Fundamentals of Measurement and Error Analysis

Firstname Lastname

Date

1. Replace the red text at the top of this page with your name and the date.

2. As you enter your work, please make sure that your answers stay red (like this). This will make them easier to see, and thus it will be easier for us to grade them accurately. To convert black text to red, highlight it and then click on the “A” symbol in the menu bar above, to the right of the “**B**”, “*I*”, and “U” symbols. Select the red square to turn your highlighted text red.

3. Delete these 3 initial instructions from this template as soon as you have followed them.

Performing a Simple Experiment

Planning Your Experiment, and Collecting Data

1. In the space below, describe your experimental plan.

Replace this text with your description, making sure to keep the text red.

Table 1.2: Experimental Data I: Insert Table Title Here

|  |  |
| --- | --- |
| Trial | Value (define units here) |
| Trial 1 | value 1 |
| Trial 2 | value 2 |
| Trial 3 | value 3 |
| Trial 4 | value 4 |
| Trial 5 | value 5 |
| Trial 6 | value 6 |
| Trial 7 | value 7 |

2. Go ahead and put in the measurements from your seven trials from Table 1.2 below, and calculate μ.

μ = $\frac{1}{7}$$×$ (insert list of values 1-7 here) = insert mean value (units)

3. Perform the same operation for your innermost five trials from

Table 1.2 below.

μ = $\frac{1}{5}$$×$ (insert list of 5 inner values here) = insert mean value (units)

4. Do roughly 67% of our five bean weights (described on pages 7-9 of the lab chapter) lie between 0.311 and 0.371 grams? ( Yes / No )

*(Delete either “Yes” or “No” and the dividing “/” symbol so that your answer is clear, and then delete this sentence.)*

Learning about Histograms

5. Set the web application to show a distribution of seven tortilla chip

lengths, with a precision of 0.05 cm. What happens if you turn data clipping on and off? When you remove the lowest and highest values from the sample, the observed value for sigma (the spread around the mean value) always ( decreases / stays constant / increases ).

*(Delete the two incorrect answers and the dividing “/” symbols so that your answer is clear, and then delete this sentence.)*

6. Now change the number of measurements from seven to 70,000 chip lengths. When you remove the lowest and highest values from the larger sample, the change in the observed value for sigma is (smaller / the same / larger ) than/as when this is done with only seven data points.

7. Clipping the two outermost values from a distribution of only seven points will almost always cause the estimated value for sigma to drop to well below 100% of the underlying value. Why then do we suggest doing this in some real experiments?

Replace this text with your answer.

8. If a histogram of seven data points looks more like a picket fence than a bell curve, roughly how many points do you need to measure before the sample looks recognizably like a smooth bell curve?

Replace this text with your answer, and place a copy of your JPG-format image of a bell-shaped histogram here.

9. As you increase the number of measurements of a particular quantity, what happens to the relationship between the underlying and the observed values of μ and σ - do the observed values become more accurate, getting

closer to the underlying values? ( Yes / No )

Replace this text. To insert a red μ or σ symbol, either copy the ones shown in this sentence or select them from the “Insert > Special Characters...” menu above, selecting “Other European Scripts” and “Greek” from the list of special character set options (listed as “Symbol” and “Arrows” initially).

10. Can you ever measure an observed value for σ which is less than the

measurement precision? ( Yes / No )

11. Set the web application to show a distribution of 1,000 book lengths, with a precision of 10 pages, and then change the quantity being measured from book lengths to tortilla chip lengths. What are the key differences between the two histograms, and why are they so different? What can you conclude about the way in which you should decide if your measurement precision is sufficient for a given experiment?

Replace this text.

Plotting and Analyzing your Data

12. Create a histogram plot from your seven measurements. The mean and sigma values will appear, labeled as “Mean value of μ ± σ.” Record the values below.

μ ± σ = insert mean ± sigma values (units).

Remove your highest and lowest measured values from the set of seven, and remake your histogram. Record the new values for μ and σ below.

μ ± σ = insert mean ± sigma values (units).

