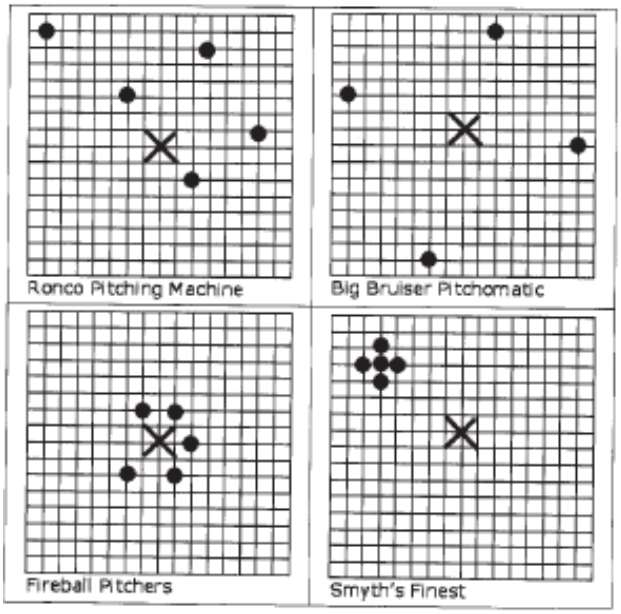
Unit 1: Pendulum for Pros

Pre-Lab Activity I (Due the day before your lab section meets during the first week of the lab at 11:59pm):

1. You arrive home after your first lab and say to your friend, "Today was the best day of my life! I did a really interesting experiment in physics! The fun part was comparing my measurements with those of the other students in the class." Your friend looks puzzled and asks, "What is an experiment?"
    a. What do you say to your friend?
    b. Your friend wants to find out more, and asks, "What do you mean by a 'measurement'?" What explanation do you give to your friend?
2. Your lab partners are in an argument over the mass of a cart that you're using in the physics lab. One lab partner is convinced that the cart's mass is $m = 503.1 \pm 0.1g$. However, your other lab partner argues that the mass is $m = 502.4 \pm 0.6g$. Your TA is kicking you out since your lab period is ending, so there's no more time to take additional measurements of the cart's mass. How are you going to reconcile their argument? Explain your reasoning.
3. How do you know if an experimental result is acceptable or trustworthy? What gives you confidence that your data are trustworthy?
4. Below are four grids showing the results of four different pitching machines. The X represents the target and the black dots represent where different pitches landed after aiming for the target. How could you quantify the reliability of each machine? Provide at least three different ways.



Pre-Lab Activity II (Due the day before your lab section during the second week of the lab at 11:59pm):

1. An experimenter measured the period of the pendulum at 10 and 20 degrees using the same timer that you used in lab. All measurements are of a single period taken from the lowest point in the swing, and the experimenter was careful when setting up and releasing the bob. The experimenter conducted 14 trials for each degree and location combination and recorded the time in seconds for the pendulum to complete one period. Using their data, compare the period of the pendulum at 10 degrees and 20 degrees.

Trial	10 deg.	20 deg.
1	1.23	1.27
2	1.36	1.35
3	1.35	1.38
4	1.36	1.27
5	1.30	1.33
6	1.27	1.33
7	1.30	1.26
8	1.32	1.26
9	1.26	1.36
10	1.26	1.27
11	1.38	1.29
12	1.29	1.24
13	1.29	1.29
14	1.32	1.32

