Teacher's Preparatory Guide

Learning Set on Size, Scale, Function, and Measurement Systems

Purpose: The purpose of this lesson is to familiarize students with size, scale, and measurement by exploring size and scale through a variety of activities.

Time Required:

1. Focus Activity: *Why Size Matters*
   (86 minute)
2. Explore Activity: *Scale and Measurement Systems*
   (86 minutes)
3. Reflect Activity: *Tools of Measurement*
   (86 minutes)
4. Apply Activity: *Using Tools of Measurement*
   (86 minutes)

Level: This activity is designed to be used at the 9th grade level in a general science or physical science class setting in conjunction with a unit on measurement; however, it is flexible in design and could easily be adapted to other grade levels in other classes.

Materials

- Construction of butch paper
- Haldane's essay
- Student worksheets
- Stopwatch or clock with second hand
- String
- Masking tape
- Scissors

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Teacher Background: Background information on the unit is found in the discussion below for each of the activities. Student worksheets follow the discussions.

Activity Set Structures

A. Focus - *Why Size Matters*

One of our obligations as educators is to help our students understand why the concepts we want them to learn are important. Establishing the relevance of our course content to our students' everyday lives is vital to our success as educators and our students' success as learners. Keeping this in mind, we can establish the importance of size by stressing its effect on how objects function.

The unit can begin with a brief introduction to an old idea that Hollywood has exploited many times in science fiction movies. The idea that we can enlarge or shrink entire objects or even human beings has been used in such films as *Honey; I Shrunk the Kids, The Amazing Colossal Man*, and *The incredible Shrinking Woman.*
Students are then asked to take a critical look at the scientific validity of this possibility by considering why this would or would not be possible. After choosing to focus on either miniaturization or enlargement, each student is asked to individually consider the impact such a change would have on the way a human being functions. After students have reflected individually, they are asked to get into small groups of people who have focused on the same extreme (miniaturization or enlargement) and share ideas. Following these group discussions, bring the class back together to discuss the ideas produced by the different groups of students.

The ideas generated by the students at this point and the subsequent discussion may be rather simple and naïve, therefore, to get students to inject more scientific notions into their analysis of the issue, the teacher then shares excerpts from Scottish geneticist J.B.S. Haldane's essay *On Being the Right Size*. Below is an excerpt from the essay which should be copied and handed out to the students.

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Excerpt from J.B.S. Haldane's essay *On Being the Right Size.*

The most obvious difference between animals are difference in size, but for some reason the zoologist have paid singularly little attention to them. In a large textbook of zoology before me I find no indication that the eagle is larger than the sparrow, or the hippopotamus bigger than the hare, though some grudging admissions are made in the case of the mouse and the whale. But yet it is easy to show that a hare could not be as big as a hippopotamus or a whale as small as a herring. For every type of animal there is a most convenient size and a large change in size inevitably carries with it change of form.

Let us take the most obvious of possible cases, and consider a giant man sixty feet high – about the height of Giant Pope and Giant Pagan in the illustrated Pilgrim's progress of my childhood. These monsters were not only ten times as high as Christian, but ten times as thick, so that their total weight was a thousand times his, or about eighty to ninety tons. Unfortunately, the cross sections of their bones were only a hundred times those of Christian, so that every square inch of giant bone had to support ten times the weight borne by a square inch of human bone. As the human thigh-bone breaks under about ten times the human weight, Pope and Pagan would have broken their thighs every time they took a step.

...the eye is a rather inefficient organ until it reaches a large size. The back of a human eye on which an image of the outside world is thrown, and which corresponds to the film of a camera, is composed of a mosaic of" rods and cones" whose diameter is little more than the length of an average light wave. Each eye has about a half a million, and for two objects to be distinguishable their images must fall onto separate rods and cones. It is obvious that with fewer but larger rods and cones we should see less distinctly. If they were twice as broad, two points would have to be twice as far apart before we could distinguish them at a given distance. But if their size were diminished and their number increased we should see no better. For it is impossible to form a definite image smaller than the wave-length of light. Hence a mouse's eye is not a small-scale model of a human eye. Its rods and cones are not much smaller than ours, and therefore there are fewer of them. A mouse could not distinguish one human face from another six feet away. In order that they should be of any use at all the eyes of small animals have to be much larger in proportion to their bodies than our own. Large animals on the other hand only require relatively small eyes, and those of a whale and elephant are not much larger than our own...

