This is a one-week lab.

Reading. In this experiment, all data will be given and it will be located in the Home page of the Canvas site. Before coming to lab, you should review section 2-10 (Introducing Microsoft Excel), section 2-11 (Graphing with Microsoft Excel) and Chapter 4 (Statistics) which are located in your textbook (9th edition of Harris) [1]. This experiment is adapted from an experiment in a previous edition (8th) of the Harris textbook, and from an article published by T.H. Richardson [2]. You might want to refer to both sources in writing up and analyzing your data.

Introduction. The use of United States one-cent coins, more commonly known as pennies, as the objects to be measured in this lab is not the main point of the lab. They merely provide a convenient, mass-produced, inexpensive mass for us to use. We will use the data and apply various statistical tests.

Figure 1: Designs of Lincoln's penny

Pennies are minted in the US by the United States Mint. Since 1909, the front of the coin featured a bust of Abraham Lincoln (1809 – 1865), in commemoration of the centennial of his birth. The back of the one-cent coin has varied through the years. From 1909 to 1958, the reverse side featured wheat stalks, while from 1959 to 2008 the design featured the Lincoln Memorial on the reverse side. To commemorate the bicentennial of Lincoln's birth, the reverse side of the one-cent coin featured four different designs, as shown in **Figure 1** [3]. In 2010, a design featuring the Union Shield was adopted.

There are currently four branches of the US Mint, centered in Washington, DC, that actively produce coins: Denver, CO; Philadelphia, PA; San Francisco, CA; and West Point, NY. The facility at which a coin was minted is usually indicated by the mint marks D, P, S, and W, respectively, for these locations. On the one-cent coin, this mint mark is located on the front, just below the date. However, prior to 1980, coins minted in Philadelphia did not bear the P mint mark, and except for pennies, coins minted in 1980 and after started to bear the mint marks D, S and W. Thus, a penny with no mint mark was probably minted in Philadelphia.

A 2001 penny showing the "D" mint mark below the date, indicating that this penny was minted in Denver.

The composition of the one-cent coin has likewise changed through the years. A summary of these changes is given in **Table 1** [4].

Table 1. Composition of US One-Cent Coins by Year

Years	Material
1793–1857	copper
1857–1864	88% copper, 12% nickel (also known as NS-12)
1864–1942	bronze (95% copper, 5% tin and zinc)
1943	zinc-coated steel (also known as steel penny)
1944–1946	brass (95% copper, 5% zinc)
1946–1962	bronze (95% copper, 5% tin and zinc)
1962–1982	brass (95% copper, 5% zinc)
1982–2009	97.5% zinc core, 2.5% copper plating
2009 (Limited)	bronze (95% copper, 5% tin and zinc)
2010–present	97.5% zinc core, 2.5% copper plating

In this laboratory exercise, we will focus on pennies bearing dates of 1962 to present, although if you find a pre-1962 penny in your batch you should include it. As can be seen in **Table 1**, there was a major change in the composition of the pennies that are likely to be found in current circulation. Pennies minted in 1982 and before consist of a brass alloy (95% copper and 5% zinc) and weigh approximately 3.1 g. Pennies minted in 1982 and later weigh approximately 2.5 g, and consist of a zinc core with a copper plating. The composition change occurred *during* 1982, so we will refer below to 1982.0 and 1982.5 to separate those pennies minted before and after the 1982 composition change, respectively.

Lab Report

Along with this Lab Manual, you are being given a PDF file consisting of Professor Beebe's analysis of data from a class in the past. Your Lab Report will consist of your analysis of your class's aggregate data. For each plot in my analysis, you are expected to create a plot with the same information, using your class's data. **To be clear, each of your plots should have exactly the same axis labels, axis ranges, titles, on-plot notations, etc, as those in Professor Beebe's analysis.** The various detailed suggestions below are meant to be guidelines for those students needing additional help. What matters in your Lab Report is how well you create the same plots (using your data) as Professor Beebe created with his example (using different data).

Analysis Suggestions

If you make mistakes with your Excel file, perhaps by jumbling up the date and mass information per penny when you do the sorting, remember that you always have a fresh data file available on Canvas. You might want to just start over.