    a. Describe the decisions you make to compare the periods.
    b. Describe at least two new ways to improve the provided measurements.
    c. Discuss how you plan to improve your own results during this week's lab period and describe why you chose that plan.
2. In class, we discussed standard deviation and standard uncertainty in the mean. We concluded that the standard deviation can be used as a measure of the uncertainty in a single timing measurement and that the standard uncertainty in the mean can be used as the uncertainty in the average of several timing measurements. In some situations, though, we might attribute the uncertainty to the rounding of the last readable digit of the measuring tool (the "rounding uncertainty").
    a. Why did we use the standard deviation as a measure of the uncertainty in the single timing measurements rather than the rounding uncertainty on the timers themselves?
    b. When do you think rounding uncertainty is an appropriate measure of the uncertainty?
    c. When do you think standard deviation or standard uncertainty are appropriate measures of the uncertainty?
3. Reflect on your findings and process from last week.
    a. What new questions do you have as a result of your investigation?
    b. Describe and justify at least two new ways that you can improve your measurements next time.
    c. Some students found that the period of the pendulum is different at 10 and 20 degrees. What are three possible explanations that could explain such results? We'll discuss these in the next lab.

Unit 1: Model testing

Objectives:

By the end of these activities, you should be able to:

2.b) i, ii, iii. Identify and distinguish possible sources of uncertainty, instrumental precision, and systematic effects and determine how to quantify those sources of uncertainty.

1.b) i. Decide how much data to collect to obtain desired uncertainty or range, and determine ways to reduce sources of uncertainty, systematics, or mistakes.

2.c) Compare pairs of measurements by determining the degree to which uncertain measurements are distinguishable.

3.a) Draw appropriate inferences from analyses conducted.

3.b) If data do not come out as expected, test whether the results are repeatable or reproducible under the same conditions or improved precision, or design new experiments/tests to explore other explanations for the disagreement.

3.c) If data come out as expected test whether the results hold with higher levels of accuracy and precision, or extend the scope of the experiment to check if there is "new" physics at these levels.

4.a) Describe the experimental goals, process, data, results, and conclusions in a lab notebook including justifications for all decisions made, and supplementing, rather than replacing content when changes are made.

What goes in my lab notes?

Think of your lab notes as a stream of consciousness. They should be quick notes that tell your TA what you were doing and why you were doing it at several time points throughout the lab. They should NOT be formal descriptions of your methods and procedures. They should be bullet points. They should NEVER be crossed out or deleted – only added to and extended. You should try to update them throughout the lab – don't leave it to the end!

Activity I: Introduction to Measurement

Whenever we collect data, it's always important to make sense of the data. There are a lot of ways and tools to do this. Today, we're going to talk about making sense of data through comparisons. First, let's get some data to play with.

A. Reliability and systematics

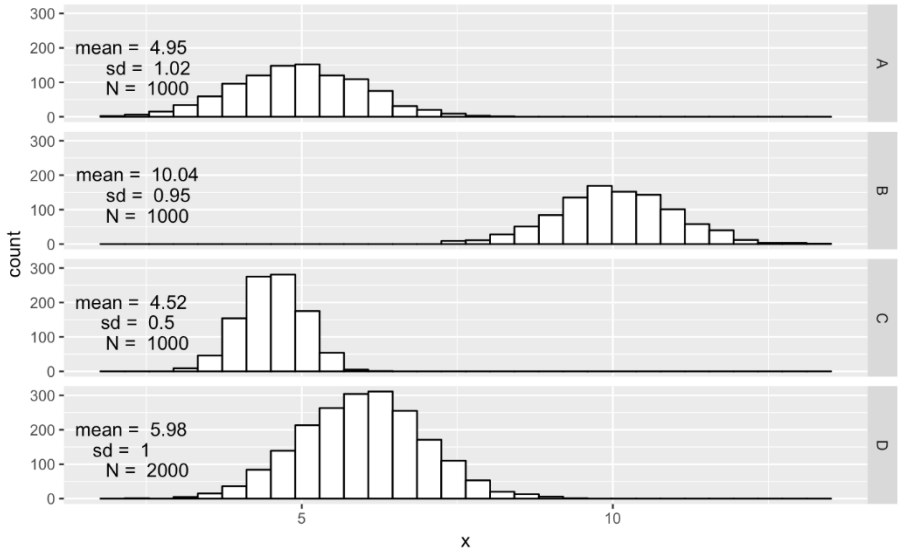
When timing the period of a pendulum, we could start the stopwatch at various times along its path. Does it make a difference? We'll test whether it's a) more reliable and b) systematically different to start and stop the stopwatch when the pendulum is at its *highest* position versus its *lowest* position.