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A review of Haldane's essay can be followed by the 8 minute video *Size and Scale – Being the Right Size*. This video is available from the United Streaming Educational Video Service (www.unitedstreaming.com). After reading the excerpt and viewing the video, students are asked to reflect more deeply on this issue and to offer more profound considerations of what would happen to the ability of a human being to function properly if he/she was shrunk or enlarged.

Another cinematic connection that could be made – and one that has a nice nanotechnology connection - is the 1966 classic *Fantastic Voyage* in which a medical team is miniaturized and injected into a dying man. This would allow the teacher to introduce the notion of *nanorobots* that could be used to heal injuries in people. While science fiction writers have been posing this for a while, the teacher could discuss with students whether it is a real possibility.

B. Explore - *Scale and Measurement Systems*

Once we've established the importance of size, we need our students to recognize the importance of scale and the need for accurate measurement. A discussion of scale can be enhanced by the use of the classic 1977 video *Powers of 10* by Ray and Charles Eames or by exploring the similar websites:

- www.powersof10.com
- www.wordwizz.com/pwrsof10.htm
  http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/index.html

The *Power of 10* video and website lead very well into the introduction of measuring systems and establishing measurement standards as well as the use of scientific notation. How much emphasis the teacher places on each of these concepts will depend upon the academic level of the students in the class and the course curriculum.

Because the metric system of measurement is based on the power of 10, this is an excellent time to demonstrate its ease of use over the English system with which students in the United States are more familiar. A nice way to demonstrate this is to have students compare different sized wrenches. Putting metric wrenches in order is rather simple as they will have their sizes written in millimeters. They are simply arranged as follows: 3mm, 4mm, 5mm, 6mm, etc. To arrange wrenches using the English system and marked in fractions of inches the fractions will have to be converted to a common denominator before they can be put in order. For example, the following wrench sizes 3/4", 1/2", 7/16", and 5/8" would need to be converted to 12/16", 8/16", 7/16", and 10/16" before they can be placed in the proper order. You could use real wrenches or develop a cardboard "set" for the classroom.

For additional enrichment, the teacher might consider the 30 minute video *Elementary Video Adventures – Measurement and Scale*. This video is available from the United Streaming Educational Video Service (www.unitedstreaming.com).

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C. Reflect - *Tools of Measurement*

The Focus and Explore activities introduce the students to the concepts of size, scale, and measurement systems. The reflect activity emphasizes the tools used to make these measurements and their connection to the size of the object being measured.

A discussion of scale and measurement standards can be enhanced by the following brief activity which aides students' understanding of these concepts.

- Teacher has students work in groups.
- Each group is given a piece of string and some tape.
- The group is then asked to decide upon an item which will serve as their measurement standard unit of length to be used to measure the length of miscellaneous items located in the classroom.
- Once the group decides upon a standard unit of length, they mark off this standard distance on their string with the tape.
- Using their string measuring device (tool of measurement), they then proceed to measure 5-10 common items found in the classroom.
- When all the groups have completed their measurements, the class comes together and compares their numbers.
- The teacher leads the entire class in a discussion of why groups using different standard units got different number values when measuring the same items.

This would be a good point for the teacher to demonstrate the use of some common tools of measurement. It would also be appropriate to discuss terminology related to measurement and the International System of Units (SI) (http://physics.nist.gov/cuu/Units/).

As a culmination of this, students can visit the web-based animation prepared Penn State University's Center for Nanotechnology Education and Utilization (CNEU): www.cneu.psu.edu/Amy/index.html. The animation ties together the themes of size & scale, function, and tools by taking a closer and closer look at the wings of the Blue Morpho butterfly to understand how color is produced by them. The discussion of the function of the butterfly scales can lead to further dialogue about the application of similar ideas in nanotechnology. Students can be introduced to what nanotechnology is through the panel discussion video *Introduction to Nanotechnology* (26 minutes) prepared by CNEU: www.cneu.psu.edu/edTools.html.

D. Apply - *Using Tools of Measurement*

No specific Apply activity has been included. To summarize concepts addressed in the previously completed activities and to apply those concepts, teachers are encouraged to use lab activities which give students the opportunity to practice using various tools of measurement. Activities used would be determined by the tools available to students and teachers. Teachers could have students draw or produce an object 10X larger or smaller than its present size and describe what features (determine a set maximum of things) within the structure would have to change because of the increase/decrease in size. Alternatively, have students produce a series of pictures of objects of different sizes.

