How small IS nano?

A lesson on scale

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LESSON OVERVIEW

Lesson Description

Topic: Scale

How the topic is contextualized: Students are initially asked to think of how the world would look if they were 10x smaller or 100x smaller. From there, students will create models of themselves 10x and 100x smaller, then create a model of the micro and nano scales magnified by 1,000,000x.

Importance of the topic: This lesson is designed to help students build an understanding of proportional reasoning and benchmark objects at the micro and nano scales. Research shows that students lack knowledge in both of these areas, and it is important to understand relative size and scale to understand topics in all areas of science.

Connection to other science topics: Scale and relative size are important in all STEM fields. Students need a basic grasp of scale to build deeper understandings of a variety of science topics.

Description of what students will do to investigate the topic: Students will create models of various "mini" worlds and use proportional reasoning to compare objects of various sizes. Students will develop knowledge of relative and absolute size for several benchmark objects, and use these to estimate relative size for other objects in the nano- and microscales.

Learning Goals

- Students will use measurement and proportion to create models to scale.
- Students will extrapolate from 100x smaller to 1000x and 10,000x smaller using proportional reasoning, and be able to explain that a point exists where objects become too small to see.
- Students will create a model of the logarithmic scale, and use it to explain relative size differences between objects at different points on the scale (ex. Between millimeter and meter, micrometer and millimeter).
- Students will use benchmark objects to predict size of objects to an appropriate power of 10.

Big Ideas in Nano

Size and Scale

- An understanding of size and scale and related factors (such as proportionality) help students to describe matter and predict its behavior.
- This lesson focuses on scaling and proportionality to help build students' proportional reasoning skills, and uses analogies to help them gain an understanding of the relative size of nanoscale objects.

Tools and Instrumentation

- Development of new tools and instruments drives scientific progress and allows scientists to detect, manipulate, and observe objects on the nanoscale.
- As students focus on magnification of small objects and shrinking themselves into "Mini-mini-Me's", they will be introduced to the idea that at some point, the naked eye is no longer a sufficient visualization tool. They will learn the limit of the naked eye and the optical microscope, and get a brief introduction to other possible means of visualization.

Standards

Indiana Learning Standards

7th Grade: 7.2.4

8th Grade: 8.2.1, 8.2.2

Physics: P.1.4

National Science Education Standards

Grades 5–12

No specific standards written, however, this is a great link between math and science.

- Benchmarks for Science Literacy – Project 2061

Grades 6 – 8

9A: The Mathematical World – Numbers

12B: Habits of Mind – Computation and Estimation

Grades 9 – 12

9A: The Mathematical World – Numbers

11D: Common Themes – Scale

12B: Habits of Mind – Computation and Estimation

LESSON PREPARATION

Teacher Background Content Knowledge

- Scale is an interesting area because it transcends all fields of science, and is something that students may have a difficult time grasping.
- Knowledge of important benchmark objects
  - What they are
  - Approximate powers of 10
- Knowledge of the logarithmic scale/metric units
  - How a logarithmic scale differs from a linear scale, and when each is particularly useful.
- See supplemental information.

Student Prior Knowledge Expectations

It is helpful if students have some previous experience working with exponents. This may help them understand the difference between linear and logarithmic scales more easily.

Potential Student Alternative Ideas

- Students may believe that objects related by powers of 10 have a linear relationship with one another. For example, a student might believe that the distance between objects at 10^{-9} and 10^{-7} is the same as the distance between objects at 10^{7} and 10^{9}.
- Students may believe that negative powers are 10 are negative numbers, and that larger negative exponents indicate a larger number than smaller negative exponents.
- Students tend to think that all objects too small to be seen with the naked eye are roughly the same size, even though their sizes may be vastly different (Tretter, Jones, Andre, Negishi, & Minogue, 2006).

- Pre-college students tend to group all micro- and nano-scale objects into a single category, lacking benchmark objects (Tretter et al., 2006).

