they function.

- Connections to the Nature of Science
  - Scientific Investigations Use a Variety of Methods
  - Scientific Knowledge is Based on Empirical Evidence

Common Core State Standards

- CCSS.ELA-LITERACY.RST.6-8.4
  Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

- CCSS.ELA-LITERACY RST.6-8.7
  Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

- CCSS.MATH.CONTENT.6.RP.A.1
  Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.

- CCSS.MATH.CONTENT.6.RP.A.3
  Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

- CCSS.MATH.CONTENT.7.RP.A.1
  Compute unit rates associated with ratios of fractions, including ratios of lengths, areas and other quantities measured in like or different units.

- CCSS.MATH.CONTENT.7.RP.A.2
  Recognize and represent proportional relationships between quantities.

MATERIALS

- Computer with internet access
- Graph paper
- Meter ruler
- Modeling materials or 3D printer

BACKGROUND FOR TEACHER

The goal of this lesson is for students to compare the size, structure and function of viruses, bacteria and some different human cells. Students may have misconceptions about the relative sizes of microscopic organisms. For example, they may think that bacteria are about the same size as cells of people. Students might think that all human cells are too small to see or that all their cells are the same size. Students might also have misconceptions about the relative sizes of bacteria and viruses. Such misconceptions arise from the difficulty of visualizing cells, bacteria and viruses. When a student looks at a micrograph of a virus, they may have difficulty understanding how small it actually is. This lesson addresses such misconceptions by using scale models. Scale diagrams show the relative sizes of cells. Students also calculate the ratio of linear sizes. This activity enables students to identify patterns related to size, leading to an understanding that an increase in size can lead to an increase in complexity. Students will also be able to explain that smaller organisms can infect larger organisms or be ingested by them, but rarely the other way around. Modeling cells, bacteria and viruses in 3D serves to emphasize the relationship between size and complexity. Depending on prior knowledge, consider reviewing the definitions of viruses, bacteria and eukaryotes, particularly the cells of eukaryotes (see Glossary). As an example of a eukaryotic cell, this lesson focuses mostly on human immune system cells, particularly the dendritic cell. Because our immune systems are tasked with fending off viral and bacterial infections this example is relevant for of how our immune systems work.

TEACHER NOTES

The over-arching question of this lesson is: How does size relate to function? After completing the lesson, students should be able to identify and illustrate relative sizes, structures, and functions of human immune system cells, bacteria and viruses. Pooling the class data will help students see the size trend from viruses to bacteria to eukaryotic cells. If needed, guide them to infer that smaller size is a key factor enabling organisms to infect others. If needed, review metric units of size (e.g., millimeters, microns and nanometers). In this context, it may help students to provide a linear scale of units and to review powers of ten. In Elaborate, when students build their scale models, time and resources may not allow for detailed models. In this case, groups should focus on differences in size and shape. If a 3D printer is unavailable, modeling clay will work as an alternative for this activity.

Tips for 3D print models included in this lesson
If you are using the 3D printing files associated with this lesson, here are some tips that we found helpful.

For comparison of size

In nature:

- Dendritic cell - about 12 µm or 12,000 nm
- *Streptococcus pyogenes* - about 2 µm or 2,000 nm
- Influenza - about .12 µm or 120 nm

This results in a size difference on a scale of:

100	to	16	to	1
Dendritic cell		*S. pyogenes*		Influenza

If you print the dendritic cell at 4 inches in diameter, you can capture the size difference to scale. Note: The influenza virus is still too small to print, but you can cut a 1 mm size of printer filament for comparative purposes.

- Dendritic cell: 4 inches in diameter
- *Streptococcus pyogenes*: .25 inches in diameter
- Influenza: .04 inches in diameter (about 3/64 of an inch or 1 mm)

For showing detail of structure

The detail and differences related to the dendritic cell, *Streptococcus pyogenes*, and influenza virus can be appreciated by printing each at 2 inches in diameter. Of note, the *S. pyogenes* prints as a solid model whereas the other two utilize internal scaffolding.

Whittle-Down Strategy
Use this strategy in Explain: (1) Students work individually to generate a list of five words. Encourage students to use any words that are relevant to the concept of sizes of

viruses, bacteria and immune system cells. (2) Students work in pairs or small groups. (3) In their groups, students share and discuss their words. Encourage students to use evidence-based reasoning in their justifications for words they chose. One student records all of the words contributed by each member. Through discussion each group narrows (whittles) down the list of words to the three that they consider to be the most relevant. (4) The aim is for students to focus on the terms that are the most relevant to understanding the topic. (5) Each group shares its three words with the class, again using evidence-based reasoning to justify why they included those words. (6) Display the words to the class, using your preferred method (whiteboard, flipchart, etc.). Students work individually to write a summary of why those words help to explain the key concepts (viruses, bacteria and eukaryotic cells, scaling, comparative sizes, square-cube law, etc.).