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National Science Education Standards

Middle School Content Standard

- Standard A
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- Standard E
  - Abilities of technological design
  - Understanding about science and technology
- Standard F
  - Science and technology in society
- Standard G
  - Science as a human endeavor
  - Nature of science

High School Content Standards

- Standard A
  - Abilities necessary to do scientific inquiry
  - Understanding about scientific inquiry
- Standard E
  - Abilities about technological design
  - Understanding about science and technology
- Standard G
  - Science as a human endeavor
  - Nature of scientific knowledge

Standards for School Mathematics

- Numbers and Operation
  - Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Measurement
  - Understand measurable attributes of objects and the units, systems, and processes of measurement

Apply appropriate techniques, tools, and formulas to determine measurements

PA State Science Standards Addressed:

3.1.10 D 3.1.12 D 3.7.10 B 3.7.12 B	➢ Convert one scale to another ➢ Analyze and apply appropriate measurement scales when collecting data ➢ Describe and demonstrate the operation and use of advanced instrumentation in evaluating material and chemical properties ➢ Apply and evaluate the use of appropriate instruments to accurately measure scientific phenomena within error limits
3.7.10 A 3.7.12 A	➢ Apply advanced tool equipment manipulation techniques to solve problems ➢ Select and safely apply appropriate tools, materials, and processes to solve problems

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References

J.B.S. Haldane, 1927. *On Being the Right Size.* Essay published in *Possible Worlds and Other Essays*. *Possible Worlds and Other Essays* (1927), Harper and Brothers, London: Chatto & Windus 1937 edition, Transaction Publishers 2001 edition. Also available on the web from numberous sources.

Internet Resources

www.unitedstreaming.com – Educational Video Service

www.cneu.psu.edu - Penn State University Center for Nanotechnology Education and Utilization

www.powersof10.com – official Powers of 10 website

www.wordwizz.com/pwrsof10.htm - A Question of Scale

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/index.html -Secret Worlds: The Universe Within

Student Handouts Are On the Pages Below

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Student Worksheet

Name: _____ Date: _____

Does Size Matter?

Individual View

Imagine that scientists have the ability to shrink or enlarge a human being. Choose one extreme (miniaturization to 6 inches tall **or** enlargement to 60 feet tall) and in the space provided below write down some thoughts as to what impact this would have on the ability of a human being to function and why you believe it would or would not be possible for a human being to survive at this size.

Group View

Now, get together in your group with students who chose the same extreme and discuss the impact on the function and survival of a human being at that size. On the construction paper provided list the main thoughts of your group. Once you have completed your group list, post it in the front of the room so we can refer to it for our class discussion.

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Read the following excerpt from the Scottish geneticist J.B.S. Haldane's essay *On Being the Right Size*. After reading the following excerpt and viewing the short video *Size and Scale – Being the Right Size,* we will revisit as a class the impact of size on human function.

Excerpt from J.B.S. Haldane's essay *On Being the Right Size.*

> *The most obvious difference between animals are difference in size, but for some reason the zoologist have paid singularly little attention to them. In a large textbook of zoology before me I find no indication that the eagle is larger than the sparrow, or the hippopotamus bigger than the hare, though some grudging admissions are made in the case of the mouse and the whale. But yet it is easy to show that a hare could not be as big as a hippopotamus or a whale as small as a herring. For every type of animal there is a most convenient size and a large change in size inevitably carries with it change of form.*
> *Let us take the most obvious of possible cases, and consider a giant man sixty feet high – about the height of Giant Pope and Giant Pagan in the illustrated Pilgrim's progress of my childhood. These monsters were not only ten times as high as Christian, but ten times as thick, so that their total weight was a thousand times his, or about eighty to ninety tons. Unfortunately, the cross sections of their bones were only a hundred times those of Christian, so that every square inch of giant bone had to support ten times the weight borne by a square inch of human bone. As the human thigh-bone breaks under about ten times the human weight, Pope and Pagan would have broken their thighs every time they took a step.*
>
> *...the eye is a rather inefficient organ until it reaches a large size. The back of a human eye on which an image of the outside world is thrown, and which corresponds to the film of a camera, is composed of a mosaic of" rods and cones" whose diameter is little more than the length of an average light wave. Each eye has about a half a million, and for two objects to be distinguishable their images must fall onto separate rods and cones. It is obvious that with fewer but larger rods and cones we should see less distinctly. If they were twice as broad, two points would have to be twice as far apart before we could distinguish them at a given distance. But if their size were diminished and their number increased we should see no better. For it is impossible to form a definite image smaller than the wave-length of light. Hence a mouse's eye is not a small-scale model of a human eye. Its rods and cones are not much smaller than ours, and therefore there are fewer of them. A mouse could not distinguish one human face from another six feet away. In order that they should be of any use at all the eyes of small animals have to be much larger in proportion to their bodies than our own. Large animals on the other hand only require relatively small eyes, and those of a whale and elephant are not much larger than our own...*

