1988

Energy in Perspective Laboratory #7: Predictability, Measurements & Uncertainties

Robert G. Fuller
Uinv. of Nebraska Lincoln, rfuller@neb.rr.com

Exploration

Not all repeated measurements of the same physical quantity will give the same numerical value. Consider the following case:

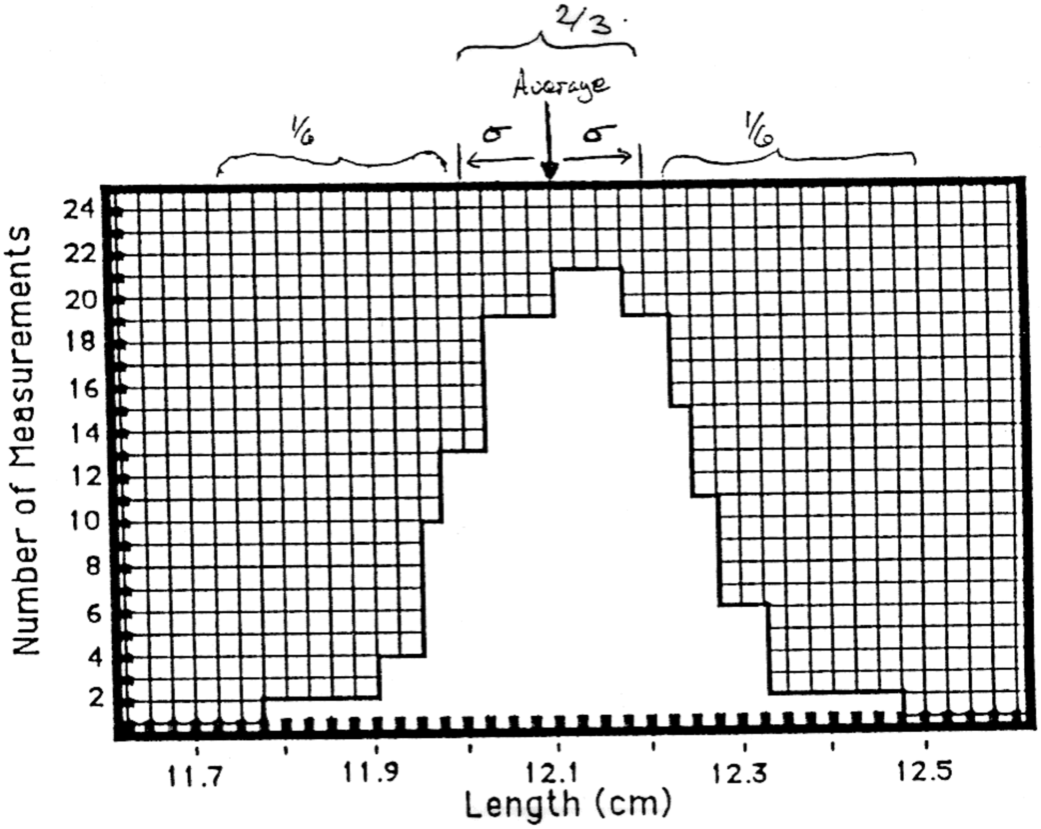
Two groups, morning and afternoon, of students went out on campus and made repeated determinations of the height of Hamilton Hall and Mueller Tower. The six morning teams made a total of 18 different determinations on the height of each structure. The eight afternoon teams obtained 24 values. Shown below:

1. List a variety of ways you can determine a "best" value for each height.
2. Select a method and do it for each height.
3. What is a value for the uncertainty or possible error in your "best" values and how can you determine that.
4. Determine the "best values" for the heights of the 2 buildings from:
   morning data, afternoon data, all data.
5. Estimate an uncertainty for each group's data and all of the data.

Morning Groups	
Hamilton	**Mueller**
25.3	21.4
29.0	21.6
33.4	29.9
39.1	28.3
35.1	34.4
34.2	35.2
26.5	25.6
36.2	21.8
37.9	18.9
30.0	20.9
22.7	24.0
24.2	31.0
31.7	26.9
23.5	19.9
31.2	32.3
25.5	22.5
33.8	23.2
31.8	21.2

Afternoon Groups	
Hamilton	**Mueller**
36.7	25.2
31.0	22.0
43.4	31.9
35.5	31.0
34.2	33.5
31.5	12.9
32.0	22.8
34.9	24.6
28.7	19.7
30.4	28.6
25.4	25.4
31.0	24.0
30.2	25.5
28.3	18.5
24.1	13.9
51.4	22.4
57.4	18.4
22.0	14.9
26.8	17.8
38.9	26.2
28.5	16.3
28.4	25.1
45.9	25.1
34.9	20.1

Invention



The graph above is called a histogram. It represents the number of times a particular value of a measurement (in this case length) is made for each .25cm interval. For example the histogram represents the fact that 10 of the 100 measurements gave lengths between 11.950cm and 11.975cm. Clearly, values near the middle of the range come up more frequently than do values at either end of the range. From this graph one could estimate a mean of 12.1cm or so and a probable range of 12.0cm to 12.3cm.