LESSON RESOURCES

- Lesson animations:
    - *The Scale of the Universe 2* https://www.youtube.com/watch?v=uaGEjrADGPA
    - *A Virus Attacks a Cell* https://vimeo.com/227174435
- Lesson glossary
- "What Causes the Disease?" Game Supplement
- 3D model printing files:
    - Influenza virus 3D model, NIH 3D print exchange, https://3dprint.nih.gov/discover/3dpx-000030
    - *Streptococcus pyogenes* 3D model, provided by NIH 3D print exchange, https://3dprint.nih.gov/discover/3DPX-004652
    - Dendritic cell 3D model, provided by Donny Bliss and Sriram Subramaniam, NIH, (file available in lesson 1 resources section on website)

ENGAGE

1. Ask students to name different diseases they have heard of, writing their responses on the board.
2. Ask students to guess if each disease listed is caused by bacteria, a virus, or neither, and record their responses next to each disease. Alternatively, conduct the sorting game activity "What Causes the Disease?" using the Game Supplement in the lesson resources.
3. Ask students to hypothesize how the relative sizes of viruses and bacteria compared with human cells may relate to function.

EXPLORE

1. As a class, review definitions of the glossary terms virus, bacteria, eukaryote and prokaryote.
2. Working in small groups, students conduct research to classify the diseases they listed according to whether they are caused by viruses, bacteria, or neither. Refer to the "List of Diseases and Causes" in the lesson rubric to check the accuracy of the student findings.
3. Have students research the size of the virus or bacteria they identify as the disease-causing agent.

EXPLAIN 1

1. Show students a meter ruler. Point out the one millimeter gradations and compare them to the full length of the ruler. Explain that the meter is 1000 times the length of the millimeter.
2. Have students share the sizes they found during their research and record on the board for all to see. You may want to use a 2 column format and record viruses in one and bacteria in the other. This will help students identify patterns in step 3.
3. Discuss what patterns they see.
4. Show *The Scale of the Universe 2* animation. Ask students to journal their impressions related to size.
5. To bring focus back to their research, introduce the relative size of human cells. Some examples:
   - Blood cell: about 6-8 µm (microns) in diameter
   - Dendritic cell: 12 µm in diameter
   - Bone cell (osteocyte): about 15 µm in diameter
   - Liver cell (hepatocyte) 20-30 µm in diameter
   - Cheek cell: about 60 µm in diameter
6. Have students use their graph paper to create a linear scale from 0 to 0.1mm in increments of 0.01mm.
7. Students indicate the absolute sizes of their virus, bacterium and a human cell (from your example) on the linear scale. (Students will find that their scales are too big to accurately show the sizes of bacteria and viruses relative to the human cells.)
8. Ask students to calculate the ratios of sizes of their virus, bacterium and human cell. For example:
   - If a virus measures = 0.005 µm, a prokaryote = 5 µm , and a human cell = 50 µm, that is a is a ratio of 1:1000:10000
   - Influenza virus = .12 µm, *Streptococcus pyogenes* 2 µm, dendritic cell = 12 µm is a ratio of 1:16:100
9. Check student understanding using a formative assessment strategy (e.g., thumbs up/down or stop/go cards).

EXPLAIN 2

1. Students watch the animation *A Virus Attacks a Cell*. Ask students to journal their impression of the virus's size compared to the size of the cell it infected.
2. From the videos they watched and their online research, students generate a list of five words in the student worksheet key concepts summary table ("my words") box. These can be any words that are relevant to the concept of sizes of viruses, bacteria and human cells, as well as other concepts they encountered in the lesson (scaling, comparative sizes).
3. Students move into small groups and share their words along with their reasoning for the words they chose with the group.
4. One student in each group records the complete list of words.
5. Each group narrows (whittles) down its list to the three most important words. All students record the group choices in the "my group" box on their worksheets.
6. Groups then share their words with the class.
7. Display the words to the class using your preferred method (board, flipchart, etc.).
8. Students work individually to write a summary of why those words help to explain the key concepts.

ELABORATE

1. Students work in small groups to build scale models of a virus, a bacterium and a human cell using a 3D printer or modeling materials.
2. As students are building their models, encourage them to think about how size is related to function. In particular, reinforce the concept that small size allows viruses to produce many infective particles with the resources of a single bacterium or human cell.

EVALUATE

1. Students work individually or in pairs (e.g., struggling or ESL students) to complete the "Structure and Size Comparison" questions on the worksheet. Depending on the class math level, you may wish to complete the first question together as a class.
2. Review answers as a class.
3. Use an exit slip strategy to assess student understanding. Sample questions might include:
    a. What similarities and differences did you notice about the words from the "whittle down" activity each group shared with the class?
    b. How did the modeling activity help you to think about the differences between viruses, bacteria, and human cells?
    c. What do the differences between the sizes of viruses, bacteria, and human cells tell you about how they function?