Potential Student Difficulties

- Students may have difficulties with exponents and understanding proportional reasoning.
- Low knowledge of metric units and powers of 10.
- Students often confuse atoms and cells, and often do not have a clear understanding of their relative sizes.
- Students may not be familiar with some of the benchmark objects. Teachers can vary these benchmark objects based on their curricula and students' prior knowledge.

Materials

Item	Number/Amount
Modeling Clay	1 package/2 groups
Measuring tape (or string and meter stick)	1/group
Markers/pens/pencils	Several/group
Index cards	1/student
Images of benchmark objects 100x larger	1 set/class
Butcher paper	2 sheets/group
1 mm diameter wire cut into 100 mm lengths	2/group
Posters/models of benchmark and unknown objects	1 set/class
Meter stick	2/class
Traffic cones	1/poster to stand up objects
Colored tape/caution tape	1 roll/class

Cautions/ Potential Pitfalls

When using a 1mm diameter wire as their "nanometer stick", students may actually believe that one nm is as big as the diameter of the wire. It is important to contextualize this activity within other instruction about scale to address this potential misconception.

Pre-Class Preparation

Getting the Materials Ready

Teachers can take a digital picture of each student next to a measuring stick that indicates their height. Teachers can then shrink this down using Photoshop and provide each student with their "Mini-Me" and "Mini-mini-Me" after the lesson.

Safety Issues

None

DOING THE LESSON

Opening

- Have students respond to the following questions in their journals or on a sheet of paper.
    - What do you think the world would look like if you were 10x smaller? What about if you were 100x smaller?
    - What is the smallest thing that you can see? How big do you think it is?
    - If you were the size of a bacteria, how many steps do you think it would take you to walk across the width of a human hair?

Discussion

If this lesson is following the card sort lesson on size, ask students to think back to their clothesline activity.

What if we were able to show using a clothesline how far apart these objects really are? How long would our clothesline need to be, to stretch all the way from the nanoscale to the size of the moon?

The purpose of this lesson is to help students begin to grasp the concept of scale, and of how far apart these items really are from one another if we correctly use a linear scale. It is not important that students understand the logarithmic scale per se (although it may be appropriate for certain classes), but that they understand how far apart these items are from each other, and that they are not evenly spaced.

Body

The Mini-Me and Mini-mini-Me activities can be used to help students begin to understand that there will be a point at which their mini-self can no longer be seen. Students may be surprised to see just how much smaller their Mini-mini-Me is! This will lead into a discussion of how small they think they would have to shrink before they could no longer be seen with the naked eye.

The football field activity is intended to tie together the lesson on scale and the lesson on relative size, using the same benchmark objects as the card sort activity on the small end of the scale. This is intended to help students begin to see the differences in size between the objects, and that they are not linearly related.

Activity 1 – Mini-Me

1. Ask students will get into groups of 3-4. Students will sketch what they think they would look like if they were 10x smaller- estimate their height, armspan, etc.
2. Students will take turns using a measuring tape to measure their arms, legs, head, and torso in centimeters. Students will then use conversions to figure out what the dimensions of their mini-me would be.
3. Once all students have completed their measurements and conversions, students should create their "mini-me" out of clay or some other modeling material. Ask them to compare their mini-me to their drawing. Was it the same size? Larger or smaller than they expected?
4. Have students measure a few familiar objects, and use butcher paper to draw them 10x larger, as seen from the perspective of their "mini-me"

Activity 2 – Mini-mini-Me

1. Based on their mini-me, ask each student to estimate the size of their mini-mini-me by drawing their prediction on a sheet of paper.
2. Ask students to use their measurements to scale down by 100x.
3. Once students have figured out the dimensions of their "mini-mini-me", ask each student to create their mini-mini-me. Students can use clay, but they may find it very difficult! Students can also use markers and index cards for their mini-mini-me.
4. Discussion: Ask students whether their mini-mini-me was larger or smaller than they expected. How small do they think they would be 1000x smaller? 10,000x smaller? Is there a point where they would no longer be able to be seen? Where do they think this point might be?

