



**Title:** Data Analysis – Introduction to Measurement Error and Outliers

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**Grade Level:** Middle School

**Type of Lesson:** STEM

**Learning Objectives:**

1. Introduction to a few key statistical concepts: measurement error and outliers.
2. Gain an understanding that even the best scientific work still has error; it's part of the nature of science.
3. Get first hand experience in basic data analysis by analyzing data collected in class.

**Materials Required:**

1. Pennies (approximately 15 for a class of 30)
2. Stopwatches (again, ~15 for a class of 30)

**Duration:** Approximately 1 hour

**Audience:** This lesson was developed for 7<sup>th</sup> grade, but can be adjusted for older or younger audiences.

**Background Information:** Familiarity with averages and graphing.

**Lesson Vocabulary:**

1. **Measurement error:** the difference between a measured value and the true, theoretical value.
2. **Sampling error:** error that arises from only measuring a portion of a population, rather than the whole population.
3. **Outlier:** a measurement that's far away from other measurements, an extreme measurement.

**Preparation (~5 minutes):** Gather stopwatches and pennies. Make sure stopwatches are in working order. If desks/tables are not uniform in height, gather some yardsticks students can share.

**Engage:** Begin the lesson with a fun activity. 1) Ask the students to use a stopwatch to measure how long it takes for a penny to fall from a set distance (to avoid having everyone need a yardstick, use desk-height if it's uniform). Students can work easily in

pairs, with one student dropping the penny (and holding the yardstick if necessary), and the other timing. 2) Ask them to do the same thing, but vary the height: 25 cm, 50 cm, 75 cm and 100 cm. Do not worry too much about accuracy – that’s part of the point of the lesson! Each pair of students should take one measurement for each height, and you should record the measurements either on the board, or in Excel on a projector if possible.

### **Explore:**

There will be a lot of variation in the measured times. Ask the students to do a **think-pair-share**: why didn’t they all get the same number? This think-pair-share may turn into a classroom discussion, which is great. There are many sources of error in this experiment, such as:

- Pennies may not all have been dropped from exactly the same height, or may not have been dropped in the same way (some horizontally, some vertically, etc.)
- The reaction times for starting and stopping the stopwatch for the various teams may be quite different
- The pennies themselves might be slightly different shapes or weights
- The stopwatches are not perfect! They are only so accurate, and have limitations.

Try to guide the discussion so three important categories of error are highlighted:

- Human error (method of dropping, drop height, reaction times)
- Instrument error (the stopwatches are only so accurate)
- Sampling error (the pennies are not identical)

It is not necessary to define these three categories, just highlight that there are many sources of error (particularly error stemming from the instrument itself).

### **Explain:**

Lead the discussion on sources of variation/error into a brief lecture (~5 minutes, depending on your particular goals).

1. Science is a search for the truth, or reality of a situation (i.e. the *actual* time it takes for the penny to hit the ground)
2. Because of **measurement error**, the real, theoretical truth, can never be exactly known!
  - a. Define measurement error: the difference between a measurement and the actual value
  - b. From the earlier discussion, both “human error” and “instrument error” are part of measurement error
  - c. Even with the best instruments in the world, there will still be some measurement error, although it may be very small. (All instruments have limitations)
3. **Sampling error** is another reason the truth can’t be exactly known.
  - a. All pennies are very similar, but they’re not exactly the same. We can’t measure every single penny!

It’s important to discuss that although all data have error, that doesn’t mean that scientists are unable to draw strong conclusions from data. The more data are collected, the more we understand and the closer we come to the theoretical truth.

There is a video that I think does an excellent job at illustrating truth versus measurements or data: <http://spark.ucar.edu/dog-walking-weather-and-climate>  
The video explains the relationship between climate and weather, but it works equally well for this. Where the narrator mentions climate, think truth, weather, think data.

**Extend:**

Come back to the measurements of how long it takes for a penny to fall. Ask the students what they would do with those measurements, if someone asked them for just one number representing the fall-time of a penny. Most likely, someone will suggest taking the average.

**Think-pair-share:** Why is the average a better representation of the measurements than simply choosing one of them?

Use Excel to take the average so the students can see on the projector (or on the board). Now introduce the concept of an outlier.

**Outlier:** a measurement that is far away from other measurements, or an extreme measurement.

What are some causes of outliers?

- In many cases, an outlier is a measurement that happened to have a lot of measurement error.
- It could be that it's caused by sampling an extreme individual (say, a penny that had a piece of gum stuck to it – you might not expect it to behave like the others)
- It could be that you're not accounting for something in your expectations. What if age of penny affected how long it takes to fall? Age doesn't have an effect, but if it did, and you happened to have a very old penny, it would be an outlier. But in this case it would be a totally valid measurement that provided some unexpected information.

What effect do outliers have on conclusions?

- Ask the students to imagine that one of the penny measurements was an outlier. Go ahead and replace one of the measurements with something way off (if the average was about 0.5, replace one of the measurements with something like 3).
- Recalculate the average. It will be very different! Outliers have an extra-large effect on our conclusions. This is why we should be suspicious of outliers – IF we have reason to think the outlier data point is wrong (say, we remember being distracted when taking the measurement). In this case, we should exclude that data point from our analysis.

**Evaluate:**

This lesson was originally designed to go along with a larger experiment where students measured heart rate, internal temperature, and external temperature under cold and heat stress. The evaluation portion was closely tied to that experiment, but could easily be modified for use with any other experiment, or with the penny data.

Ask students to answer the following questions, either in class or for homework:

1. What is measurement error?
2. Graph your data from the experiment on cold and heat stress. What conclusions, if any, can you draw?
3. Discuss the quality of the experiment you did on cold and heat stress. List at least 4 sources of error.
4. Do you think any of your data points are outliers? If so, should you exclude them (why or why not)?