MASS OF U.S. PENNIES
TEACHER NOTES

DESCRIPTION

Students often struggle with the concept of isotopes: atoms of the same element but different atomic masses. Particle physicists deal with a similar situation when trying to determine the mass of particles that are predicted by the Standard Model. In this activity, students work in groups of two or three to represent data through histograms for analysis and interpretation. Students use an electronic balance to determine the mass of a large number of U.S. pennies (one-cent coins) of varying ages. The metallic composition of the penny has changed over the years. Different compositions can have significantly different masses. A sufficiently random selection of hundreds of pennies should allow the students to discover the years in which the composition changed.

STANDARDS

Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems
2. Developing and Using Models
3. Planning and Carrying Out Investigations
4. Analyzing and Interpreting Data
5. Using Mathematics and Computational Thinking
6. Constructing Explanations and Designing Solutions
7. Engaging in Argument from Evidence
8. Obtaining, Evaluating, and Communicating Information

Crosscutting Concepts

1. Observed patterns . . . guide organization and prompt questions.

Common Core Literacy Standards

Reading

9-12.3 Follow precisely a complex multistep procedure . . .

9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards

MP2. Reason abstractly and quantitatively.

MP4. Model with mathematics.

MP5. Use appropriate tools strategically.

MP6. Attend to precision.

IB Physics Standard 1: Measurement and Uncertainty

1.2.6 Describe and give examples of random and systematic errors.

1.2.8 Explain how the effects of random errors may be reduced.

1.2.11 Determine the uncertainties in results.

IB Physics Standard 7: Atomic Nuclear and Particle Physics

7.3 The structure of matter

ENDURING UNDERSTANDINGS

Scientists can analyze data more effectively when they are properly organized; charts and histograms provide methods of finding patterns in large data sets.

LEARNING OBJECTIVES

In this activity, students will know and be able to:

- Make a histogram to determine if the mass of all U.S. pennies is the same within experimental uncertainty.
- Determine the year that the composition of the U.S. penny changed.
- Explain how this method of determining the change in U.S. penny composition relates to the concept of isotopes from your study of chemistry.

PRIOR KNOWLEDGE

Students must be able to keep careful records of observations and know how to make histograms.

BACKGROUND MATERIAL

Plan ahead to make sure you have enough pre-1982 pennies so that they represent approximately 10-50% of your total sample of pennies.

A histogram is a common data representation in particle physics. Histograms are graphical representations of a frequency table. If your students can learn how to make histograms by completing the activity *Histograms: The Basics*.

You can find inexpensive small balances that read to the hundredth place at Amazon and other vendors for less than $20.00. The mass scale should have a minimum reading of 0.01g.

IMPLEMENTATION

One method of starting this activity is to instruct the students to write down as many characteristics of each penny as they can. Many of these characteristics are qualitative and a few are quantitative. Help the students focus on the characteristics that are measurable in the lab and can be represented with a number value. The most important characteristics for this activity are mass and mint date, but if students want to record things like diameter or thickness, they can draw conclusions from those data as well. If time is a factor, then limit data to mass and mint date.

Have student groups construct a data table to organize their data. Make sure that mass is one of those quantities. Students should document their procedure before experimentation and review it after completing the experiment so they can include any changes made during data collection. They can make a histogram for each characteristic they study. They may also make scatter plots to see how one quantity might affect the other. The most telling of these is mass as a function of mint date but lead them to this rather than simply assign it.

A data table with several quantities may look like this:

Penny	**Mass (g)**	**Mint Year**	**Diameter**
1			
2			
3			

It is also useful to help them with making their first and most important histogram with a table like this:

Mass bin (g)	**Number of pennies/0.1 g**
0.0-0.1	
0.1-0.2	
0.2-0.3	

The mass of the U.S. penny changed significantly in 1982. You can ensure that your *class* "discovers" this by inspecting your penny collection to see if there are enough pre-1982 pennies to show the mass difference. The lab works quickly if each group has 10–20 pennies with various mixtures of pre-1982 and post-1982 pennies.

Have the students make a histogram of their group data, but the sample size is too small to see a consistent effect. It is best if there are at least 100 data points to make the *class* histogram. The mass histogram will very likely reveal that pennies come in two different masses: "light" and "heavy." However, there is nothing to suggest *why* the masses change. The answer to that question requires more investigation.

If students record the mass *and* mint year of each sample, they'll have enough information to begin to answer the question about *why* the mass changes. For this part of the investigation, it is best to create is mass vs. mint date scatter plot. This plot provides information about when the change in mass occurred. Students *may* make a more advanced analysis using the radii, thicknesses, and masses of pennies to find their densities and use these data to possibly indicate whether a there was change in composition of the pennies in 1982. Here, knowing the uncertainty in those measurements is critical. You can also suggest additional tools and measurements that the students should make in order to determine why the mass changes. This is the nature of science; one experiment leads to another.

ASSESSMENT

One technique for reporting out is to ask students to confer in their group, present their answers on a white board and share their ideas and answers with the class.

You might ask students questions such as:

- What do you conclude about the masses of pennies from your histogram? What is the evidence that supports your conclusion?
- Is there a single best value for the mass of a U.S. penny? Is there more than one best value for the mass of a U.S. penny? Do the values agree within uncertainty? What evidence can you provide to support your answer?
- What do you conclude from the mass vs. mint date plot? What is the evidence that supports your conclusion?
- Is there evidence from your data to support the claim that the composition of a U. S. penny has always been the same? Explain your claim.
- What additional measurements might you make to learn more? What tools might you need?

Extension questions:

- If they collected other quantitative data for each penny, what conclusion can they draw from the plots made with those data?