Lab 1: Measurement Errors

Adapted from Holtzman's Intro Lab for Astr110

Purpose: to give students practice making measurements and estimating error, as an introduction to understanding measurements in science.

Materials: a ruler

Introduction

Astronomy, like all other sciences, relies on collecting good data. But what exactly does this mean? How do you know if a measurement is good or bad? What limits the quality of a measurement? In science measurements are accompanied by error bars, which quantify the extent to which the measurements can be trusted. A number without an error estimate is like a number without any units: pretty meaningless.

For example, a weight measurement would be written as: 25 ± 2 pounds. The ± 2 pounds means that the weight could really be anywhere from 23 to 27 pounds.

Section 1: Measuring the Room

We want to replace the carpet in the lab room. How would you know how much carpet to purchase? You would measure the area of the room. However, no measurement is perfect, so you want to order a little bit of extra carpet just in case. But how much extra should you order? Carpet is expensive, so you want to make sure you order a reasonable amount of extra material.

Each group will measure the area of the room and estimate the error in their measurement. For simplicity, ignore any protrusions along the walls. Just treat the room as a giant rectangle with smooth, straight sides.

This activity is intentionally a simple one. The point here isn't to learn how to calculate an area, which most people already know how to do, but to learn about measurement errors. Focus on thinking about how to estimate the errors in your measurements and how this translates into an error in your final answer. Quantitatively, how good is your measurement of the area of the room? How much can you trust it? How would you take this into account if you were going to buy carpet for the room? How much extra carpet would you buy, since you know that your measurement isn't absolutely perfect?

For all calculations, be sure to show all of your work. Not only is this good practice, it will also help you get partial credit if you make a mistake.

For all answers, be sure to write units. An answer without a unit is meaningless in science.

Step 1: Measure the length of the room, and estimate the amount of error in your measurement. That is, how much do you trust your measurement? Is it good to the nearest meter, centimeter, 1/3 of a centimeter? As an example, if you measured the length of a wall to be a 100 cm, but only trusted your measurement to the nearest centimeter, you would record the wall length as:

$$100 \pm 1 \text{ cm}$$

In this example, the wall is 100 cm long, give or take a centimeter. Due to the limitations of your ruler, the wall could be as long as 101 cm or only 99 cm.

Q1.1: Length of room (3pts): _____ ± ______

Step 2: Similarly, measure the width of the room, and estimate the amount of error in your measurement.

Q1.2: Width of room (3pts): _____ ± ______

Step 3: Calculate the area of the room by multiplying the length by the width.

Q1.3: Area of room (4pts): _____

Step 4: You estimated errors in your wall length measurements. Somehow we need to use these numbers to estimate the error in the area of the room.

1. Taking into account the errors you wrote down in Steps 1 and 2, what is the largest area that the room could possibly have? [Hint: This number should be larger than your answer to Step 3.]

Q1.4: Largest area of room possible (3pts): _____

2. Similarly, what is the smallest area that the room could possibly have? [Hint: This number should be smaller than your answer to Step 3.]

Q1.5: Smallest area of room possible (3pts): _____

3. You've now determined a range of values that represent the area of the room. We want to express the area as a value plus/minus an error. To do this, subtract the maximum and minimum area, and then divide your answer in half:

   estimated error in the area = (maximum area – minimum area)/2

Q1.6: Estimated error in area of room (5pts): _____

Step 5: Write your final answer for the area of the room, complete with an error estimate. Don't forget to include units!

Q1.7: Area of room (6pts): _____ ± ______

When you are finished, write your results (length, width, area) on the board at the front of the room. Remember to include error and units. Once all groups have calculated an area and estimated an error for the area, your TA will lead a discussion about the results.

Q1.8 (3pts): How much carpet should be ordered, based on everyone's results?

Q1.9 (3pts): Should only one group's measurements be used? Should an average be used?

Q1.10 (3pts): The TA will make a plot of all the area measurements on the board, including error bars. Are all the measurements the same? Is there a spread around a particular value?

Section 2: An example in Astronomy

Estimating the area of the room might seem trivial, but the ability to estimate the error in a measurement is vital to astronomy, as this next example will show.

In an effort to observe the faintest galaxies, astronomers pointed the Hubble Space Telescope at a small dark patch of sky for 10 entire days. The resulting image is the Hubble Deep Field, part of which is shown to the right: every one of the objects is a distant galaxy.