If instead of 100 measurements, you took several thousand, your graph would look like a smooth bell shaped curve. For this curve (sometimes called a normal or gaussian distribution) **most points lie somewhere between the average (mean) value and one standard deviation (denoted by σ{sigma}) away from the average value.** For the above histogram, σ = 0.1 cm; most measurements are between 12.0 cm and 12.2 cm. **It can be proved that, for completely random uncertainties, about 63% of the points are within 1σ from the mean.** This means that a data point is twice as likely to be within ± 1 σ of the mean than outside. **Frequently we use σ as the length of the *error bar* to show on a graph of our data.**

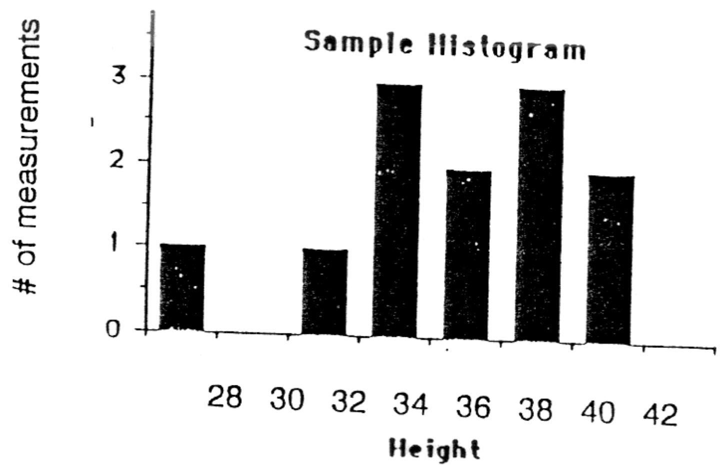
Supported by the Fund for Improvement of Post secondary Education, US Dept. of Education
Workshop Physics: Appendix C - Statistical Measures of Uncertainty
Authors: R. Boyle & P. Laws V1.0 -- August 26, 1987

More Invention

-> Make six histograms; one for each data set.

Morning Group	Mueller Tower	Morning Group	Hamilton Hall
Afternoon Group	Mueller Tower	Afternoon Group	Hamilton Hall
All Data	Mueller Tower	All Data	Hamilton Hall

To make these histograms: divide the heights from lowest to highest into about 12 equal intervals and plot a bar graph. As an example, for the Mueller Tower morning group data interval 1 could include all heights from 28.0m to 29.9m; interval 2 all heights from 30.0m to 31.9m and so on. This height histogram consists of a bar graph showing how many measurements gave heights that lie in each range.



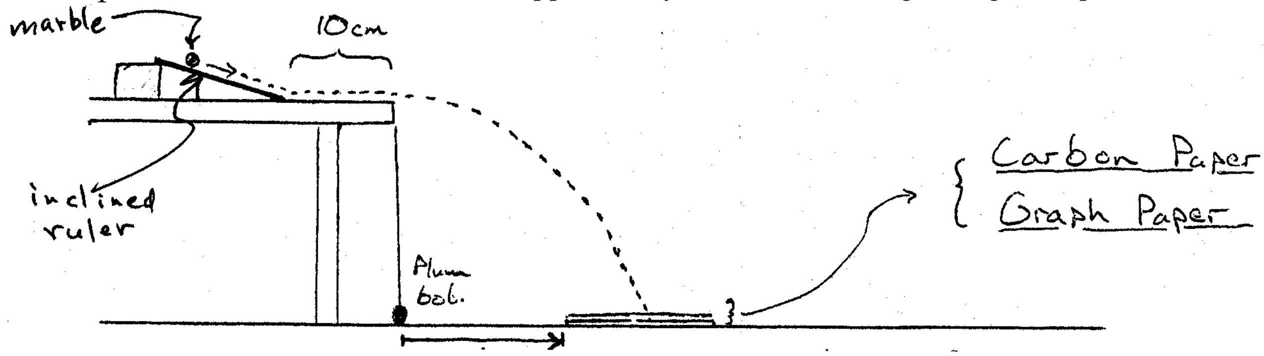
-> Examine the data and determine its estimated uncertainty **(One definition of uncertainty, called sigma, σ, is defined as including the central 2/3rds of the data)** by 'eyeballing' the histogram and eliminating the top 1/6th and the bottom 1/6th of the height data. Draw vertical lines on your histograms showing the estimated uncertainties in each. Put an arrow on each histogram to show the location of the average height according to the data plotted in the histogram.

