Lab 2: Measurement and the Height of Pupin

1 Accuracy, Precision, & Bias

A fundamental activity in science is the testing and falsification of theories for how the world works. As scientists, we compare theories against data collected from experiments or observations of the natural world. In astronomy, observations are often quantitative measurements (e.g., how much energy does the Sun output in one second?) to be compared with predictions from mathematical theories (if the Sun fuses X amount of hydrogen per second, it should emit Y joules per second).

Repeating an observation several times often gives several slightly different results, even with the same method. The situation is even more confusing when different techniques give quite different results for the same quantity. How does a scientist determine which is the "real" answer, or whether their set of varying measurements for a quantity agree with a predicted value? This lab gives you a chance to explore these questions while performing your own measurements. A few useful definitions:

Precision: how close a measurement is to other measurements performed the same way.

Accuracy: how close a measurement is to the "true" value. A collection of measurements is called **biased** if they are all inaccurate in the same way.

Example: Let's say you measure the distance between two points several times and get 2.15cm, 2.10cm, 2.11cm, 2.20cm, and 2.13cm. We might choose the average value 2.14cm as our estimate of the true distance. The most discrepant measurement from the average was 2.20cm. This differs from the average by 0.6cm, so we might say the **precision** of our measurement is 0.6cm. There are other ways to calculate the precision of a measurement, so it's important to specify how you determined precision when you report a value.

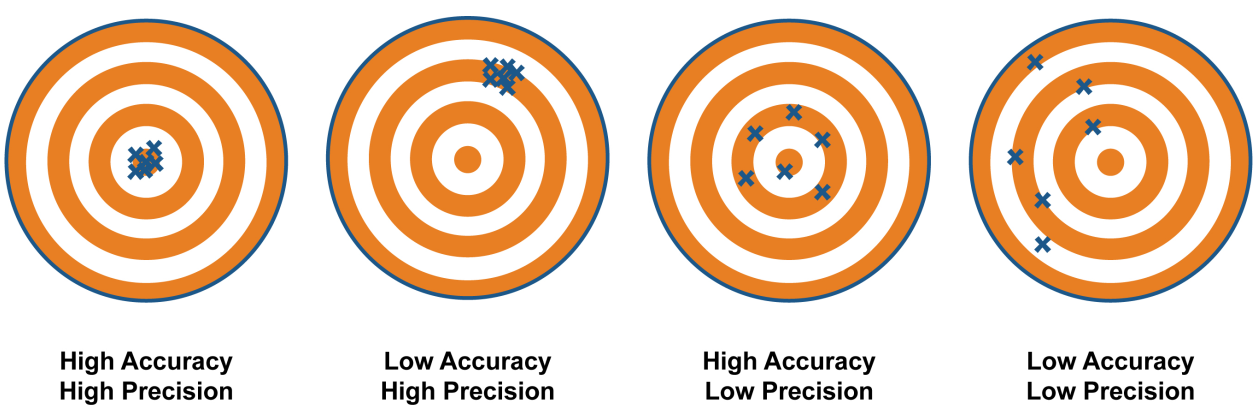

Figure 1: "Measurements" of varying accuracy and precision. Credit: A. Keller.

Now let's say that the ruler we used was poorly manufactured, and the true distance was 3cm. We would then say that the **accuracy** of the measurement was only 0.86cm. This ruler introduced a **bias** into our data. Note that it is sometimes impossible to know how accurate a measurement is, since all you have to compare it with may be other measurements, which are all slightly flawed.

Discuss the following as a group and **answer briefly in your notebook**.

1. How would you define the word *experiment* (noun)? How does an experiment differ from a measurement?
2. Measurement uncertainty is sometimes broken down into "random" and "systematic" uncertainty. How would you define random and systematic uncertainty? Relate these terms to accuracy, precision, and bias as defined above.

2 Repeatable Measurements

Let's measure how long it takes for an object to fall some distance in the Earth's gravitational field. An object with initial velocity v_i that experiences acceleration a will travel a distance

$$x = v_i \times t \ + \ \frac{1}{2} a \times t^2 \tag{1}$$

over a time duration t. At Earth's surface, the gravitational acceleration g is 9.8 m/s^2. Note that $v_i = 0$ if you are just dropping the object.

1. With your group, select an object and height from which you'll drop that object. **Measure the height and report it in your lab notebook.** How precisely can you measure this distance?
2. Before you start measuring, it's always good to estimate what value you expect to get. Use the distance equation to calculate how long your object should take to hit the floor once dropped. **Show your work.**
3. Think about any problems you might encounter, or how your experimental design (e.g., choice of object, height) will affect your results. **Do you think your measurements will differ from your theoretical expectation? Why or why not?**
4. **Now use a stopwatch to time an object falling from whatever height you picked. Repeat this measurement ten times**. The best way to present this is in a table. Remember to label columns and rows, and to report units, so that someone who was not present in our lab could understand what was done.

5. The stopwatch you used is probably precise to a hundredth of a second, but your measurements should be spread out over a larger range of values. **What different effects are contributing to the uncertainty in your measurement? How big is each effect?**

6. **Report the average of your measurements and error on your average** (subtract the absolute value of the distance from Question 2 from the average). **Show your work!** You can throw out measurements that you know are bogus, but be sure to justify it if you do.

7. **As a group, report a numerical uncertainty for your measurements.** To keep it simple, the uncertainty can be calculated by subtracting the average from the highest and lowest value. Use whichever gives a larger uncertainty.

8. **Do your measurements agree or disagree with your theoretical expectation for the free-fall time? Explain.** You might visualize your measurements in some way to help make your case.

3 Measuring the height of Pupin

Design an experiment

8. As a group, come up with (at least) two methods of measuring the height of Pupin from 5th floor to roof, and **record the procedure for each in your notebook. Which methods do you expect to work best and worst? Why? How will you determine the precision of your measurements?** Show your methods to your lab instructor before proceeding.

Make your measurement

9. Once you have your instructor's approval, go measure the height of Pupin Hall! Repeat your experiment five times. **Determine a single value for the height of Pupin and the precision of that measurement.** After everyone has made their measurements we'll compare techniques and results.

4 Conclusion

10. Which technique do you think worked best, and why?

11. How did you decide which technique worked best?

12. What were your favorite and least favorite parts of this lab?