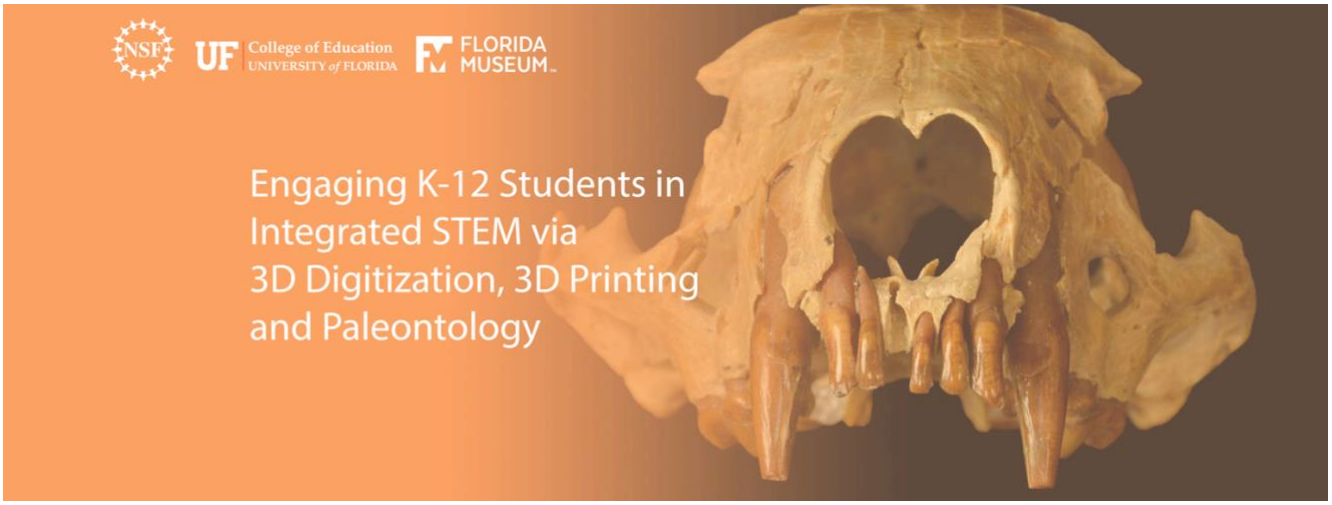

AUTHOR (S)

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LESSON TITLE

Supersized Life: Comparing Across Scales

GRADE LEVEL

4th-5th grade, could be adapted 6th, 8th grades.

TIME FRAME

Two 45-60-minute class periods

DRIVING QUESTION

How wide is the scale of living beings that we encounter, even if we can't see them?

LEARNING GOALS

To prepare and empower students to undertake a more formal study of exponents and logarithms by creating and solving math problems involving changes on a logarithmic base-ten scale. To give students an intuitive sense and appreciation of how large changes by orders of magnitude are.

STEM INTEGRATION

Science: Students will learn about animals and viruses that are usually too small and fragile to see and manipulate through 3D printed models of these organisms and information sheets.
Technology: Students will learn about the 3D printing process and work with 3D printed models.

Mathematics: Students will spend much of their time using measuring tools and solving mathematical puzzles.

ASSESSMENT

Formative Assessment: A written pre-test will be administered at the beginning of Day 1. It consists of 3-4 word problems focusing on comparisons of two objects at different scales. For example: "Some scientists found out that water bears (1 mm long) can survive in space. An astronaut wants to take more water bears into space with her to do some research. He has a tube 10 mm long to carry all of his specimens. Approximately how many water bears could he fit inside the tube to take with him into space?" Only 5-10 minutes should be needed for the test.

Summative Assessment: Questions and answer keys submitted during the final activity on Day 2 serve as an assessment both in terms of quantity (number of question-answer sets submitted) and quality (number of correct answer keys).

ANCHORING EVENT & PROCEDURE

DAY 1:

Objective: By the end of the lesson, students will be able to compare object measurements within the metric system by multiplying or dividing numbers by powers of ten to solve word problems.