13. How do the two μ estimates compare (by how many σ do they differ)? Did your value for σ change in a predictable fashion? Do your two estimates of μ agree with those that you determined earlier by hand?

Replace this text.

Table 1.3: Experimental Data II: Insert Table Title Here

|  |  |  |  |
| --- | --- | --- | --- |
| Trial | Value (define units here) | Trial | Value |
| 1 | value 1 | 16 | value 16 |
| 2 | value 2 | 17 | value 17 |
| 3 | value 3 | 18 | value 18 |
| 4 | value 4 | 19 | value 19 |
| 5 | value 5 | 20 | value 20 |
| 6 | value 6 | 21 | value 21 |
| 7 | value 7 | 22 | value 22 |
| 8 | value 8 | 23 | value 23 |
| 9 | value 9 | 24 | value 24 |
| 10 | value 10 | 25 | value 25 |
| 11 | value 11 | 26 | value 26 |
| 12 | value 12 | 27 | value 27 |
| 13 | value 13 | 28 | value 28 |
| 14 | value 14 | 29 | value 29 |
| 15 | value 15 | 30 | value 30 |

14. Examine your data, and decide whether your measurements were made with sufficient accuracy. Was the limiting precision good to at least one-hundredth of the mean value? Are there any changes that you need to make to your plan, now that you have taken a small set of test data?

Replace this text.

15. When you are done, create a new histogram from your larger data set. Be sure to include a plot title, label the *x*- and *y*-axes, and add a caption to go with the figure in the lab report explaining its contents and your primary conclusions. (You should do this with all of the figures that you include in your lab reports.)

Insert PNG-format figure here.

Reproducing Your Experiments

Table 1.4: Experimental Data III: Insert Table Title Here

|  |  |
| --- | --- |
| Trial | Value (define units here) |
| Trial 1 | value 1 |
| Trial 2 | value 2 |
| Trial 3 | value 3 |
| Trial 4 | value 4 |
| Trial 5 | value 5 |
| Trial 6 | value 6 |
| Trial 7 | value 7 |

16. For your partner's experiment, your

μ ± σ = insert mean ± sigma values (units), and their (5-value trial)

μ ± σ = insert mean ± sigma values (units).

17. For your experiment, your (5-value trial)

μ ± σ = insert mean ± sigma values (units), and their

μ ± σ = insert mean ± sigma values (units).

18. Discuss the results that you and your partner obtained for both

experiments. How close do you think that your mean values should be (in units of σ) in order for you to say that you described and conducted reproducible experiments? By how many σ do your mean values actually differ? If the difference is larger than your requirement, brainstorm with your partner and identify the most likely reasons for the discrepancies. *You may each write answers to this question, or you may create a single answer together and place it in both of your lab reports.*

Replace this text.

19. Having gone through the experience of having another person attempt to duplicate your experiment based on your written notes, how would you alter your experiment and change your experimental description, if you were to do this exercise again with a new partner?

Replace this text.

The Role of Errors

Three Types of Error, or Variation

1. Select one of the ten experimental questions. Identify a possible systematic error that could pose a hazard to performing this experiment well, and then describe how to eliminate it.

Replace this text.

2. Compare the value of σ for your 30-point data set, and the precision

*P* (the smallest difference that you could measure between two values).

$μ$ = insert mean (units), σ = insert sigma (units), and *P* = insert precision (units).

Which of these two values represents your natural variation? ( σ / *P* )

Which of these two values represents your measurement error? ( σ / *P* )

Is your precision less than (or equal to) one-hundredth of your mean value? ( Yes / No )

$P ÷ (0.01 ×μ) = $replace this text.

How does your precision compare to your value for σ?

$P ÷ σ = $replace this text.

In general, would you prefer that *P* / σ be smaller or larger than one?

( Smaller / Larger )

Error Bars

3. If the error bars on all of the points in Figure 1.4 were all the same length, how would the derived average values change? The red line on the left panel would ( drop / stay at the same height / rise ), and the blue line on the right panel would ( drop / stay at the same height / rise ).

