Measurement and Its Error: A Discovery Approach

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With any measurement comes error. Having an appreciation of the error in a measurement is an important aspect of any scientific investigation. This appreciation develops into a mind set of minimizing error, which is an added advantage to any investigation. Here are two simple, inexpensive, short activities to get students (upper elementary - college) engaged in measurement and its error. Each task is done in a small group of 3-4 students.

Activity 1: (30 minutes)

Each group must <u>invent</u> a new unit of measurement. (No two groups can have the same new unit.)
Use the new unit to determine the area of the classroom.
Compare your group's unit to another.
What is the conversion factor between the two different units?
Using e-mail, how would you explain to students in another place how to use your unit?

Conducting the Activity:
For this activity, no standard measuring devices, such as rulers or metric sticks, are allowed to be used. Let the students come up with items – notebooks, umbrellas, calculators, scarves, string, footsteps, chairs, floor or ceiling tiles, or paper strips. Hopefully they see very early to invent a distance unit since area is to be determined. Then they go off to measure the room using their small unit to measure a long distance, hence making a series of measurements. Observe the groups to see how they handle this. This will provide discussion points later.

Next they come up with unit conversions between various group units. These are not the most accurate conversions since students are estimating in whole units. Some groups may have flexible units that permit fractional units.

The last part, to transmit their explanation of the unit via e-mail, will raise the issue of the need for a standard unit although not all groups will come up with this. Some groups will realize they need to compare to a known distance unit or set their own well defined standard.

Discussion Points:
Creating the unit is usually no problem, although some groups will use items that are elastic and invent the "rubber ruler," which allows a nice discussion point for possible error. The series of measurements using the short units to measure the long distances around the room is another common source of error. The unit conversion factors can be used to get into a discussion on calibrating the unit in fractional parts and how you might do this. Folding one of the flexible units (paper, string) is a good way to illustrate this. Ideally, can you break the unit down into tenths (we want to go metric!). Why are inches on a ruler broken down as 1/2, 1/4, 1/8, 1/16, 1/32? How do you accurately find half of a unit if it is not flexible?

The idea of a standard unit is a new idea for many students. They may make the comparison to a known unit; however, ask them about the known unit, what is the standard? For the background on the meter as a standard, see the NIST website at http://physics.nist.gov/cuu/Units/meter.html.

Activity 2: (15 minutes)

Using only a ruler or metric stick, determine the diameter of the ball provided.

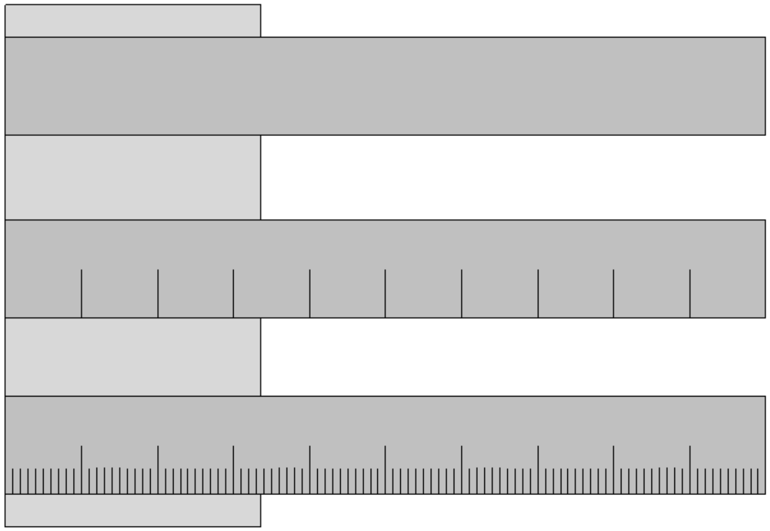
Compare your results with another group.
Did your group encounter any problems in making this measurement?

Conducting the Activity:
The spherical object turns out to be a nice challenge for most groups. Use of a nerf ball (made of sponge) adds a flexible object with more problems and potential error. Many creative methods will arise - eyeballing the height on the ruler, placing a second ruler on top of the ball and trying to level it by eye and get height on the first ruler, with the ball on a piece of paper trace a circle on the paper and measure the circle's diameter. Some groups will flatten a nerf ball to make a linear measurement across it.

Discussion Points:
This is a case of the wrong measuring device for the object; hence, errors abound. Eyeballing is a less accurate judgment with or without the second ruler. Did any group make multiple measurements especially to check to see if the object was actually spherical (this is fun with nerf balls, especially if flattened)? Typically the ends of rulers do not start at zero; hence a bias of several millimeters often occurs. Did anyone correct for this? (This is usually not a problem with meter sticks.) Adding a level to the second ruler would be a good addition and remove some operator error. Some may want to wrap the ball with string to get the circumference, measure the string's length, and convert this to diameter. However, it should be noted that in this case the diameter is a "result" or "indirect" measurement rather than a direct measurement. Large calipers would be another usable measuring device.

Some final Thoughts:
Making a measurement requires that you have the proper measuring device, it is calibrated to the appropriate level for the accuracy required, and multiple measurements are needed to be sure of the measurement and judge precision.

The concept of instrument calibration and significant figures can be addressed by the figure below. Estimate the width of the box with each ruler. Remember that you can only estimate one place better than the calibrated units on the ruler. We have made meter sticks calibrated in meters, decimeters, and centimeters to use in class from wooden molding available in hardware stores.



Did you get 0.3, 0.33, and 0.335? Exploring the quantitative measures of accuracy and precision such as the mean for multiple trials, percent error to access accuracy if a true value is known, and percent coefficient of variation for precision would be the next concepts introduced.

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