5. Ask each group to select another (fairly small) object to draw 100x magnified on a piece of butcher paper. These objects together along with images of bacteria, viruses, etc. magnified 100x will create a picture of the world as seen by their mini-mini-me.

Activity 3- Football Field

1. Introduction (indoors before football field)
    a. Students will be asked to start with the size of a human hair at .1 mm. They will use butcher paper and a meter stick to measure out the distance to the next object on the clothesline, which is the thickness of a penny, followed by a mouse and a human. The next smallest object is a red blood cell, and the next largest is a mountain. Students will be asked how large the paper would need to be just to represent one more order of magnitude. Students may suggest making a mm represent either a meter (for larger objects) or a micrometer (to show smaller objects).
    b. Discussion questions
        i. How can we represent more than a few powers of ten at one time?
        ii. Are powers of 10 evenly spaced from one another?
        iii. How does this look different than the way we placed objects on the clothesline?
    c. These questions will be revisited after the activity.
2. Students will position cones or other markers along the field to indicate 10-fold size differences in the micro and nano worlds.

    a. The full 100 m (approximating that 1 yard represents 1 m) length of the field will represent 0.1 mm (1,000,000x magnification), 10 m will represent 10 micrometers, 1 m will represent 1 micrometer, and 10 cm will represent 100 nm, the upper limit of the nanoworld.

3. Students will mark off the boundary of the nanoworld (last 10 cm of the field) with colored tape. Students will also place posters to indicate the smallest thing that can be seen with the human eye and with the optical microscope.
    a. The objects used will be the same as the benchmark objects used in the relative size lesson. Other objects will also be used to represent other powers of 10 on the scale (see appendix). Not all of these are exactly 1 to the power of 10; however, we are less focused on absolute size and more focused on relative size to a power of 10.
4. Each student will be given a 1 mm diameter wire. Since we are magnifying everything by 1,000,000, we have also "magnified" a nanometer, and our 1 mm wire represents a nanometer. We now have a "nanometer stick". Students will start at the nanoworld, and measure the distances between the objects.

    *Note: Once we move past the nanoworld, this will get tedious! Students can then use distances they have already measured, and use the length of the wire (which is 100 mm, representing 100 nm) to measure the rest of the field. They can also use the meter stick, but this will require greater proportional reasoning skills.
5. Students will complete a worksheet in groups of 4 that will help them make comparisons between objects. For example, if 100 m represents .1 mm, then the width of a human hair will take up the entire football field. If this is true, how big would an atom be?
6. Students will place additional objects on the field, using reasoning skills related to relative size.
    - These can be objects students have studied in class, have prior knowledge of, or have an interest in.
7. Ask students about other benchmark objects from the relative size lesson.
    - What about the hydrogen atom? How small would that be?
    - At this level of magnification, how many football fields would it take to represent the thickness of a penny?

Wrap-up

The football field activity is intended to tie together the relative size lesson with mini-me and mini-mini-me.

How tall was your mini-mini me? If the football field represents .1 mm, how many football fields would it take to represent the height of your mini-mini-me?

How many times would you have to shrink down your mini-mini-me so that you could no longer be seen with the naked eye?

The extra objects that students placed on the field should be added to the clothesline in the classroom to help students build up their knowledge of benchmark objects. These objects can vary based on the content of the course and students' prior knowledge/interests. This will reinforce the relative size lesson and help them further contextualize size and scale within their other science content knowledge.

- Revisit earlier discussion questions- discussion of why we use powers of 10 instead of placing them the exact distance apart (linear vs. logarithmic).
- Even using a football field, we can only show 6 orders of magnitude at a time with a linear scale. The clothesline is what scientists call a logarithmic scale, and they use it to represent objects that are too far apart to place at their exact distances.