4. If the error bars on point 3 in Figure 1.4 became smaller, the blue line on the right panel would ( drop toward point 3 / stay at the same height / rise away from point 3 ).

5. What can error bars add to an analysis?

Replace this text.

Evaluating Data, and Model Fits

Mean and Spread (Standard Deviation) Values

1. In Figure 1.5, how do the means of the two distributions compare (roughly)? Which one has a higher σ value? Identify another significant difference between the two sets of data.

Replace this text.

Slopes and *y*-intercepts

2. In Figure 1.6, the slope for the left panel sample is ( smaller than / the same as / larger than ) the slope for the right panel sample. The *y*-intercept is larger in the ( left / right ) panel sample, and the points in the ( left / right ) panel sample show more scatter (lie further from the line).

3. If you determined that a star was moving at a speed of 15.0 ± 0.5 km sec-1 in a particular direction, but I found that its speed was 14.2 ± 0.5 km sec-1, could our results be consistent? Roughly how much smaller would my velocity have to be in order for you to say that either our two studies must have observed different stars, or something else was significantly different about them? You may assume that a 5σ or larger deviation is significant.

Replace this text.

Root Mean Square Deviations

4. In Figure 1.7, the rms value for the line in the left panel is 5.7, while the value for the right panel is 10.5. Does the lower rms value belong to the line which passes most closely through the points? ( Yes / No ) What would it mean if a data set had an rms value of exactly zero? Does this seem very likely to happen?

Replace this text.

Trends, or Relationships, Between Variables

Learning about *xy* (or Scatter) Plots

1. Does *y* increase, or decrease, as *x* increases? At what altitude do the peak temperatures occur? What is your general conclusion about a possible connection between maximum solar altitude and the peak local

temperature?

Replace this text.

2. If another survey of different locations derived a slope of 0.786 ± 0.055 for this relationship, would your results be consistent? Why, or why not?

Replace this text.

3. What is the physical meaning of the *y*-intercept for these data (what does it tell us about the relationship between the Sun's maximum altitude and the local temperature)?

Replace this text.

4. The plot is also labeled with a correlation coefficient, *R*. If *R* is near to 1, then *x* and *y* are positively correlated (*y* increases with *x*). If *R* lies between -0.5 and 0.5, *x* and *y* are fairly independent of each other (you cannot predict *y* from *x*). If *R* is near to -1, *x* and *y* are negatively correlated (*y* decreases as *x* increases). Based on its value, is there a strong relationship between *x* and *y*? ( Yes / No )

5. Save a copy of your plot, and include it in your lab report here. Be sure

to include a figure caption in the report, describing the primary conclusions that one can draw by examining the plot. If you are unsure what to write, imagine that you were showing it to a friend and explaining what it meant to you. That explanation can form the bulk of your figure caption.

Insert figure here.

Final (post-lab) Questions

1. Imagine that you measure parallax angles for nearby stars and find a mean value of 0.40 ± 0.04 arcseconds, while someone else finds a value of 0.41 ± 0.08 arcseconds in a similar survey. Would you say that their technique was less precise than yours, with a larger measurement error? ( Yes / No )

If a third scientist found a value of 0.80 ± 0.04 arcseconds is the discrepancy more likely caused by systematic error or by measurement error? ( Systematic Error / Measurement Error )

2. You want to study the population of dogs in your neighborhood. Since you often take an evening walk, you collect data by walking around the block every evening for a month and taking note whenever a dog barks at you through a fence. Is your survey sample biased in any way? If so, how?

Replace this text.

3. People often confuse “causation” (where a change in one variable

*causes* a change in another) with “correlation” (where two variables vary

together in a predictable fashion). Gravity causes dropped objects to fall to the ground, but purchasing flood insurance does not make your property more likely to flood. Identify an example of causation and an example of correlation, and describe the variables involved. (You get an extra pat on the back if your variables are astronomical in nature.)

Replace this text.

Summary (300 to 500 words)

Replace this text.

Extra Credit

Replace this text.