Student Worksheet

Name: _____ Date: _____

Scale, Measurement Systems, and the Powers of Ten

Visit the following websites to see 3 demonstrations of the Powers of 10.

- www.powersof10.com – official Powers of 10 website
- www.wordwizz.com/pwrsof10.htm - A Question of Scale
- http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/index.html -Secret Worlds: The Universe Within

Using the www.wordwizz.com/pwrsof10.htm - A Question of Scale website, complete the chart below:

Prefix	What power of 10 does this prefix represent	What object exist at this distance from the earth or at this scale?
peta-	$1x10^{15}$	Entire solar system
giga-	1,000,000,000 or $1x10^{9}$	Distance of the earth and moon
kilo	1,000 or $1x10^{3}$	Distance from 1 town to another
deci-	.1 or $1x10^{-1}$	A lily flower with a bee on it
centi-	.01 or 1 x 10^{-2}	Approximate width of your pinky fingernail
milli-	.001 0r $1x10^{-3}$	A bee's eye
micro-	0.000001 or $1x10^{-6}$	Virus on a bacterium
nano-	0.000000001 or $1x10^{-9}$	Structure of DNA
pico-	0.000000000001 or $1x10^{-12}$	Inside the electron cloud

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Student Worksheet

Name: _____ Date: _____

Which is Easier, the SI System or the English System?

Important Note

This is a timed activity. Do not begin the activity until instructed by the teacher.

1. Complete this page of the activity sheet first. Do not look at the other side until instructed to do so.
2. Use a stopwatch or the clock to time how long it takes you to complete the two tasks on this side of the activity sheet.
3. Read the directions and begin.

Directions for task #1

Listed below are various sized metric wrenches. Your first task is to rearrange the wrenches in proper order from the smallest size to the largest size.

6mm	10mm	3mm	5mm	2mm	4mm
_____	_____	_____	_____	_____	_____

Smallest ----------→ Largest

Directions for task #2

Listed below are 6 pairs of various sized metric wrenches. Your task is to compare the wrenches in each pair and choose the larger of the two.

6mm _____ 4mm

4mm 5mm

7mm _____ 2mm

3mm 6mm

5mm _____ 4mm

10mm 7mm

How long did it take you complete the 2 tasks on this side of the activity sheet? _____

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Complete this side of the activity sheet after you have completed the front side of the activity sheet.

1. Use a stopwatch or the clock on the wall to time how long it takes you to complete the two tasks on this side of the activity sheet.
2. Read the directions and begin.

Directions for task #3

Listed below are various sized non-metric wrenches. Your first task is to rearrange the wrenches in proper order from the smallest size to the largest size.

1/2 inch	1/4 inch	3/8 inch	9/16 inch	3/4 inch	15/32 inch
_____	_____	_____	_____	_____	_____

Smallest ----------→ Largest

Directions for task #4

Listed below are 6 pairs of various sized non-metric wrenches. Your task is to compare the wrenches in each pair and choose the larger of the two.

1/2 inch		3/8 inch	
9/16 inch	_____	15/32 inch	_____
9/16 inch		1/4 inch	
15/32 inch	_____	3/8 inch	_____
1/4 inch		3/4 inch	
15/32 Inch	_____	9/16 inch	_____

How long did it take you complete the 2 tasks on this side of the activity sheet? _____

Which side was easier to complete? _____

Which side would you like to have graded? _____

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Student Worksheet

Name: _____ Date: _____

Group members: _____ _____

_____ _____

Making Your Own System of Measurement

Objective:

Your group's objective is to develop your own measurement system and use this system to measure common objects located in the classroom.

