Using the upcoming Solar Eclipses to Teach Measurement Error with Authentic Data

"You can't believe scientists. Even they admit that their measurements have errors!"

Have you heard, and perhaps been infuriated, by statements like that? As a scientist, you know that it is vital that we report the accuracy of measurements alongside the measurements themselves. However, unless we teach students the meaning of measurement error, they may misunderstand or be misled about what such "errors" mean. Fortunately, an excellent "teachable moment" is almost at hand.

Figure 1 Path of the 2023 and 2024 solar eclipses

In October 2023 and April 2024, two dramatic solar eclipses will cross the US. Every state in the continental US will see at least part of the sun covered by the moon. The earth is unique among solar system planets in having a moon that almost exactly matches the apparent size of the sun. However, the moon's orbit around the earth isn't a circle; it's elliptical by about 5%. That means the moon can appear larger or smaller by 5%. When it is larger, it can completely cover the moon and produce a total eclipse, as seen at right. When it is smaller, a "ring of fire" or annular eclipse occurs. The US will see a total eclipse on April 8, 2024 and an annular eclipse on October 14, 2023.

A simple, inexpensive apparatus lets students safely take photos of the sun or the moon with their smartphone, on any day. Comparing their sizes can offer a great lesson on measurement error and basic statistics. Since the data is authentic, and taken by the students themselves, they are more engaged in the activity and curious of the answer.

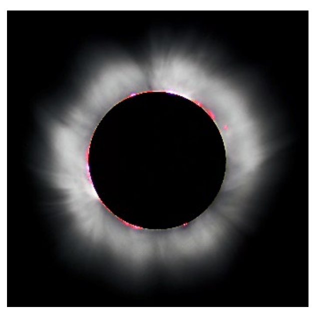


Figure 2 Total Eclipse


Figure 3 Annular Eclipse

A bonus to the activity is that students will be prepared to watch the sun safely on the eclipse days, and likely will be excited to do that and to share safe viewing methods with their friends and family.

Overview of the Activity: Students take photos of the sun and the moon, using a smartphone camera. Measure the apparent sizes and decide if the moon can cover the sun. Compare measurements made by different students or groups of students in a histogram to decide the accuracy of measurement. Discuss why different measurements give slightly different answers. *Originate* the concepts of mean, standard deviation, standard deviation of the mean, and "outliers," based on the students own data.

Goals:

1. Understand that the sun and moon are nearly the same apparent size in the sky; even through the sun is about 400 times further away than the moon. (It is about 400 times larger.)

2. Understand why different measurements of the same thing produce slightly different results. ("measurement accuracy")
3. Learn that a histogram of multiple similar measurements gives a good idea of measurement accuracy.
4. Learn that the mean is more accurate than any individual measurement.
5. Learn that the accuracy of the mean = accuracy of one measurement / square root of the number of measurements.
6. (Optionally) Learn to identify "outliers" as possible errors.

Introduction: One must never look at the sun without special eye protection <u>designed for viewing the sun</u>. Similarly, you should not point the camera of a smartphone at the sun unless it is protected by a filter, because strong sunlight can ruin the camera. Fortunately, the author of this activity observed at several recent eclipses that people *want* to take pictures when there's and eclipse, and invented a simple filter and free app that make it easy to photograph the sun safely, on any clear day.

Equipment: "Solar Snap," a set of filters and app that make it easy to safely take photos of the sun.[1]. Solar snap allows zooming the size of the image. For this activity, the zoom needs to be the same while taking photos of the sun and moon, so that you can fairly compare them.

Timing: Students will be taking photos of the sun and moon. Those are both in the sky at the same time when the moon is around First Quarter phase. You should look that up and plan this activity accordingly. Enough of the moon needs to be illuminated to allow measuring its diameter. Many students will be surprised that the moon is visible in the daytime sky! At First Quarter phase, around 2 or 3 in the afternoon, both the moon and sun will be visible. They are higher in the sky in spring than fall.

Procedure: Students, or groups of students, are given Solar Snap for their phone. Following the instructions, they attach the filter to their phones, download the free app using the QR code, and go outside and take a picture of the sun. (If necessary, they can download the app on their own at home, if the school doesn't want them using Internet.) Have students use the Zoom control to make the size of the sun equal to the size of the white circle on the Solar Snap screen. The sun photos will look like the one at right. Have students take 3 or 4 pictures of the sun.

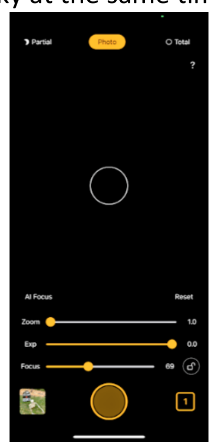


Figure 4 Solar Snap app screen

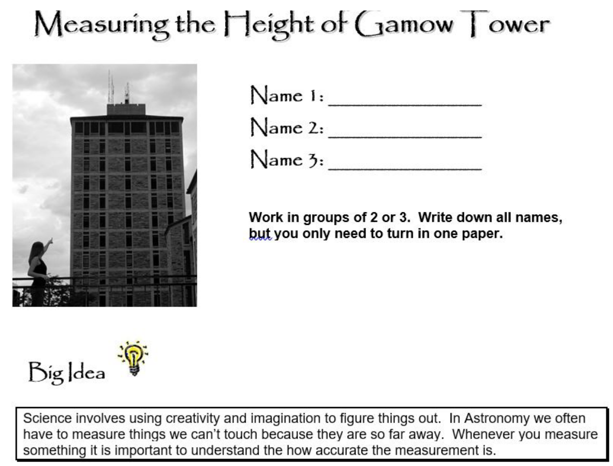
Then have the students take photos of the moon using the Solar Snap app but not the filter – the moon is much dimmer than the sun, and imaging it doesn't require a filter. The zoom should not be changed from what is used on the sun. Photos of the moon will look like the one at the right. Enough of the moon needs to be lit to enable measuring its diameter. Have the students take 3 or 4 images.


