

What is the Smallest Thing I can “see”?

Relative Size: A Card Sort

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Content Area: General Science/ Math
Grade Level: 7-12

LESSON OVERVIEW

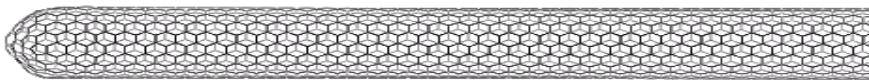
Estimated Time of Lesson: 1 - 2 hour(s)

Description

- Topic: Relative size (range of size) and tools
- How the topic is contextualized: Students are initially supposed to think of the smallest thing they can think of. From there, students are sorting cards by size of which many of the objects are familiar to them.
- Importance of the topic: This lesson should help students develop an understanding of relative size across all scales, which is very important in science, engineering, and math areas.
- Connection of the topic to other science concepts: Relative size cuts across all fields of science, technology, engineering, and math. Having an understanding of size allows students to have a firmer grasp of the material typically studied in STEM classrooms, such as cells, DNA, atoms, and molecules.
- Description of what the students will do to investigate the topic: Students will develop strategies for estimating and characterizing the sizes of objects. Students will also be introduced to the type of “instrument” that can be used to visualize objects including an introduction to seeing objects on the nano-level.

Learning Goals

- Students will be able to compare, estimate, and characterize the sizes of objects ranging from the nano- to the macroscale.
 - Students will be able to order/ rank objects according to relative size and provide a logical reason for those rankings.
 - Eg. Molecules are larger than atoms because atoms make up molecules.
 - Students will be able to estimate sizes of objects to an appropriate power of 10 ranging from 10^{-15} to 10^{15} meters.
 - Eg. Mitochondria = 10^{-7} m; Red Blood Cell = 10^{-6} m
 - Students will be able to classify sizes by regions: astro-, macro-, micro-, and nano-worlds and recall what sizes correspond to each.
 - Eg. Astro- is 10^{15} - 10^6 ; macro- is 10^6 – 10^2 ; micro- is 10^4 to 10^{-7} ; and nano- is 10^{-9}
 - This should get students to think about a continuum. The ranges of these worlds are meant as examples, not exact answers.



- Students will be able to decide what types of instruments/ tools they would use to observe objects at the astro-, macro-, micro-, and nano-worlds.
 - Eg. To visualize a red blood cell, you could use an optical microscope. To visualize molecules, you can use SPM.

Big Ideas in Nano

- Size and Scale
 - Factors relating to size and scale (e.g. size, scale, scaling, shape, proportionality, and dimensionality) help describe matter and predict its behavior.
 - This lesson focuses on relative size with some brief incorporation of scale. Knowing the range of sizes of submicroscopic objects helps students to flesh out/ expand their conceptions of the unseen world.
- Tools and Instrumentation
 - Development of new tools and instruments helps drive scientific progress. Recent development of specialized tools has led to new levels of understanding of matter by helping scientists detect, manipulate, isolate, measure, fabricate, and investigate nanoscale matter with unprecedented precision and accuracy.
 - As students are selecting instruments used to visualize the objects they have ranked, students will be introduced to scanning probe microscopy, a new tool used to visualize objects at the nano- and atomic-scales.

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

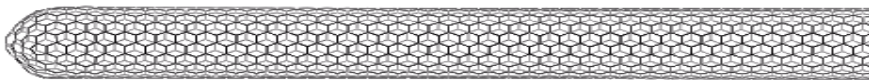
9A: The Mathematical World – Numbers

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

Background Knowledge for the Instructor

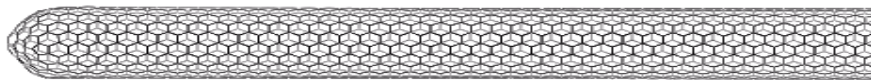
- This is an interesting area because size and scale transcends all areas of STEM and is a skill that students struggle with.
- Knowledge of objects on cards
 - What they are and what are their approximate sizes
 - List of some objects and sizes attached
- Powers of 10/ logarithmic scale/ metric units
 - The number line is important due to showing a continuum of sizes and objects that relate to those sizes. Although the number line is on a logarithmic scale, it still gives students of an idea of the range of sizes. Also, by keeping the number line up the entire year, students can add new items to the line throughout the year.
- Knowledge of tools, specifically scanning probe microscopy (SPM)
 - SPM gives images of the surface of the sample by using a physical probe that “feels” the surface, instead of “looking” at the surface.