In what follows, each task should be completed/performed in Excel for the set of all coins of any given year. For example, you should set up a column for each year, and at the bottom of each column you should have the various items requested. You will also perform averages over several years. Remember that in the year 1982, pennies were produced with two different compositions. Sort the heavier 1982 pennies (nominally 3.1 g) into a 1982.0 year column, and the lighter 1982 pennies (nominally 2.5 g) into a 1982.5 year column.

Removal of Outliers

1. You can assume that pennies weighing more or less than certain arbitrary limits must have been corroded, worn, or otherwise modified such that *they are no longer part of the original population*. They are considered to be *outliers*.
2. Working with the pre-1982.0 pennies (nominally 3.1 g) and post-1982.5 pennies (nominally 2.5 g) as separate groups, use the DATA/SORT function to rank the penny masses from lowest to highest.
3. Use the AVERAGE, STDEV, MIN and MAX functions to calculate the average, standard deviation, minimum, and maximum, respectively, for the mass of both groups (pre- and post-1982) of penny sets. Also calculate the relative standard deviation in parts-per-thousand. Be sure to work with values to the 0.0001-gram decimal place.
4. Calculate the 3-sigma upper and lower limits above and below the average mass of each group of penny sets. The first group includes all years before and include 1982 and the second group includes all pennies from 1982.5 and all years after 1982.5. After doing so, color the cells yellow for those pennies that are greater than 3-sigma above the mean, and less than three-sigma below the mean.
5. By copying only your uncolored values to new columns on the right, you are leaving the outliers behind. Again use the AVERAGE, STDEV, MIN and MAX functions to calculate the average, standard deviation, minimum, and maximum, respectively, for the mass of both groups of penny sets. Also calculate the relative standard deviation in parts-per-thousand. Do this for the mass of both groups of pennies.
6. In an iterative process, repeat the above steps until you find that there are no longer any pennies in the retained data that fall outside the three-sigma limits. Use this as the final data set on which to perform your statistical calculations. It may be helpful at this point to further separate your data into a column for each year and save your file with a new name.

Year-by-Year Analysis

7. Using *all* of the data (before and after the year 1982), make a plot with the year on the horizontal axis and the mass of the penny on the vertical axis. Be sure to include an error bar, equal to plus or minus one standard deviation, for each year's average.

Year-by-Year Analysis 1982.5 - present

8. Make a new mass *vs*. year plot, looking only at the data for pennies minted in and after 1982.5, and excluding any pennies from 2009. Add a linear trendline to the data and show the trendline's function on the plot (slope *m*, intercept *b*, and correlation coefficient *R*). Also calculate the standard deviation of the slope σ_m, using formulae from chapter 4 of the textbook, or using Excel's built-in functions. Compare the slope *m* and its error σ_m. Can you conclude with some confidence that there has been an historical trend in the mass of pennies since 1982.5?
9. Now use Student's *t*-test (see Table 4-4 in your textbook) at 95% confidence to see if the slope is negative (*i.e.*, that the mass is decreasing), positive (*i.e.*, that the mass is increasing), or zero (*i.e.*, that the mass remains the same each year). For this exercise, since the number of coins is significantly greater than 120 (the highest finite number of degrees of freedom in the table) use $t = 1.960$, the *t* value for an infinite number of degrees of freedom at the 95% confidence level.
10. Using the same subset of the data (years 1982.5 through 2010, excluding 2009), select the years with the highest and lowest *average* masses. Use the *t*-test for comparison of means to compare the average mass of these two years at the 95% confidence level. Are the two average masses significantly different?

Year-by-Year Analysis of 1963 - 1982.0

11. Make a new mass *vs*. year plot, looking only at the data for pennies minted from 1963 to 1982.0. If you have data for pennies from before 1963 you can choose to exclude them or include them. Add a linear trendline to the data and show the trendline's function on the plot (slope *m*, intercept *b*, and correlation coefficient *R*). Also calculate the standard deviation of the slope σ_m, using formulae from chapter 4 of the textbook, or using Excel's built-in functions. Compare the slope *m* and its error σ_m. Can you conclude with some confidence that there has been an historical trend in the mass of pennies between 1963 and 1982.0?
12. Now use Student's *t*-test (see Table 4-4 in your textbook) at 95% confidence to see if the slope is negative (*i.e.*, that the mass is decreasing), positive (*i.e.*, that the mass is increasing), or zero (*i.e.*, that the mass remains the same each year). For this exercise, since the number of coins is significantly greater than 120 (the highest finite number of degrees of freedom in the table) use $t = 1.960$, the value for an infinite number of degrees of freedom at the 95% confidence level.
13. Using the same subset of the data (years 1963 through 1982.0), select the years with the highest and lowest average masses. Use the *t*-test for comparison of means to compare the

average mass of these two years at the 95% confidence level. Are the two average masses significantly different?