Whole Group Discussion: Ask students to share what they know about 3D printing. Introduce 3D printing with video. Ask students: How could scientists who study microscopic organisms use 3D printing to share their work with the public? The goal is for them to conclude that blowing up or enlarging microscopic items by powers of ten can make them more accessible to the public. Identify the 3D prints in the kit for the students and share the information sheets about each object.

Whole Group Activity: Share *Plagioctenoides* (small mammal) tooth at 10x and 100x actual size. Allow them to touch the item and explain that the actual tooth is ten times smaller than the 10x printout, or 100 times smaller than the 100x printout which makes it difficult to see. Ask students to estimate the size of a tooth that is 1,000 times the original size by holding out their hands. Then, students will work together to lay out the 100x tooth printout 10 times along a table to visually estimate how large a 1,000x tooth would be. Ask students if they are surprised by the size of a 1,000x tooth. Take the time to connect the phrase "ten times larger" with multiplication and the literal use of ten copies of the 100x model to get to 1,000x. It may also be helpful to model the inverse operation, or division, by asking "How could we figure out how many prints could fit in a space this big?" and gesture to physically divide the space, or use division.

Whole Group Activity: Poll the class: Would a tooth blown up to 10,000x life size tooth fit in the classroom? Allow students to discuss, then use transect or measuring tape to measure the room in metric units, convert all measurements to millimeters, and use arithmetic to answer the question. Depending on how well the students grasp arithmetic, the problem can either be solved with rounded or exact measurements.

Whole Group Activity: Ask the students to convert in the other direction: Ask them to calculate the life size of the tardigrade based on knowing that the 100x printout is 100 times larger than life size. Make sure students understand whether they need to multiply or divide to answer the problem, and why. Students should calculate the life size, then try to draw the life size on a sheet of paper using a ruler. Ask them if they are surprised by how small a tardigrade is in real life.

Whole Group Discussion: Ask students to tell what they know about measurement and estimation. When students have shared, ask them: Why might scientists use estimation when dealing with measurements? If helpful, use estimation review videos.

Small Group Activity: Students work in groups to answer: How much larger would the *Plagioctenoides* (small mammal) tooth have to be in order to be the same size as the mammoth tooth? Give them rulers, size reference sheet, and pencil and paper. After 5-10 minutes, come together and compare answers.

Whole Group Discussion: Discuss student answers to the question and if necessary, review concepts. Review the day's learning by asking students to share something they learned (for larger groups, have students share this with a partner or small group.) Explain that in the next session, students will be responsible for creating questions. If students are interested to learn more about the organisms they measured today, distribute the information sheets about each object.

DAY 2

Objective: Students will generate and answer questions that require conversions within the metric system and multiplication and division by tens to compare object measurements.

Small Group Activity: With the help of the size reference sheet, students will work in pairs or small groups to answer warm up questions, which can be placed at stations around the room. After one full rotation, review questions and answers in a whole group setting.

Small Group Activity and Assessment: Display question stems on the board and ask students to create as many questions as possible, complete with a correct answer key. If desired, activity can be framed as a competition where each group scores one point for submitting a question with a correct answer key. Submitted questions and answer keys can also serve as an assessment both in terms of quantity (number of question-answer sets submitted) and quality (number of correct answer keys).

Extension Idea: If there is time, students can challenge each other by exchanging questions with another small group and trying to answer each other's questions.

STANDARDS

NEXT GENERATION SCIENCE STANDARDS (NGSS)

List relevant NGSS standards for the intended grade level.
http://www.nextgenscience.org/search-standards

Analyze and interpret data from fossils to provide evidence of the organisms and the environments in which they lived long ago. 3-LS4-1	
Science Practices	**Connection to the Lesson**

Developing and Using Models	Students use 3-D models of living beings, and discuss why they are working with models instead of the real thing (answer: biological scale, the real thing is too small to see).
Disciplinary Core Ideas	**Connection to the Lesson**
NGSS 3-LS4-1: Some kinds of plants and animals that once lived on Earth are no longer found anywhere.	Students will work with some animals that are still living (head lice) as well as remains of animals that are now extinct (tooth of a mammoth, tooth of the small mammal *Plagioctenoides*). They might notice that the living animals are represented by a complete body, but the extinct animals are represented by only pieces of the body: the evidence in the fossil record is incomplete.
Crosscutting Concepts	**Connection to the Lesson**
Scale, Proportion, and Quantity: **Natural objects and/or observable phenomena exist from the very small to the immensely large or from very short to very long time periods.**	Students will compare objects from across the size scale of natural objects, from virus to star, and see that the scale is large, requiring many orders of magnitude.