Student Prior Knowledge Expectations

- Powers of 10/ logarithmic scale (suggested, but not required)
- Knowledge of the objects that will be used in the activity
 - Students do not need to know sizes, but should have an idea of what the objects are in order to be able to estimate the sizes.

Potential Student Alternative Ideas

- Negative powers of 10 are negative numbers.
- Students tend to think that all objects that are too small to be seen with the naked eye are roughly the same size, whereas in fact their relative sizes may be vastly different (Tretter, Jones, Andre, Negishi, & Minogue, 2006)
- Pre-college students tend to group all micro- and nanoscopic objects into a single category, lacking benchmark objects in these unseen worlds (Tretter et al, 2006)
- Middle school students may believe that small macroscopic items like ants or grains of salt are in fact smaller than atoms and cells (Tretter et al, 2006)
- Students may think that $10^0 = 0$, not 1
- Students may believe that larger negative exponents indicate a larger number than smaller negative exponents.
- Students may believe based upon the cards that atoms and molecules are colored.



Potential Student Difficulties

- They may not have knowledge of some of the objects in the smaller scales
- Low knowledge of metric units
- Low knowledge of powers of 10/ logarithmic scale
 - Having students look at the nature of scale may help this misconception (see NCLT PD lesson on scale by Emily Wischow)
- Students often confuse atoms and cells, and do not usually have a clear idea about their relative sizes.
- Students may not group consistently based on the size order of objects, grouping instead by other characteristics (Tretter et al, 2006). They may also group objects that were not contiguously ranked.
- Students may order representations of objects by the size of the representation rather than the object itself.
- Relative size is easier for students to understand than absolute size (Tretter et al, 2006; others); however, experts rely on absolute size when thinking about the relative size of two objects. Absolute size requires understanding the relative size differences between units. Thus, relative and absolute size conceptualizations build on each other iteratively.
- Students will experience very little difficulty in organizing the macroscopic images on the cards; however, when organizing the microscopic images on the cards, students will have a more difficult time.

Materials

Item	Number/ Amount
Card Set	1/ student
Worksheet	1/ student
Clothesline	1/ class
Clothes pins	Dependent upon class
Number cards (paper numbered 0, 10^{-15} , 10^{-14} , ... 10^{15})	1 set/ class
Prefix & symbol cards	1 set/ class
Pictures of visualization tools	1 set/ class

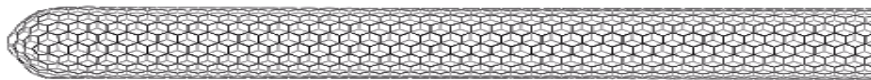
Cautions/ Potential Pitfalls

- The card images should be images your students are semi-familiar with or they will have a very difficult time organizing the cards in order.

Pre-Class Preparation

Getting the Materials Ready

- Have all card sets cut out and ready for each student.
 - Choose cards that fit your class needs.
- Hang up clothesline across front (or back) of room.

**Safety Issues**

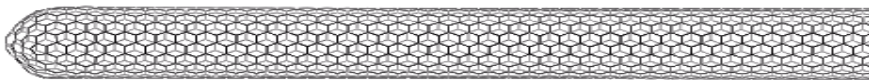
- None

DOING THE LESSON**Opening**

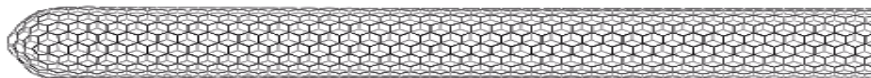
- Have students respond independently to the following questions on a sheet of paper or in their class journals.
 - What is the smallest thing that you can think of?
 - What is the smallest thing that you can see with your eye?
 - What is the smallest thing that you can “see” using technology?
 - Why does size matter?
- These are general questions for students to think of to get them ready for the activity. You may want to inform your students that they will not be graded on it, allowing the students to feel more comfortable in responding.

