Quantum Scale

Overview:

In this activity students explore size and scale by organizing objects by size in comparison to a human. They determine how "quantum" fits into this scale. They then explore the idea of Powers of Ten more thoroughly to better understand how quantum particles are exponentially smaller than other small objects.

Materials:

- Select Sizing Things Down cards listed below (21) and others, if you desire, from the National Informal STEM Education (NISE) Network Exploring Size - Powers of Ten Game webpage (cards are also available in Spanish from this link).

  In order from large to small

  - Universe (+26)
  - Sun (+9)
  - Earth (+7)
  - USA (+6)
  - Mount Everest (+3)
  - Football field (+2)
  - Tree or blue whale or school gym (+1)
  - Human (0)
  - Soccer ball (-1)
  - Paper clip or quarter (-2)
  - Pea or ant (-3)
  - Grain of sand (-4)
  - Pollen grain (-5)

  Additional cards for Middle School students

  - Red blood cell (-6)
  - Carbon Atom (-11)
  - Water molecule (-11)
  - Proton (-15)

- Sizing Things Down Orders of Magnitude Poster (1)
- NIST metric prefixes table (attached)

Optional Materials
- Paper clip (10)
- Plastic ants (10)
- A small amount of sand
- Round removable stickers (24 - to cover numbers on cards)
- Soccer ball
- Quarters (one or more up to 10 - optional)

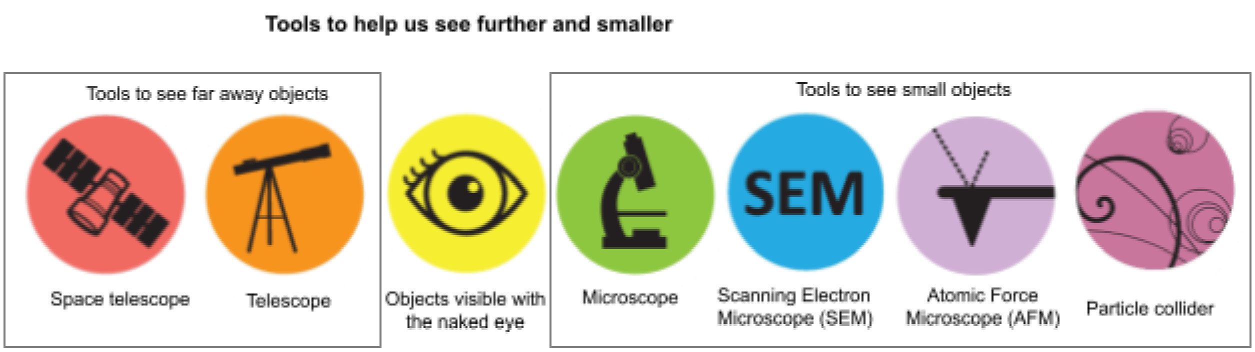
Preparation:

Find a soccer ball to use for this activity. For elementary students, first remove the cards representing the smallest objects (red blood cell, carbon atom, water molecule and proton). These objects are beyond the scope of being easily understandable to students at this age.

Depending upon your group size and the time you have available there are two options:

- Option 1: Choose enough cards representing objects larger than a human so that each student gets one. Also choose enough cards representing objects smaller than a human so that each student gets one.
- Option 2: Choose the same number of cards across the span from very large to very small so that each student gets one.

Be aware that the cards show more than just the labeled object. They also show the tool necessary to see or detect the object (described below), as well as the power of ten that object represents. You may want to cover the power of ten portion of each card using the provided round stickers to help students figure out relative scale without that clue.



Directions:

Part I

Option 1

1. Pass out cards representing objects larger than a human (+1 and up) to the students. Be sure at least one object from each of the nearby size categories (+ 1, 2 and - 1, 2, 3, 4) are represented.Give yourself the human (pirate - 0) card. Ask students to arrange themselves in order of largest to smallest down to the size of a human.
2. Let them struggle with trying to get in order (numbers can be covered ahead of time using round stickers if the group is older and it is too easy). You may need to step in to guide students to have civilized debate about the order. It may be

necessary to discuss that some of the pictures were taken through microscopes or telescopes. They may look different when scaled to fit on the card, but are much larger or smaller in reality.

3. Once they have established an order, ask them to explain their reasoning (especially if some are out of order).
4. Once they are finished, have students leave their cards in the order and then sit down where they can see all of them.
5. Pass out cards representing objects smaller than a human (-1 and down) to the students. Give yourself the human (pirate - 0) card. Ask students to arrange themselves in order of largest to smallest from the size of a human down. Build on the sequence you made before so that you have a full size scale from largest to smallest.

Option 2

6. Start enough cards for each student to have one, ranging across the span of sizes - large and small. Be sure the human (0) and at least one object from each of the nearby size categories (+ 1, 2 and - 1, 2, 3, 4) are represented.
7. Ask them if they can get in order from largest to smallest.
8. Let them struggle with trying to get in order (numbers can be covered ahead of time using round stickers if the group is older and it is too easy). You may need to step in to guide students to have civilized debate about the order. It may be necessary to discuss that some of the pictures were taken through microscopes or telescopes. They may look different when scaled to fit on the card, but are much larger or smaller in reality.
9. Once they have established an order, ask them to explain their reasoning (especially if some are out of order).
10. Once they are finished, have students leave their cards in the order and then sit down where they can see all of them.