CCSS STANDARDS

Common Core Mathematics Standards

Performance Expectation	**Connection to Lesson**
CCSS.MATH.CONTENT.5.NBT.A.1: Recognize that in a multi-digit number, a digit in one place represents 10 times as much as it represents in the place to its right and 1/10 of what it represents in the place to its left.	Students will compare numbers that differ only in place value, both a mathematical sense as well as a physical, real-world sense (by measuring how big an object would be if it were made 10 times larger, 100 times larger, 100 times smaller, etc.) on Day 1.
CCSS.MATH.CONTENT.5.NBT.A.2: Explain patterns in the number of zeros of the product when multiplying a number by powers of 10, and explain patterns in the placement of the decimal point when a decimal is multiplied or divided by a power of 10. Use whole-number exponents to denote powers of 10.	Students will multiply and divide by powers of 10 throughout the lesson.
CCSS.MATH.CONTENT.5.NBT.A.3: Read, write, and compare decimals to thousandths.	In order to solve some of the questions posed during Day 2, students will need to work with very small numbers < 0.01 mm
CCSS.MATH.CONTENT.5.MD.A.1: Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to	Students will do exactly what is described in the standard in the first day of the lesson when they measure the size of the classroom and compare it to the size of super-large objects.

0.05 m), and use these conversions in solving
multi-step, real world problems.

RESOURCES & MATERIALS

- LCD projector
- 3D files for printing:
    - Note: Only the teeth of *Plagioctenoides* and the mammoth are directly used in the lesson plan. The contents of the rest of the kit can be altered to suit the classroom needs and resources.
    - a rhinovirus (common cold virus) at 10,000,000x and 1,000,000x life size (https://www.thingiverse.com/thing:883015)
    - a tardigrade (water bear) at 1000x, 100x, and 10x life size (https://www.thingiverse.com/thing:3075812)
    - a head louse at 100 and 10x life size (https://www.thingiverse.com/thing:3075825)
    - a *Plagioctenoides* (small mammal) molar at 100x and 10x life size (https://www.morphosource.org/Detail/MediaDetail/Show/media_id/6214)
    - a woolly mammoth molar printed out at life size (https://www.morphosource.org/Detail/MediaDetail/Show/media_id/6213)
- Transect tape or a measuring tape with metric measurements.
- Rulers with metric measurements, 1 for each student
- Reference sheet of object measurements
- Pre-test sheet
- Scratch paper for students
- Sample Question Bank
- Question Stems
- Information Sheets about the animals and virus
- Introductory 3D printing video: https://www.youtube.com/watch?v=Vx0Z6LplaMU
- Optional: If students seem to need a review of estimating and/or rounding, these videos from brainpop.com provide a concise and easy-to-understand explanation of each concept:
  https://www.brainpop.com/math/geometryandmeasurement/estimating/
  https://www.brainpop.com/math/numbersandoperations/rounding/

KEY ACADEMIC AND/OR SCIENTIFIC LANGUAGE

Fossil: Remains of animals that are no longer alive today.
Louse: a small, parasitic animal with no internal skeleton.
Mammal: A group of animals with hair. They give birth to live babies.
Mammoth: an extinct relative of the elephant.

Molar: Teeth at the back of the jaw in mammals. They are usually the most complicated teeth in the jaw and are used for crushing or grinding up food.
Plagioctenoides**:** a small, extinct, insect-eating mammal that is related to shrews and moles alive today.
Tardigrade: or **water bear**. A group of microscopic animals that happen to look a little bit like tiny bears. They have no skeleton inside their body and are not actually closely related to bears. They live in water.
Virus: a very simple agent that infects living beings in order to make more copies of itself.