Assessment

Formative Assessments Table

Assessments	Where in lesson	Possible correct responses
Students' scaling of measurements to make mini and mini-mini me	1-2 and 2-2	Students should use division by factors of 10 to determine the dimensions of their mini and mini-mini-me's.
Students' assessments of their predictions	1-3 and 2-4	From the mini-me to mini-mini-me activity, teachers should monitor the development of students' proportional reasoning skills as they begin to build an understanding of powers of 10.
Discussion of limits of the naked eye	2-4	Throughout the discussion, teachers should monitor students ideas about where this "limit' might be, and help students tie this idea to the relative size lesson.

Football field measurement worksheet	3-4	Monitor students and check to see that they are effectively measuring objects and comparing them by powers of 10.
Discussion of benchmark objects	3-6	Throughout the discussion, monitor student responses for progress of their ability to use proportional reasoning to determine relative size.
Placement of new objects	3-5	Monitor students' placement and ask questions about rationale to assess reasoning skills for relative size.
Wrap-Up	Steps 2 and 3	Students should be able to approximate how large their mini-me would be based on the measurements they took and the size of the field.

Summative Assessment

As the lesson progresses, students should keep track of the objects they are measuring. They should be able to approximate the size of the objects on the football field to the correct power of 10, and should be able to place the new objects to within an order of magnitude.

Students should also be able to approximate the size of their mini-mini-me in relation to the football field to an order of magnitude.

ADAPTATIONS

Extensions

- For upper level students with more math background, the lesson can introduce the logarithmic scale directly and address the differences between the logarithmic and linear scales. This may not be appropriate for younger students who are just being introduced to exponents.

Simplifications

- To save time, the teacher can set up the football field ahead of time, and have students measure with their nanometer stick.

RESOURCES

- All images for the football field activity were found by searching using Google Image.
- This lesson was based on activities created at Pennsylvania State University and the University of Michigan (University of Michigan lessons written by Clara Cahill and Cesar Delgado).
- Tretter, T. R., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2006). Conceptual boundaries and distances: Students' and adults' concepts of the scale of scientific phenomena. Journal of Research in Science Teaching, 83, 282-319.

SUPPLEMENTAL MATERIALS

Lesson Summary

This lesson addresses scaling of objects by powers of 10. It can be difficult for students to understand the differences between objects at various powers of 10, particularly since many of them have little experience working with exponents or logarithmic scales.

The lesson opens with a discussion of the previous activity related to relative size (clothesline activity), and asks students to think about how long the clothesline would have to be to accurately represent the distances between the objects. This will be revisited later in the third activity.

Students then create a "Mini-Me" and a "Mini-mini-Me" to see what they would look like at 10x smaller and 100x smaller. Students magnify everyday objects 100x to create a "mini-mini world", and see pictures of smaller objects (such as red blood cells) magnified 100x.

The football field activity is intended to help students relate the smallest thing they can see (about the width of a human hair) to objects on the nanoscale. A football field is measured out, and objects are magnified by 1,000,000x. Based on this magnification, the width of a human hair would span the football field, and a nanometer would be 1mm. This activity allows students to create an actual linear representation of 6 orders of magnitude, and shows the need for logarithmic representations of the nanoscale as compared to the micro- and macroscale. Students measure objects on the field using a "nanometer stick", and compare across orders of magnitude. Students then place unknown objects on the field using their reasoning skills.

The lesson concludes with students revisiting their mini-mini-me's, and estimating how big they would be at 1,000,000x magnification (in number of football fields) to help them gain an appreciation of the relative scale. The major summative assessment is the measuring and comparison component of the football field activity, which ties together the lessons on relative size and scale.

Connections to content areas

An understanding of scale is important to general science, biology, chemistry, physics, math, engineering, and technology. The deeper students understanding is in the area of size and scale, the more they may be able to understand in other fields, such as how small an atom really is how a mitochondria compared to a red blood cell. Scale and metric units are covered or reviewed in many science classes in the traditional science curricula.

Standards

<u>Indiana Learning Standards</u>

7th Grade

7.2.4 – Express numbers like 100, 1,000, and 1,000,000 as powers of 10.