Your instructor will get a pendulum swinging. Measure the period of the same pendulum by recording the time for the pendulum bob to move through a single period starting from its *highest* position and from its *lowest* position (whichever order!).

Record your measurements for the period on the board.

B. Inventing comparisons

We will try to invent several ways to **quantify the reliability** of the measurements and **quantitatively compare** the two sets of measurements of the period of the pendulum to find out how **distinguishable** (or different) they are. Consider the following contrasting cases to help you in your investigation.



Before coming up with a solution, qualitatively **rank the reliability of each of the cases** provided by your instructor and explain your ranking. Then, qualitatively rank the **distinguishability** of each pair of cases and explain your ranking.

Come up with at least **two different ways** of quantifying reliability of and three different ways of quantifying the difference between the measurements.

"What goes in my lab notes?" reminder:

You should have a couple bullet points that briefly summarize the ideas from Activity I.

Activity II: Investigating Period of a Pendulum

The goal of this activity is to evaluate whether the period of a pendulum depends on the angle of amplitude of the swing. The model that we're testing is:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

This model assumes that:

- The only forces on the pendulum are due to gravity and tension in the string.
- The pendulum string is massless.
- The initial angle of amplitude is small.
- The pendulum bob behaves like a point mass.

A. Initial investigation

Write down a plan for a high-precision measurement of the period of a pendulum at amplitudes of **10° and 20°.**

- What are the main sources of uncertainty in the measurement? **Rank them** based on how big their effect is likely to be on your measurements.
- Include a clear description of how you will determine and minimize the uncertainty in your measurements.
- Use the earlier discussion and data collected to inform your decisions.

Carry out your plan to measure and compare the period of the pendulum at 10 and 20 degrees using the methods discussed in Activity I. What does the comparison suggest?

B. Revised and improved investigation

Based on your interpretation of your initial data set, develop a plan for improving the quality of your investigation and jot down your notes in your lab notebook.

- Discuss your results and your plan with other groups.
- If you get some good ideas and feedback from the discussion, record changes to your plan in your notes.
- Your notes should include a short discussion about **why** you chose that method.

Perform your revised measurements and analysis:

- Compare your measurements and evaluate whether your improved measurement plan led to actual improved measurements (e.g. are your uncertainties in your measurements smaller this time?).
- Describe the best ways you can reduce the uncertainty in the measurement of the period of a pendulum by comparing the measurements and methods of other groups.

Keep repeating this cycle of comparing and improving until you are confident with your results. Describe how your ideas about whether the period depends on amplitude changed or evolved during the lab and provide evidence to support your conclusion.

"What goes in my lab notes?" reminder:

You should have many bullet points that summarize all the different methods you've tried, why you tried them, and what you found from each one. Each new experiment should follow logically from the previous ones.

Activity III: Extend the Investigation

To really test models, we have to push them to their limits. Your instructor will lead a discussion about possible other explanations of the data from this lab. The rest of the lab will involve designing and carrying out experiments to test these explanations.

An important thing to consider as you design your experiment is:

- What evidence will you need to make a convincing argument one way or another?
- What quality of uncertainty will you need and how can you achieve it?
- What comparisons between data can you make?

As with the last activity, after coming up with and testing an initial plan, evaluate your data and find a way to improve based on your comparisons. Record your decisions in your lab notebook.

The goal, by the end of the lab, is to have confidence in an explanation for why (or whether) the periods of the pendulum were different that is supported by evidence. This can also involve evidence that shows that an explanation is not correct, which can often be more powerful than evidence that supports an explanation.

"What goes in my lab notes?" reminder:

You should have a quick summary of what you and others in the class found originally, which explanation you tested, and how you tested it (stream of consciousness, not lab report). You should also have your data and interpretations of those data, including whether other groups' results supported or disagreed with yours. Any other musings on the nature of science or pendulums are acceptable.