Application

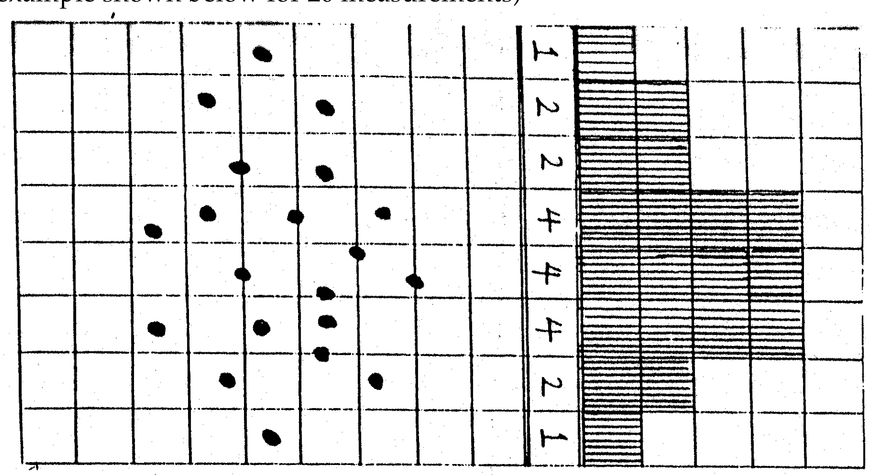
How Far Will a Marble Go?

The purpose of this experiment is to collect **a lot** of data on how far the marble will travel before hitting the floor for **6** different starting heights. The manipulated variable is starting height. The responding variable is horizontal distance traveled in the air.
Needed: ruler, marble, graph paper, meter stick, carbon paper, support blocks, plumb bob.

1. Set up the ruler as shown below. (support firmly to avoid its moving during the experiment)



2. Roll the marble down the ruler (starting from rest) from the 6cm and 30cm marks and note where the marble lands. Place a sheet of graph paper around these spots and attach to the floor with masking tape. Cover the graph paper with carbon paper (carbon side down!).
3. Use a plum bob to mark the point on the floor directly beneath the edge of the table from where the marble will leave and become a projectile. Measure the distance to the edge of the graph paper. (of course the graph paper should be square with the table!)
4. Roll the marble down the ruler 24 times for each of the 4 different starting locations; 7.5cm, 15cm, 22.5cm, and 30cm. Use a different sheet of graph paper for each height's 24 trials.
5. Repeat steps 2 through 4 with <u>2 blocks supporting the upper end of the ruler.</u>
6. Make histograms for each of your 8 data sets. Do this on the graph paper that shows the data. (see example shown below for 20 measurements)



7. Using your histogram, draw 2 **dark** lines about the mean so that 2/3rds of the dots fall inside the lines and 1/6th fall outside of each of the lines.
8. Plot one data point on a graph of "best" value for distance traveled versus starting height, showing error bars. Show it to an instructor.

Write Up Page:

Write-up:

I PURPOSE

II BUILDING HEIGHTS

Show ALL computations done for the write-up. They should be neatly hand written.

A) Using the combined data of the morning and afternoon groups, *compute* the average value and standard deviation for the heights of Hamilton Hall and Mueller Tower.

B) Compare with the histograms (i.e. values of σ) made in lab.

III ROLLING AND FLYING MARBLES

A) *Compute* the average value of distance traveled for *each set* of 'flying marble' data.

B) *Find* the standard deviation for *each set* of 'flying marble' data from its histogram. (see pages 2 and 3 of lab handout.)

C) For the 4 data sets using 1 block, draw a graph of distance from the table versus starting location. Do the same for the 4 data sets using 2 blocks.
   1) Use the computed average values of each set for the distance
   2) Use the 'eyeballed' standard deviation of each set for the uncertainty. That is, draw in the **error bars** on each of your data points!

   (You should end up with two sets of data on your graph which have 4 data points each and each data point has an error bar.)

IV ERRORS

A) Explain errors and uncertainties in the marble experiment.
   1) Systematic errors?
   2) Statistical Uncertainties?

V CONCLUSIONS AND DATA

State any conclusions from the lab. This should include your analysis of the distance traveled versus starting height data, including slopes and starting values as appropriate. Include data sheets.

Note: Ten bonus points will be awarded if you do *all the computations* (and do them correctly!) .

Note: Ten bonus, bonus points if you write a one page explanation of how you would expect the distance traveled by the marble through the air to depend on starting height, if you neglected friction. You may consult a physics book, a physicist, etc., just include citations for all of your sources of information. Is the ideal relationship between these two variables, non-linear, partly linear, or linear? Why?