RUBRIC: LIST OF DISEASES AND CAUSES

Use this chart as a reference for the disease classification exercises in the Engage and Explore portions of the lesson.

Disease	Pathogen/Cause	Agent
AIDS	Human immunodeficiency virus (HIV)	Virus
Alzheimer's	Multiple (A combination of genetic, lifestyle, and environmental factors)	Neither
Amoebiasis (amoebic dysentery)	Amoeba	Neither
Autism	Multiple (Genetics, paternal age, some viral infections (e.g., maternal rubella infection during pregnancy, and environmental exposures (e.g. thalidomide))	Neither
Cancer	Multiple (Genetics, environmental exposures, chronic viral infections (e.g. HPV, hepatitis B))	Neither
Cervical cancer	Human Papillomavirus (HPV) (Also some anal, vulvar, vaginal, penile and oropharyngeal cancers)	Virus
Chagas disease	Trypanosoma cruzi	Neither
Chickenpox	Varicella zoster	Virus
Cholera	*Vibrio cholerae*	Bacteria
Common cold	Rhinoviruses and Coronaviruses	Virus
Chronic Traumatic Encephalopathy (CTE)	Injury or trauma	Neither
Dengue	Flavivirus	Virus
Diabetes	Multiple (Genetic and environmental factors)	Neither
Diphtheria	*Corynebacterium diphtheriae*	Bacteria
Ebola	Ebola virus	Virus
Hepatitis A	Hepatitis A virus	Virus
Hepatitis B	Hepatitis B virus	Virus
Hepatitis C	Hepatitis C virus	Virus
Influenza	Influenza virus	Virus
Japanese encephalitis	JE Virus	Virus

Disease	Pathogen/Cause	Agent
Lyme disease	*Borrelia burgdorferi*	Bacteria
Malaria	*Plasmodia*	Neither
Measles	Measles virus	Virus
Meningococcal meningitis	*Neisseria meningitidis*	Bacteria
Mononucleosis	Epstein Barr virus	Virus
Mumps	Mumps virus	Virus
Norovirus gastroenteritis	Norovirus	Virus
Pertussis	*Bordetella pertussis*	Bacteria
Pneumococcal disease	*Streptococcus pneumoniae*	Bacteria
Pneumonia, epiglottitis bacteremia, meningitis	*Haemophilus influenza* type b	Bacteria
Poliomyelitis	Polio virus	Virus
Rabies	Rabies virus	Virus
Rotavirus gastroenteritis	Rotavirus	Virus
Ringworm	Trichophyton and microsporal fungii	Neither
Rubella	Rubella virus	Virus
Salmonellosis	Salmonella	Bacteria
Syphilis	*Treponema pallidum*	Bacteria
Tetanus	*Clostridium tetani*	Bacteria
Thyroid disease	Multiple (Autoimmune diseases, treatments for disease (e.g. radiation therapy, surgery), and too much or too little iodine)	Neither
Tick-borne encephalitis	Tick-borne encephalitis virus	Virus
Tuberculosis	*Mycobacterium tuberculosis*	Bacteria
Typhoid	*Salmonella typhi*	Bacteria
Yellow fever	Yellow fever virus	Virus
Zika	Zika virus	Virus

RUBRIC: STUDENT WORKSHEET

Key Concepts Summary Table

- Students should be able to articulate and justify how the words they chose help to explain the key concepts of the lesson.

Questions: Structure and Size Comparison

1. The influenza virus measures 120 nanometers (nm) across. The bacterium that causes diphtheria 0.5 microns (µm) in diameter. What is the approximate ratio of the sizes of these two disease-causing agents? Show your method.

- Sample answer:
  1. Convert both numbers to the same units. (Since 0.5 microns is a decimal it is easier to start by converting microns to nanometers, but either approach is fine.)
     0.5 microns = 500 nanometers
  2. Divide the larger number by the smaller to get the ratio.
     500:120 = 50:12
  3. Simplify by dividing by the highest common factor.
     50/2 = 25
     12/2 = 6
  4. Therefore, the ratio is 25:6 (about 5:1).

2. What is the significance of the size of viruses compared to human cells?

- The small size of the virus allows it to more easily get to and infiltrate a human cell.

3. Josh couldn't make it to class and missed this lesson. Describe an example using everyday objects that illustrates the difference in scale between a human cell and a virus that you could use to explain the model learned in this lesson to Josh.

- Answers will vary. Students should be able to articulate an example that demonstrates the differences in sizes, such as those between a virus and human cell.
  Some examples may include:
  - Length of a blue whale (100 feet) compared to a rat (1 foot) 100:1
  - Length of a cruise ship (1000 feet) compared to a smart car (10 feet) 100:1
  - Length of a football field (10,000 cm) compared to a coffee bean (1 cm) 10,000:1