PRIOR KNOWLEDGE

Students should have basic knowledge of multi-digit multiplication and long division. They should be able to multiply and divide decimals.

Use the information sheets associated with each object to provide students with an introduction to each animal and virus.

ADAPTATION TO OTHER GRADES

The lesson does not currently use exponents or scientific notation, but it could easily do so if students had to set up problems and write answers using scientific notation. If they do, then the lesson also aligns with the following standards:

Grade 6:

CCSS.MATH.CONTENT.6.RP.A.3.D: Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

CCSS.MATH.CONTENT.6.NS.B.2: Fluently divide multi-digit numbers using the standard algorithm.

CCSS.MATH.CONTENT.6.NS.B.3: Fluently add, subtract, multiply, and divide multi-digit decimals using the standard algorithm for each operation.

CCSS.MATH.CONTENT.6.EE.A.2.C: Evaluate expressions at specific values of their variables. Include expressions that arise from formulas used in real-world problems. Perform arithmetic operations, including those involving whole-number exponents, in the conventional order when there are no parentheses to specify a particular order (Order of Operations). *For example, use the formulas* $V = s^3$ *and* $A = 6\ s^2$ *to find the volume and surface area of a cube with sides of length* $s = 1/2$.

Grade 8:

CCSS.MATH.CONTENT.8.EE.A.1: Know and apply the properties of integer exponents to generate equivalent numerical expressions. For example, $3^2 \times 3^{-5} = 3^{-3} = 1/3^3 = 1/27$.

CCSS.MATH.CONTENT.8.EE.A.3: Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other. *For example, estimate the population of the United States as 3 times* 10^8 *and the population of the world as 7 times* 10^9*, and determine that the world population is more than 20 times larger*.

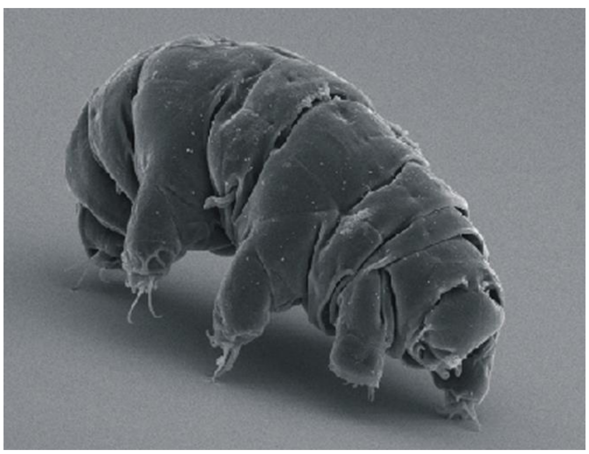
CCSS.MATH.CONTENT.8.EE.A.4: Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities (e.g., use millimeters per year for seafloor spreading). Interpret scientific notation that has been generated by technology

Tardigrades

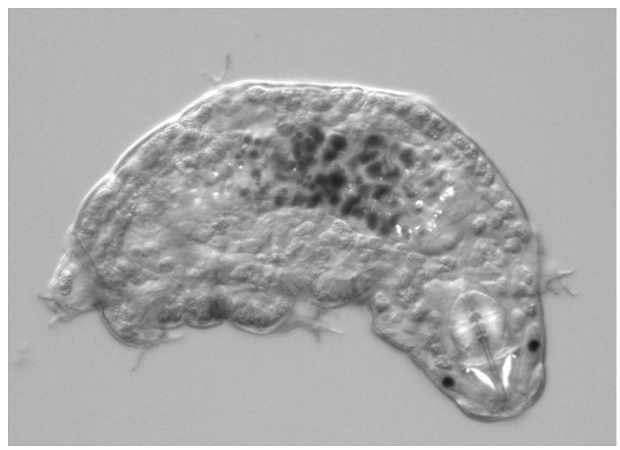
What are they?