Body**Activity– Card Sort**

1. Give each student a card set to order and hand out the worksheet in which students will record their answers of the card arrangements.
 - a. Be sure to use images your students know.
2. Tell the students to order the images on the cards from largest to smallest on their OWN and record their arrangement on the worksheet.
 - a. Students will experience very little difficulty in organizing the macroscopic images on the cards; however, when organizing the microscopic images on the cards, students will have a more difficult time.
 - b. Be sure that students understand that the images on the cards are solely images and not the actual size of the object.
3. Have students get in groups of 2-3 to discuss their answers. Students should not only discuss the order but WHY they ordered them the way they did.
 - a. The teacher should now begin interjecting into group discussions and ask students why the cards are in the order they are.
 - i. This is more important for groups with incorrect arrangements.
 - b. At this point, students can rearrange their cards and record their new arrangement under group card arrangement.
4. Interactive large group discussion for rationale of why each card is in that order. Potential discussion questions include:
 - a. What are some reasons for placing card x larger than card y?
 - b. Are there any principles that we can use to help rationalize the order the cards should be in?



5. In the front (or back) of the class, there should be a clothesline hanging with nothing on it. The students as a class should determine where each of the powers of 10 (10^{-15} to 10^{15}) go on the clothesline (similar to a number line).
 - a. Be sure that students place the powers of 10 in equal intervals on the line. This is not usually a point of confusion for students.
 - b. Ask students why they placed the numbers in the arrangement they did.
 - i. This could lead into a brief discussion of log vs. linear scales (see NCLT PD scale lesson by Emily Wischow for more information on scales)
6. At this point, a card with the number 0 can be placed along the number line (this may be a point of difficulty for students).
 - a. The students as a class should decide where the 0 belongs on the number line. Many students may believe that the 0 goes either under 10^0 or somewhere between 10^1 and 10^{-1} .
 - b. Be sure that students understand that even though a power of 10 is negative, it does not mean it is less than zero. Placing the zero card far away from the numbers should help this.
 - i. In actuality, the 0 card cannot really be placed on the number line as the log of 0 is negative infinity. However, depending upon your students you could just place it very far away from the number line and explain to them why it would be so far away.
 - c. Dependent upon your class needs, this is a good point in the lesson to actually describe what the powers of 10 mean. For example, 10^{-1} means 0.1 m, 10^1 means 10 m, and 10^3 means 1000 m. This comparison is similar to the length of a mouse, length of a sheet of paper, and typical height of mountains.
7. Students should then hang their cards/ pictures along the line.
 - a. Only one set of cards needs to be hung...you can enlarge the images for the clothesline if desired.
 - b. Students should work in groups to determine the size of the object on the card using textbooks/ Internet and can then place cards on the clothesline.
 - c. Students can also come up with other objects other than those on the cards to place on the line that they believe will help them to become more knowledgeable about what that power of 10 means.
8. Following the hanging of the object cards, students can hang up a picture of what they would use to “see” the object, such as a telescope, eye, optical microscope, or scanning probe microscope (This is help to understand how scientists are able to visualize all of these objects).
 - a. Discuss the type of ‘instrument’ if any used to visualize each of the objects, such as your eye, telescope, optical microscope, or scanning probe microscope.