Materials:

String
Masking tape
Scissors

Procedure:

1. Obtain your materials
2. Choose a common item in the room which will serve as the measurement standard for your system. Be sure the size of your standard is appropriate for the items you plan to measure.
3. Using your measurement standard, mark your string with masking tape so it can be used to measure common items in the classroom.
4. Use the string to measure 7 common items from the classroom and fill in the data chart.
5. Complete the questions and conclusions portion of the activity.

Data:

What item did you use for your measurement standard? _____

Object Measured	Length of the Object
1.	
2.	
3.	
4.	
5.	
6.	
7.	

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Questions and Conclusions:

1. Were you able to design a measurement system that was reasonably workable and accurate? Explain.

2. Could someone else use your system to measure items in the classroom and get the same results? Explain.

3. Would you get the same number values if you used a different measurement standard? Why or Why not?

4. Is your group's measurement system more or less accurate than the measurement systems developed by the other groups in the class? Explain.

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Student Worksheet

Name: _____ Date: _____

Web-based Animation of the Blue Morpho Butterfly

Visit the web-based animation prepared Penn State University's Center for Nanotechnology Education and Utilization: www.cneu.psu.edu/Amy/index.html. The animation ties together the themes of size & scale, function, and tools by taking a closer and closer look at the wings of the Blue Morpho butterfly to understand how color is produced by them. This closer and closer look occurs through three stages and covers three different instruments – optical microscopes, SEMs, and AFMs – and the different scales they allow scientist to study.

1. The resolution of the human eye is 10-20 nanometers.

2. Name the part of the human eye that performs the following functions

   The cornea and pupil allow light to enter the eye.

   The lens focuses the light

   The image is focused on the retina, turned upside down and reversed.

3. A human hair is 40 micrometers wide.

4. A hair on a butterfly's legs is 10 micrometers wide.

5. The hairs on a butterfly's leg act as sensors.

6. The resolution of the best Compound Optical Microscopes is about 200 nm.

7. Compound Optical Microscopes use compound multiple lenses to magnify an object's image.

8. The scales of a butterfly are 100nm thick and 200µm wide.

9. List four things that the scales do for a butterfly.

   A. regulate body temperature

   B. shed water off wings

   C. escape danger by detaching

   D. provide color

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Web-based Animation of the Blue Morpho Butterfly

10. The resolution of the average Scanning Electron Microscope is about

_____500nm_____.

11. With a high resolution Scanning Electron Microscopes objects as small as

_____10nm_____ can be seen.

12. The Scanning Electron Microscope use a beam of ____electrons_____ that

reflect off of the sample being analyzed.

13. The wavelength of visible light _____400 – 700nm_____.

14. The color of the images produced by a Scanning Electron Microscope is always

_____black and white_____.

15. Using the Scanning Electron Microscope, we can see that butterfly scales have air gaps

that are _____1µm_____ wide.

16. These air gaps act as _____insulators_____ and help the butterfly

regulate _____temperature_____.

17. The range of resolution of the Atomic Force Microscope is

_____0.1nm to 10nm_____.

18. The Atomic Force Microscope has a __sharp pointed tip_____ that

scans over the surface.

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Web-based Animation of the Blue Morpho Butterfly

19. The average size of the tips used by the Atomic Force Microscope are about

_____10-20nm_____.

20. The color of the butterfly wing does not come from pigment. This is due to the way the small features in the wing scales interact with light, allowing only certain

_____wavelengths of light_____ to reflect to our eyes.

21. __Reflective_____ color effects occur when very thin structures or layers of materials are present at the nanometer or micrometer scale.

22. List 2 current products where you can observe the effects of structural color.

Peacock feathers, soap bubbles, some sea shells_____

_____

23. List 2 ways structural color effects might be used in the future.

_color of commercial object like clothes, cars, toys_____

__camouflage for military use_____

Nanotechnology is defined as the creation and use of materials or devices at the nanoscale (less 100 nanometers – the molecular level)). Can you think of any other ways we can exploit our understanding of things at the nanoscale?

Student Worksheet

Name: _____ Date: _____

Introduction to Nanotechnology

Video Worksheet

View the panel discussion video *Introduction to Nanotechnology* (26 minutes) prepared by the Penn State University's Center for Nanotechnology Education and Utilization: www.cneu.psu.edu/edTools.html.

In the space below write an essay explaining what nanotechnology is, give examples of how it is already being used, and suggest ways it may affect our lives in the future. The first sentence has already been written for you.

Nanotechnology is defined as the creation and use of materials or devices at the nanoscale (less than 100 nanometers – the molecular level). _____

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