Tardigrades are tiny animals. They are also called water bears. They are invertebrates, which means that they have no bones underneath their skin. Each tardigrade has eight legs with claws on the ends. Tardigrades are most closely related to another group of animals called velvet worms. They are also closely related to a group of animals that includes beetles, butterflies, crabs, lobsters, spiders, and scorpions.

There are over 700 different species of tardigrades. Some species live in your backyard. Others live on the tops of tall mountains, or at the bottom of the deep ocean, or at the South Pole on Antarctica. Most species need to live in water. If the water dries out, tardigrades can also dry out without dying. Instead, they stop moving and curl up into a dried-out ball called a tun. They can survive as a tun for years in deserts, in ice, and even in space. If the tun is carried to a nice, wet place, the tardigrade rehydrates and starts to move around again.



SEM image of a tardigrade in active state. Photograph from Chokraje et al. 2012. Licensed under CC BY 2.5 via Wikimedia Commons



View of feeding tardigrade under a microscope. Dark spots in the body are algae being digested. Photo by Willow Gabriel.

Sources:

Bordenstein, Sarah, Science Education Resource Center at Carleton College “Tardigrades (Water Bears).” Accessed 20 February 2015. http://serc.carleton.edu/microbelife/topics/tardigrade/index.html

Goldstein, Bob, and Mark Blaxter. “Quick Guide: Tardigrades.” *Current Biology* 12(2002):R475. http://tardigrades.bio.unc.edu/tardigrades/

Schokraie E, Warnken U, Hotz-Wagenblatt A, Grohme MA, Hengherr S, et al.”Comparative proteome analysis of Milnesium tardigradum in early embryonic state versus adults in active and anhydrobiotic state.” PLoS ONE . 7(2012):e45682. doi:10.1371/journal.pone.0045682

Viruses

What are they?

Viruses are the smallest things that can infect animals and plants. They are so simple that they need to hijack the cells of other animals to complete their life cycle. Some scientists do not count them as living beings, but others do. There are many kinds of viruses with many different shapes. The printed virus is a rhinovirus, or one of the kinds of viruses that can give you the common cold.

TEM (transmission electron micrograph) image of a smallpox virus. Image from the Center for Disease Control, ID #1849

Head Louse

What is it?

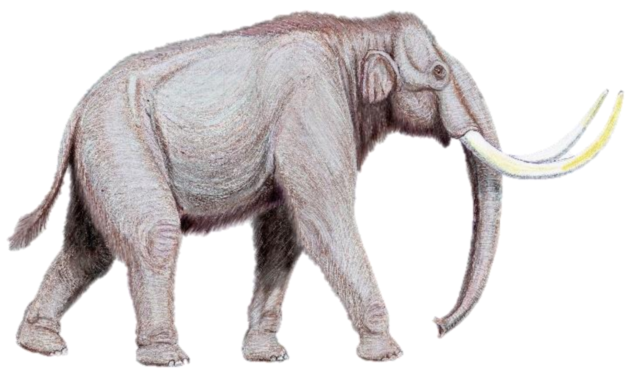
If you have ever had lice, these animals lived in your hair. Head lice are small insects that only live on human scalps. Head lice can only live on humans. Other mammals and birds have their own species of lice.

Photograph of a head louse, taken by KostaMumcuoglu.

Mammoth

What is it?

Mammoths were relatives of today's elephants. The printed tooth is a small molar from a mammoth that lived in Florida about 2 million years ago. Mammoths ate plants and used to live across the United States. They went extinct about 10,000 years ago.



Reconstruction of what a mammoth might have looked like when it was alive, based on skeletons and mummified mammoths. Drawing by Dmitry Bogdanov.

Small Mammal (*Plagioctenoides*)

What is it?

The printed tooth is a molar from the lower jaw of an animal called *Plagioctenoides*. What the rest of the body of *Plagioctenoides* looked like is still a mystery. Based on the size of its teeth, scientists estimate that individuals of *Plagioctenoides* weighed about as much as a nickel. Based on its tooth shape, scientists think that *Plagioctenoides* ate insects around 55 million years ago in Wyoming.