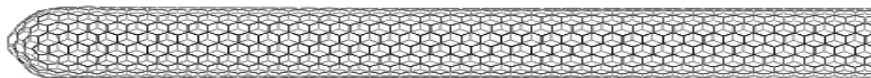


Assessment

- Formative Assessments Table

Assessments	Where in lesson	Possible correct responses/ things to consider
Individual card arrangements	Step 2	Mars, mountains, human, ant, thickness of penny, red blood cell, mitochondria, virus, molecules, atoms
Group card order and rationale discussion	Step 3	Same as above, however, through interactions with groups, you should be examining why students determined that order. Eg. Virus is smaller than red blood cell because a virus can infect a cell.
Interactive discussion of order	Step 4	Throughout the discussion, you should be monitoring student progress of their rationales for the order they determined.
Clothesline activity	Steps 5-8	Monitoring students and checking for understanding as they are placing the number cards, objects, and tools on the line. Asking questions as to what the numbers mean, why the objects have been placed in certain locations, etc.
Scale section	Step 11	Earth is 10,000,000,000 (10^{10}) times bigger than the thickness of penny. Human is 1,000 times bigger than penny. Cell is 1,000 times smaller than penny. Atom is 10,000,000 (10^7) smaller than penny.
Wrap-up	Steps 1 and 2	Students' answers will vary. After watching the video however, students should be able to think on the order of subatomic particles for the smallest object they can think of. Atoms should be the smallest thing they can "see" using technology. Currently the technology does not exist to visualize subatomic particles.

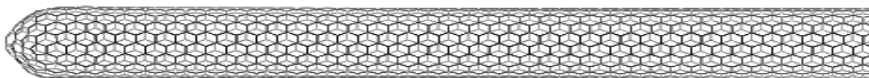
- Summative Assessment (Post-lesson assessment)
- Students are to:
 - a. Arrange the 5 new cards from largest to smallest.
 - b. Justify your arrangement of coupled boxes.
 - c. Estimate the size of each object in 10^x meters. Specify a numerical answer for x
 - d. What would you use to "see" the object?



Arrangement	Diameter of Mercury	Height of Basketball Player	Length of Business Envelope	Diameter of Cell Nucleus	Diameter of Proton
Justification between objects	Mercury is the largest of these items because it is very far away from Earth and I can still see it with my eye.	A basketball is the next biggest because I know he/she would be slightly taller than me and I am smaller than a planet, but bigger than a business envelope which I can hold in my hand.	I know that the business envelope comes next because I can see it with my eye and I can't see a cell nucleus with my eye and I can hold it in my hand and I can't hold a basketball player in my hand.	Cell nucleus is next because I can't see it with my eye, but we have seen pictures of the cell nucleus in books and you can see it under an optical microscope.	Proton is the smallest because it is part of an atom and atoms make up molecules which then make up other objects and living things in the world.
Power of 10	6	0	-1	-6	-15
To "see" the object, I would use...	Telescope or Eye	Eye	Eye	Optical Microscope	Technology not known.

Adaptations

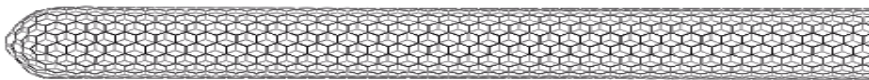
- Extensions
 - Incorporate in the prefixes and symbols for the powers of 10 if previously learned to reinforce these concepts. These can be cards placed on the number line below the powers of 10. Prefix and symbol can also be added to the formative and summative assessments if desired.
 - Adding this section in can be beneficial for students who have previously learned about prefixes and symbols as it acts as a reinforcement of the material. This section can also teach students who have not had the material before.
 - Leave the clothesline up year long. This will help students remember the sizes of benchmark objects which can further their conceptions of relative size. It can also help them remember their prefixes (if included on the line) as well as instruments used to visualize particular objects.



- You can also add onto the clothesline throughout the year as new objects are encountered in the curriculum.
- You could also connect this lesson with the NCLT PD scale lessons by Emily Wischow to enhance students' understandings of the difference between logarithmic and linear scales and why both types of scales are used.
- Simplifications
 - If students have not yet learned the powers of 10, this lesson can still be performed as written; however, you may need to spend more time explaining what the exponents mean.
 - If students have not yet learned the powers of 10, you could also remove them from the clothesline and simply begin with students placing the objects on the line and determining what types of instruments they would use to visualize each object.
 - Performing the lesson in this manner may lead to confusion in relative size in that students may clump all “small” things together in a pile rather than seeing them spread out across the number line as would be seen with the powers of 10.

