Date: April 1, 2022

From: Liam Keeley

To: Conspirators

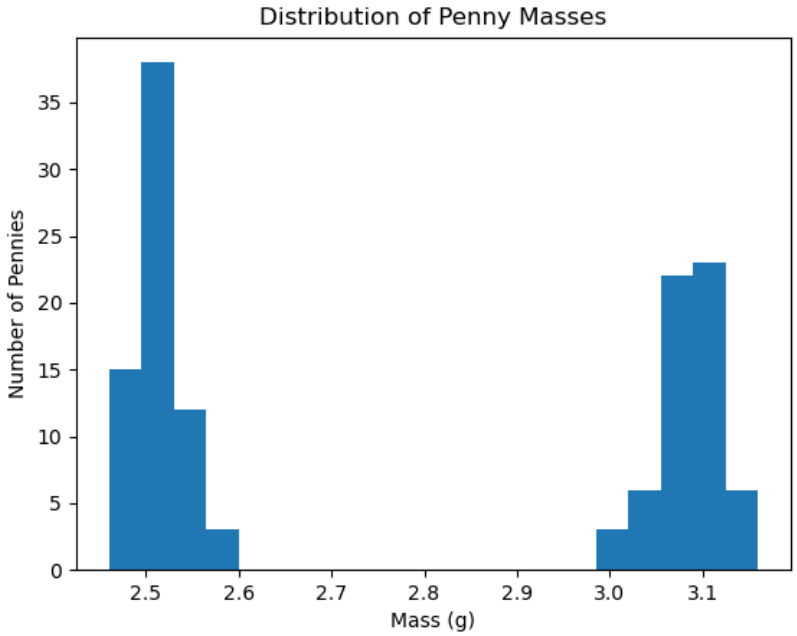
Subject: Penny Mass

Executive Summary: There appear to be two distinct types of pennies, one with a mass of $m_1 = 2.51 \pm 0.01$ grams and the other with a mass $m_2 = 3.09 \pm 0.01$ grams.

Description: To prepare for a heist of the penny bank, the mass of a penny needs to be known to determine the maximal load of the escape helicopter.

Methods: To measure the mass of a penny, 128 different pennies were measured by various members of the 2022 Experimental Physics class at Colorado College. Using this data set, I applied various statistical methods to better understand the implications of the collected penny data.

Results: First, a histogram of the penny masses was generated using matplotlib to get a general idea of the data spread. The result is shown below:



Before getting into any specifics, what is important to notice about this histogram is that it clearly shows that there are two disjoint groups of pennies, one with masses centered between 2.5g and 2.6g and the other between 3.0g and 3.1g. For this reason, it does not make sense to say there is a singular penny mass, because if a single mass was calculated–say by taking the mean value–it would be a mass that no pennies have. For this reason, the data was split into two groups: pennies with masses less than the mean mass of all the pennies and pennies with masses greater than the mean mass of all of the pennies.
After separating the pennies into these groups, there were 68 lighter pennies and 60 heavier pennies.

Both of these groups were deemed large enough that additional data was not necessary, and statistical analysis was used to determine the mass of each type of penny. Specifically, the mean of each groups was used as the best estimate and the standard deviation of the mean was used to determine the random uncertainty in the weight of the pennies. Additionally, the scales used in class also had a systematic uncertainty of 0.01. Because the systematic error of 0.01 is about three times as large as the random errors found for each groups of pennies, it was decided that this error was dominant and the random error could be neglected. Using these measures, the mass of the lighter pennies was found to be $m_1 = 2.51 \pm 0.01$g and the mass of the heavier pennies was found to be $m_2 = 3.09 \pm 0.01$g.

Take Away: While it is pretty clear that there are two types of pennies, data was not taken to determine why the pennies were different. However, a qualitative assessment of the pennies shows that they are all essentially the same size, so presumably the different pennies are made of materials with different densities. Additional research is needed to determine why the pennies are made of different materials and what percentage of each type of penny is present at the bank when it is heisted. Two possibilities that could be investigated are the year the pennies were minted–that is, if the material pennies are made of changed during some year–and the place that the pennies were minted–that is, different mints may use different materials.
At first, I thought this activity was pretty goofy, but it turned out to be surprising that there are two types of pennies, and this was a subtlety that I almost missed. My main take away is that it is important to always visualize data if possible even if it is just to get a general layout and is not super specific, and also not to underestimate problems even they seem pretty mundane on the surface. I googled the answer, and the ratio of copper to zinc was changed in 1982 and pennies minted afterwards are heavier.
To review code and data, see $https://github.com/3{-}3{-}3/Expiremental\_Physics/tree/master/Pennies$.
Detailed goals:

- Make a quantitative claim for the value of the mass of a penny.
- Argue your case for why your claim is valid/useful/trustworthy.
- (Any additional goals for what you tried to do in this piece of writing.)