8th Grade

8.2.1 – Estimate distances and travel times from maps and the actual size of objects from scale drawings.

8.2.2 – Determine in what units, such as seconds, meters, grams, etc., an answer should be expressed based on the units of the inputs to the calculation.

Physics

P.1.4 – Employ correct units in describing common physical quantities.

<u>National Science Education Standards</u>

Grades 5–12

No specific standards are written, however, it is necessary for students to understand size and scale to fully understand the size of an atom and to understand nano. Size and scale may be linked more closely with mathematics, but students do not usually transfer knowledge from one class to another so addressing size and scale in science class is beneficial, and provides a link between mathematics and science.

- <u>Benchmarks for Science Literacy – Project 2061</u>

  Grades 6 – 8

  9A: The Mathematical World – Numbers

  - Numbers can be written in different forms, depending on how they are being used. How fractions or decimals based on measured quantities should be written depends on how precise the measurements are and how precise an answer is needed.

  12B: Habits of Mind – Computation and Estimation

  - Estimate distances and travel times from maps and the actual size of objects from scale drawings.
  - Determine what unit an answer should be expressed in from the units of the inputs to the calculation, and be able to convert compound units.
  - Express numbers like 100, 1,000, and 1,000,000 as powers of 10.

  Grades 9 – 12

  9A: The Mathematical World – Numbers

  - Comparison of numbers of very different size can be made approximately by expressing them as nearest powers of 10.

11D: Common Themes – Scale

- Representing large numbers in terms of powers of ten makes it easier to think about them and to compare things that are greatly different.

12B: Habits of Mind – Computation and Estimation

- Express and compare very small and very large numbers using powers of ten notations.

Subject Matter Knowledge

Object	Approximate Size (m)	Prefix	Symbol
Solar System	3.99×10^{15}	peta-	p
Diameter of Sun	1.392×10^{9}	giga-	G
Diameter of Earth	1.275×10^{7}	*	*
Diameter of Mars	6.780×10^{6}	mega-	M
Moon	3.476×10^{6}	mega-	M
Australia	4.0×10^{6}	mega-	M
Mountains (avg. height)	$2\text{-}5 \times 10^{3}$	kilo-	k
Skyscraper	$1.5\text{-}4.4 \times 10^{2}$	hecto-	h
Sheet of Paper (length)	2.8×10^{1}	deka-	da
Giraffe	$4.8\text{-}5.5 \times 10^{0}$	----	----
Human	1.8×10^{0}	----	----
Business envelope (length)	2.4×10^{-1}	deci-	d
Mouse	$1\text{-}2 \times 10^{-1}$	deci-	d
Acorn	$1\text{-}6 \times 10^{-2}$	centi-	C
Ant	$7\text{-}15 \times 10^{-3}$	milli-	m
Thickness of penny	1×10^{-3}	milli-	m
Thickness of staple	5×10^{-4}	*	*
Dust mite (length)	4.2×10^{-4}	*	*
Width of a human hair	1×10^{-4}	*	*
Paramecium (length)	$5\text{-}35 \times 10^{-5}$	*	*
Red blood cell (diameter)	$6\text{-}8 \times 10^{-6}$	micro-	µ
Chloroplast	$2\text{-}10 \times 10^{-6}$	micro-	µ
Cell nucleus	$5\text{-}22 \times 10^{-6}$	micro-	µ
Mitochondria	$5\text{-}10 \times 10^{-7}$	*	*
Bacterium	$2\text{-}10 \times 10^{-7}$	*	*
Virus	$1\text{-}400 \times 10^{-8}$	*	*
Distance across DNA	2×10^{-9}	nano-	n
Benzene molecule	5.12×10^{-10}	***	***
Water molecule	2.75×10^{-10}	***	***
Gold atom	2.6×10^{-10}	***	***
Hydrogen atom	1×10^{-10}	***	***
Gold nucleus	1.46×10^{-14}	*	*
Carbon nucleus	5.5×10^{-15}	femto-	f
Proton	1×10^{-15}	femto-	f