Astronomers would love to get such images of the entire sky, but it would take millions of years of observing to do that! How can we take a census of the whole sky? We can assume that one patch of sky is much like another and generalize what we learn from the Hubble Deep Field.

Astronomers want to survey how many galaxies there are and have asked your help in counting the number of galaxies in the image. However, just as you needed to record an error when you measured the size of the room, you need to include an error in your galaxy counts. To get some idea of the measurement uncertainty, have everyone in your group count the number of galaxies in the image and record the totals in the space below.

Q2.1 (2pts): Number of galaxies: ____________________________________

Just as you did when you measured the room, you can use the highest and lowest measurements to estimate the error:

estimated error in the galaxy count = (highest count – lowest count)/2

Q2.2 (3pts): Estimated error in galaxy counts: ________

Now that you can estimate the error, you are set to give your galaxy count to the astronomers, who are eager for your result.

Q2.3 (4pts): **Total number of galaxies in Hubble Deep Field ________ ± ________**

The astronomers tell you that it would take 1×10^9 of these images to cover the sky. If you assume this image represents an average patch of sky, use your estimate of the total number galaxies in the image to estimate the total number of galaxies in the sky.

Q2.4 (2pts): **Number of galaxies in the sky ________**

Again, that number really should have an error estimation. Assume that the highest number of galaxies that you could have counted in the Hubble Deep Field image is your estimate plus the error, and that the lowest number is your estimate minus the error. Calculate what the highest and lowest values for the total number of galaxies in the sky could be.

Q2.6 (2pts): **Highest number of galaxies in the sky ________**

Q2.7 (2pts): **Lowest number of galaxies in the sky ________**

You can estimate your error in the total number of galaxies in the sky.

estimated error in the number of galaxies in the sky =

(highest number – lowest number)/2

Now, write your estimate of the total galaxies in the sky along with your error.

Q2.8 (4pts): **Number of galaxies in the sky ________ ± ________**

Section 3: Comparing estimates with error

Two astronomers measure the mass of a galaxy using two different methods. The first measures the rotation speed of the galaxy and calculates how much mass would have to cause that rotation. The second measures how much the mass of the galaxy distorts and 'lenses' light from background objects. Both astronomers compare their values at a bar later that week: the first astronomer calculated a mass of $(6 \pm 2) \times 10^{12} M_{sun}$, and the second a mass of $(5.2 \pm 1.5) \times 10^{12} M_{sun}$.

Q3.1 (5pts): Do both estimates agree with each other *within error*? Should the astronomers share a drink in celebration that they arrived at the same number through different techniques or argue which technique is correct?

A classmate tells you about an article about astronomers studying a dead star in a binary system, where it is orbited by a star like our Sun. By studying the motion of the Sun-like star, astronomers determined that the dead star has a mass of $3 \pm 1 M_{sun}$. The article explains that neutron stars usually have a mass of 2 M_{sun} and black holes usually have a mass of 3 M_{sun} and greater. Your classmate goes on to say that they think the dead star is a black hole.

Q3.2 (5pts): Do you agree with your classmate that the dead star is a black hole, do you argue that it is a neutron star, or do you think you cannot tell what the dead star is? Explain your reasoning.

Summary (35 pts)

Answer the following questions in complete sentences, using correct grammar and spelling. Your summary should be no less than 1 page long, double spaced, 12 point font, without weird (like 1.5" margins).

- Why should every answer you write in this class have units? **(5 pts)**

- What was the largest source of error when you measured the classroom? That is, what would make another group measure a different size? **(5 pts)**

- What would help reduce the error in your measurement of the classroom? How about when you counted galaxies in the Hubble Deep field? (**5 pts**)

- How many observatory sheets must you bring to campus observatory, and when is the last day of the first half to go? **(8 pts)**

- Plagiarism is mentioned in the course syllabus. Which situations below would be considered plagiarism and why? **(10 pts)**

    a. A student quotes a sentence from a NASA website, citing the website.
    b. A student copies specific facts from the lab manual, without citing it.
    c. A student copies their whole writeup from a NASA website, citing the website.
    d. A student paraphrases information from a website, without citing it.
    e. A student states that sun is yellow, without stating a source.
    f. A student learns from Wikipedia that the Milky Way galaxy is classified as an SBc galaxy, and cites it.
    g. A student copies a paragraph from a website, changes the wording a bit, and doesn't cite the website.

- What would you most like to learn in this course? For example, would you want to learn how stars are born, what our galaxy is like, the shapes of a few constellations? **(1 pt)**

- Have you ever taken a course with a lab component? **(1 pt)**