Comparison of Mint Locations

14. Re-sort all of your data from #6 above (*i.e.*, after removing the ± 3σ outliers) for pennies minted in and after 1982.5, and excluding any pennies from 2009, but sorted into one column for Philadelphia and a second column for Denver, and so on if you have pennies minted in other locations. Pooling all years' data for each mint location, calculate the average, standard deviation, minimum, and maximum for the mass of each mint's penny set. Report those values and their standard deviations to the 0.0001-gram.
15. Use the *t*-test for comparison of means to compare the average mass of pennies minted at the different mints at the 95% confidence level. Are the pairs of average masses significantly different?
16. Repeat the above two steps for pennies minted from 1963 to 1982.0 at the different mints for which significant data are available.

Distribution of Masses

17. Arrange the data from all years from #6 above (*i.e.*, after removing the ± 3σ outliers) for the years 1982.5 and later (excluding 2009) into a single tall column. Use the DATA/SORT function to rank the penny masses from lowest to highest. Use the AVERAGE, STDEV, MIN and MAX functions to calculate the average, standard deviation, minimum, and maximum for the mass of all pennies. Report those values to the 0.0001-gram for each year.
18. Generate a histogram for the above data. To create a histogram in Excel, there are plenty of good tutorials on YouTube to which you may refer. Or, first make sure that you have installed the Analysis Toolpack. It is not normally installed with the standard installation, but it is included in what you buy from Microsoft. You can tell if it is installed by opening the TOOLS menu. You will then see the DATA ANALYSIS sub-menu if it is installed.
19. To use Excel to generate your histogram, you need to first set up a column of "bins" having a size spacing of 0.0100 g, starting at 2.4000 and running to 2.6000 (i.e., 2.4000, 2.4100, 2.4200, 2.4300, …, 2.5700, 2.5800, 2.5900, 2.6000). Into each bin you will end up with the count of pennies having a mass in that range (*e.g.*, the count in the bin from 2.4800 g to 2.4900 g might be 27 pennies). To use Excel's TOOLS/DATA ANALYSIS/HISTOGRAM function, set up a column of bins as described above, tell Excel where it is, tell Excel where the output should be written in your spreadsheet (move over a few columns), and tell Excel to generate a plot.
20. After setting up your column of bins, the Excel command used to create a histogram is FREQ. In class or in discussion sections we will go over how to use Excel to create a histogram. You can also read about this in the many references given at the back of the textbook on page NR2, note #26.

Lab Write-Up

This lab write-up will be more extensive and lengthy than it will be for the other labs. Be sure to follow all directions carefully, and to provide all of the information/answers to questions given above. Include all graphs and data tables. See page 54 of your laboratory manual to find out the guidelines for the laboratory report.

Each student must hand in his/her own version of the Lab Report. It will be uploaded through an assignment site on Canvas. **The entire Lab Report must be combined into a single PDF file.** Be sure to include the spreadsheet of all the calculations. It is not necessary to include entire long data set as a printout. Simply print out the first pages. Make sure that all formulae are shown once in a column for each column where they are different.

Chemicals and Equipment Needed for this Lab

Laboratory computers (already in lab), or your own personal laptop computer (Mac or PC)

References Cited

1.) D.C. Harris, *Quantitative Chemical Analysis*, 9th edition (W.H. Freeman and Company, New York City, 2016). See Chapter 4.

2.) T.H. Richardson "Reproducible Bad Data Instruction in Statistical Methods," *Journal of Chemical Education*, ***68(4)***, 310-311 (1991).

3.) Images and tables were downloaded from Wikipedia, and are in the public domain.

4.) Wikipedia article, accessed 18 April 2010: http://en.wikipedia.org/wiki/Penny_%28United_States_coin%29