RESOURCES

- SRI International. (2004-2005). NanoSense Activities. <http://nanosense.org/activities/sizematters/index.html>
- 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*, 43, 282-319.
- All pictures for cards were found by using www.google.com and searching for the object under images.
- Powers of 10 videos
 - <http://www.wordwizz.com/pages/1uexp17.htm>
 - <http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/>
 - <http://www.nikon.co.jp>



SUPPLEMENTAL MATERIALS

Summary of Lesson

This lesson is designed for 7-12 grade general science students (through advanced sciences) to develop an understanding of size and scale, specifically using the metric scale and powers of ten. Students should also develop an understanding of what type of “instrument” should be used to visualize the object and the minuteness of the nanoscale.

The lesson begins by eliciting students’ ideas about the smallest thing they can think of, see with their eyes, and see with technology. Students also begin to think about why size matters. Students record their answers in their journals.

The activity portion of the lesson begins with students individually ordering a set of 10 cards containing objects of varying sizes from largest to smallest. Students then form small groups to discuss their arrangements and reach consensus on the order. Working in small groups and as a whole class, students will determine where on a clothesline that is strung across the room, the powers of 10 should fall. So 10^0 should be in the middle and then students should place other powers of 10 throughout the number line. A discussion of what these numbers mean will occur. On the line, students can then place the prefix and symbol that corresponds. Students will then work together to determine where the objects on the card fit along the line. Following this, students should determine what type of “instrument” they should use to visualize the object. Students then have to compare five cards on the basis of scale and determine how many times bigger or smaller an object is based on a central card object. After completing the activity, students return for a whole class discussion which incorporates what powers of 10 mean and a review back to the initial questions in which students revise their answers.

Assessment of this activity involves inserting five new cards with different objects into the original set of ten cards and determining the power of ten, prefix, symbol, and “instrument” used to visualize the object.

Standards

- Indiana Learning Standards

7th Grade

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

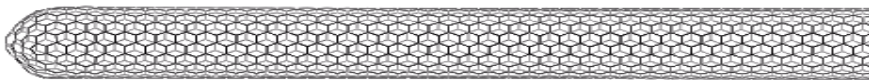
8th Grade

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.



- National Science Education Standards

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.

- Benchmarks for Science Literacy – Project 2061

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

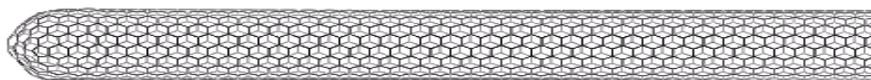
- Comparison of numbers of very different size can be made approximately by expressing them as nearest powers of 10.

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: Potential Objects for Students to Sort

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)	$2-5 \times 10^3$	kilo-	k
Skyscraper	$1.5-4.4 \times 10^2$	hecto-	h
Sheet of Paper (length)	2.8×10^1	deka-	da
Giraffe	$4.8-5.5 \times 10^0$	----	----
Human	1.8×10^0	----	----
Business envelope (length)	2.4×10^{-1}	deci-	d
Mouse	$1-2 \times 10^{-1}$	deci-	d
Acorn	$1-6 \times 10^{-2}$	centi-	C
Ant	$7-15 \times 10^{-3}$	milli-	m
Thickness of penny	1×10^{-3}	milli-	m
Thickness of staple	5×10^{-4}	*	*
Dust mite (length)	4.2×10^{-4}	*	*
Paramecium (length)	$5-35 \times 10^{-5}$	*	*
Red blood cell (diameter)	$6-8 \times 10^{-6}$	micro-	μ
Chloroplast	$2-10 \times 10^{-6}$	micro-	μ
Cell nucleus	$5-22 \times 10^{-6}$	micro-	μ
Mitochondria	$5-10 \times 10^{-7}$	*	*
Bacterium	$2-10 \times 10^{-7}$	*	*
Virus	$1-400 \times 10^{-8}$	*	*
Distance across DNA	2×10^{-9}	nano-	n
Diameter of a buckyball	0.7×10^{-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

* = no standard SI (metric) prefix. Students should categorize to closest metric unit. They can easily change the way the numbers are written as well in order to get to that metric unit.

*** = although there is no standard metric prefix for 10^{-10} , this is known as an Angstrom (\AA)