Part II

11. Discuss exponential size or powers of ten using language appropriate to the group age. Use a real soccer ball and a volunteer to see if a human is 10 soccer balls tall (discuss estimation and models - which are not always perfect). You can also use the paper clip/quarter, ants and sand for students to "see" powers of ten.

    - Soccer ball (-1) is approximately 10 times smaller than a human. Do 10 soccer balls equal a human?
    - Is a quarter or paper clip ten times smaller than a soccer ball?
    - Is a plastic ant ten times smaller than a quarter or paper clip?
    - Is a grain of sand ten times smaller than a pea or ant?

Part III

12. Show students the Sizing Things Down Orders of Magnitude Poster. The smallest magnitude this poster shows is -15. Explain to students that when we are exploring “quantum” materials, we will be talking about objects from that scale down to about -19. Remind them that each number represents ten times smaller than the one above it. For reference, if the smallest object card they use in this activity is the pollen grain (-5), quantum objects are 10 billion to 100 trillion times smaller!

Extension for Middle School

Complete activity the same as above but add in additional cards for small objects that are accessible for this age group, including:

- Red blood cell (-6)
- Carbon Atom (-11)
- Water molecule (-11)
- Proton (-15)

Explaining the science:

Things in the universe come in different sizes—and size is important! The objects on the cards are organized according to powers of ten. Each number on the scale represents a ten-fold change in size. An object marked with a 0, like a pirate, is about a meter tall. An object marked with a +1, like a tree, is around ten times bigger than a pirate. An object marked with a -1, like a soccer ball, is around ten times smaller. An object marked +2 is 10 times bigger than a tree, or 100 times bigger than a pirate.

Really tiny objects, for example pollen grains, are marked with even lower numbers. Pollen is -5, or 10^{-5} and is so tiny details like are shown on the card can only be seen using a powerful microscope. But even smaller things exist! The Sizing Things Down Orders of Magnitude Poster goes as small as 10-15 which is the size of a proton in some atoms. However, the quantum scale goes even smaller. Electrons, some photons and other quantum particles range in scale from about 10^{-15} to 10^{-19}! The extra cards in this game go down to 10^{-15}. All of these measurements are part of the metric system. The metric system is a measuring system using units based on powers of ten. Scientists use the metric system because it makes calculations easier.

We are all familiar with a meter (in fact, many elementary school kids are probably a little over a meter tall). Much smaller divisions of a meter, such as nanometers, picometers and fentometers are used to measure things that are too small to see, like atoms and molecules, the basic building blocks of our world. Quantum science focuses on things that are extremely small. Scientists use special tools and equipment to work with things that are quantum-sized. In the field of quantum, scientists and engineers are developing new technologies in fields like computing and communication using the strange properties of these quantum materials.

Standard Alignment

Standard Code	Standard Text	How does this activity support this standard?
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.	This activity supports this standard by helping students model tenfold changes in size using familiar objects.
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.	This activity supports this standard by providing a conceptual understanding of powers of ten through physical and visual comparisons. By organizing objects by orders of magnitude, students build awareness for how multiplying or dividing by powers of ten changes scale, which supports later numerical reasoning with decimal placement.
NGSS Crosscutting Concept - Scale, Proportion and Quantity	In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.	This activity supports this standard by comparing human-scale objects to massive or minuscule ones. This allows for a basis of understanding the size of galaxies and pollen molecules as compared to humans.

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NIST Metric Prefixes

Purpose	Name	Symbol	Factor	Name
Larger Quantities	quetta	Q	10^{30}	nonillion
	ronna	R	10^{37}	octillion
	yotta	Y	10^{24}	septillion
	zetta	Z	10^{21}	sextillion
	exa	E	10^{18}	quintillion
	peta	P	10^{15}	quadrillion
	tera	T	10^{12}	trillion
	giga	G	10^{9}	billion
	mega	M	10^{6}	million
	kilo	k	10^{3}	thousand
	hecto	h	10^{2}	hundred
	deka	da	10^{1}	ten
			10^{0}	one
Smaller Quantities	deci	d	10^{-1}	tenth
	centi	c	10^{-2}	hundreth
	milli	m	10^{-3}	thousandth
	micro	µ	10^{-6}	millionth
	nano	n	10^{-9}	billionth
	pico	p	10^{0-12}	trillionth
	femto	f	10^{-15}	quadrillionth
	atto	a	10^{-18}	quintillionth
	zepto	z	10^{-21}	sextillionth
	yocto	y	10^{-24}	septillionth
	ronto	r	10^{-27}	octillionth
	quecto	q	10^{-30}	nonillionth

Source: National Institute of Standards and Technology;
https://www.nist.gov/pml/owm/metric-si-prefixes