Figure 5 Smartphone sun photo taken with Solar Snap filter


Figure 6 Smartphone moon photo taken with Solar Snap and no filter

Now, it is time to measure the diameters of each object. This will simply be done in pixels, not in meters or miles. Any software that allows pixel measurement can be used. The author uses the free program GIMP[2], which is as powerful as Adobe Photoshop but entirely free. GIMP is powerful and complex. Simpler programs such as "Pixel Measure" for Android can also be used. Each student or group of students should measure the diameter of the sun, and the moon, on each image, and report their measurements. Measurements of students using the same model phone should be combined, and the data set with the largest number of measurements used. If you can assemble a data set with 20 measurements of more that is very good. Keep the sun diameter measurements in one data set, and the moon diameter measurements in another. The accuracy of one measurement is about 1% if you are careful. The largest measurement error source is likely to be that different students will set the zoom on their phone slightly differently. These measurement errors are what produce the scatter that makes the discussions below rich in meaning.

Since Solar Snap just became avaiable, student data is not available. However, for many years, the author has done something similar with simple, repeated measurements made by students, and the results and discussion should be similar when measuring sun and moon data. In the past, the author asked students to measure the height of a building, with simple cardboard triangles and meter sticks. [See box at right] The experiment has been extremely successful because 1) it allows for creativity, something that it absent in most student experiments, and 2) it introduces important statistics concepts in an intuitive way, based on students' own data.


Measuring the Height of Gamow Tower

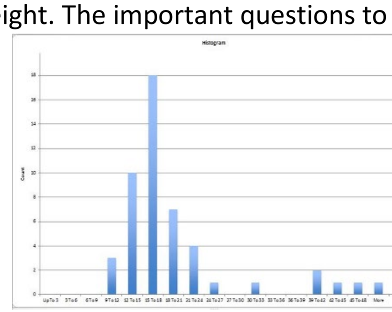
Name 1: _______________
Name 2: _______________
Name 3: _______________

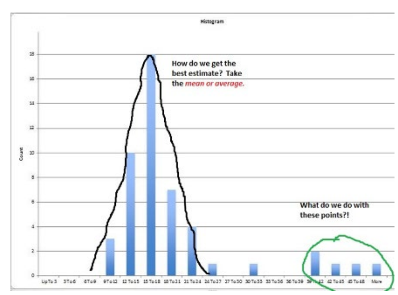
Work in groups of 2 or 3. Write down all names, but you only need to turn in one paper.

Big Idea

Science involves using creativity and imagination to figure things out. In Astronomy we often have to measure things we can't touch because they are so far away. Whenever you measure something it is important to understand the how accurate the measurement is.

Here is a typical plot of student data, in this case for the building height. The important questions to ask of your own students, about their sun and moon measurements, are the same. Here are some, along with suggested answers:





Q1: Why didn't everyone get the same answer for the diameter of the sun?

A1: Because every measurement has an error or uncertainty.

Q2: How do we get our best estimate of the actual diameter of the sun?

A2: Take the average or mean of the measurements

The shape of the histogram is like a hill. Technically, it follows what is called a "bell curve" or Gaussian curve.

Q3: What does the width of the bell curve tell us?

A3: It tells what the average or typical measurement error is. In other words, *by repeating measurements you can determine how accurate any one measurement is.* It is not a waste of money for different groups of scientists to repeat measurements. It is very useful!

Q4: Is there a technical name for the "width" of the curve?

A4: Yes, it's called the "Standard Deviation." In statistics, you may learn a formula for standard deviation, but it is more important is that you understand what standard deviation means! It is a measure of the accuracy of one measurement.

Q5: How much more accurate is the *mean* of the histogram than any one measurement?

A5: For a Gaussian curve, the Standard Deviation *of the mean* = (Standard Deviation of one measurement) / √ (number of measurements). That is, the mean is more accurate by the square root of the number of measurements. If you have 25 measurements of the same thing, with the same equipment, you will be 5 times more accurate than if you have one measurement.

Q6: What are those measurements that are far from the Gaussian curve?

A6: They are mistakes! You tell the people who made them to look carefully at what they did, because something other than the usual, random errors of measurement affected them. Every class I've taught there have been outliers, but maybe none of your students will make a mistake!

When the only errors are the random errors of measurement, about 2/3 of measurements will be within one standard deviation of the mean, and about 95% within two standard deviations of the mean. Those that are much farther away have something affecting them besides measurement error.

Supplementary questions and material

Do you think measurements made by professional scientists have measurement error? [Yes! Even if it is small, it is never zero.]

If you have a scale at home, what do you think its measurement error is? How did you decide? [A few pounds. Comparing my scale with one at the gym. In other words, multiple measurements.]

A small collection of this and other creative activities and labs may be found online.[3]

Endnotes

1. https://www.eclipseglasses.com/products/special-school-discount-program
2. https://www.gimp.org/
3. https://casa.colorado.edu/~dduncan/?page_id=1079