Estimated life size of an animal of *Plagioctenoides* based on size of fossilized teeth.

Sizes of Things

The Sun (diameter)

1,391,684,000,000 mm

1,000,000,000,000 mm rounded

The Moon (diameter)

3,476,000,000 mm

3,000,000,000 mm rounded

The Tallest Building in the World (height)

829,970 mm

800,000 mm (rounded)

T. rex (length, estimated)

12,000 mm

10,000 mm (rounded)

Great White Shark (length, average)

6,700 mm

7,000 mm (rounded)

Alligator (length, average)

3,400 mm

3,000 mm (rounded)

Woolly Mammoth Body (length, estimated)

4,000 mm

4,000 mm (rounded)

Woolly Mammoth Tooth (length, average)

310 mm

300 mm (rounded)

Plagioctenoides body (length, estimated)

70 mm

70 mm (rounded)

Plagioctenoides tooth (length, average)

1.1 mm long

1 mm long (rounded)

Football Field (length)

110,000 mm

100,000 mm (rounded)

Football (length)

279 mm

300 mm (rounded)

A Car (length, average)

4,000 mm

4,000 mm rounded

Human (height, average)

1,700 mm

2,000 mm (rounded)

Human tooth (length, average)

20 mm

20 mm (rounded)

Ant (length, average)

10 mm

10 mm (rounded)

Head louse (length, average)

2.7 mm

3 mm (rounded)

Tardigrade (average, length)

1 mm

1 mm (rounded)

The Smallest a Human Can See (average, length)

0.1 mm

0.1 mm (rounded)

Human hair (average, width)

0.1 mm

0.1 mm (rounded)

Pollen Grain (average, length)

0.02 mm

0.02 mm (rounded)

Hole in a Household Air Filter (average, width)

0.01 mm

0.01 mm (rounded)

Smoke particle (average, length)

0.0025 mm

0.003 mm (rounded)

Virus (average, length)

0.0001 mm

0.0001 mm (rounded)

1. An ant is 10 mm long. A tardigrade is 1 mm long. How many times larger is an ant than a tardigrade?

2. A football is 300 mm long. An alligator is 3,000 mm long. How many times bigger would you have to make a football in order to make it as long as an alligator?

3. An alligator is 3,000 mm long. The length of a football field is 100,000 mm long. How many alligators could fit along the length of a football field?

4. The tallest building in the world is 800,000 mm tall. The smallest a human can see is 0.1 mm. How many times smaller would the tallest building have to be shrunk in order to be too small to see?

A scientist want to design a net to catch tardigrades so that she can learn more about them. The first net she builds has holes 10 mm long. Are these holes bigger or smaller than a water bear? Will the net work?

Air filters in homes have holes about 0.01 mm wide. Are the holes smaller than pollen grains? Will the filters catch pollen?

Some scientists found out that tardigrades can survive in space. An astronaut wants to take more tardigrades into space with him to do some more research. He has a tube 10 mm long to carry all of his specimens. Approximately how many water bears could he fit inside the tube to take with him into space?

If people wanted to bring woolly mammoths back to life, the mammoths would need a place to live. Maybe they could live on a football field and eat the grass there. How many mammoths could you put along the length of a football field?

Flo wants to know who would win in a fight between a tardigrade and a shark, but the fight is only fair if the animals are the same size. How much longer would a tardigrade need to be to become approximately the same length as a shark?

How many times smaller would a *T. rex* have to be to become too small to see?

Evil Vee wants make a giant shark to swim up the St. John’s River and attack Jacksonville. The giant shark is 100 times longer than a great white shark. The St. John’s River is about 100,000 mm wide in Jacksonville. Is Evil Vee’s giant shark bigger or smaller than the width of the St. John’s River? Will it fit in the river? Will Evil Vee’s plan work?

How many times bigger/smaller would ___________________________ have to be in order to be the same size as ______________________?

How many ______________________could fit on ____________________?

How much would you have to shrink _______ to make it microscopic (too small for a human to see?)

How many times larger/smaller is _________ than _________?