

✓ Periods of a Pendulum -- Session II

✓ Learning goals

By the end of this unit (Lab 1.1 & Lab 1.2), you should be able to:

- Design an experiment with sufficiently high precision to test a model, finding efficient and effective ways to reduce uncertainty.
- Identify and quantify sources of uncertainty in data.
- Compare pairs of measurements based on their uncertainties and use those comparisons to make appropriate inferences.
- Iterate on an experimental procedure to reduce *uncertainty*, test assumptions and claims, and extend the investigation to explore the phenomenon.

✓ Setup the Notebook

To use the functions that you'll need to analyze your data, you will have to load the `utilities.ipynb` file as you did last week. Run the code cells below.

```
1 #start up
2
3 from google.colab import drive
4 drive.mount('/content/drive')
5
```

Fill in the "..." in the code cell below with the directory information where your utilities file is located on your Drive. Then run the code cell.

```
1 %run "/content/drive/My Drive/Colab Notebooks/utilities.ipynb"
```

✓ Session II: Model testing

In Session I, you came up with the most precise methods to measure the period of a pendulum.

By the end of today's lab, you will present to your TA your claim and evidence about whether the period of the pendulum depends on the amplitude of the swing.

You may have previously seen the equation $T = 2\pi\sqrt{\frac{L}{g}}$, which relates the period of the pendulum to its length L and assumes, among other things, 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, and
- the pendulum bob behaves like a point mass.

This equation and its assumptions form part of a **model**--a simplified representation of physical behavior that **describes, explains, and predicts** a physical system under certain conditions such as those as stated above. The key to the simplification, however, is that all models have limitations.

✓ A. Comparing measurements

To start to build our evidence base, use your method for precisely measuring pendulum periods from Session I to **quickly** collect measurements of the period of your pendulum when released from two angles of amplitude: 10° and 20° .

Record and summarize those data using the code cells below.

[your method briefly described here]

```
1 # Input the raw data for your measurements of the period of a pendulum using your precise measurement method
2 periods_ten = np.array([...])
3 periods_twenty = np.array([...])
4
```

```

5 #Calculate the mean, standard deviation, and standard uncertainty of the mean
6 mean_periods_ten=np.mean(periods_ten)
7 sd_periods_ten=standard_deviation(periods_ten)
8 su_periods_ten=standard_unc_of_mean(periods_ten)
9
10 mean_periods_twenty=np.mean(periods_twenty)
11 sd_periods_twenty=standard_deviation(periods_twenty)
12 su_periods_twenty=standard_unc_of_mean(periods_twenty)

```

Run the code cell below to calculate the t' value to compare the period of the pendulum when released from these two amplitudes.

```

1 t_first = t_prime(mean_periods_ten, su_periods_ten, mean_periods_twenty, su_periods_twenty)
2
3 print("First set of results:")
4
5 print("Ten degrees: Mean = " + str("%.3f" % mean_periods_ten) + " s; Standard Deviation = " + str("%.3f" % sd_periods_ten)
6
7 print("Twenty degrees: Mean = " + str("%.3f" % mean_periods_twenty) + " s; Standard Deviation = " + str("%.3f" % sd_periods
8
9 print("t-prime = " + str("%.3f" % t_first))

```

Q. What are some plausible explanations for why your measurements yielded this t' value? Come up with as many as you can think of! Try thinking mechanistically and physically -- thinking outside the box is highly encouraged!

[your response here]

Q. Given the goal to determine whether the period of the pendulum depends on the angle of amplitude, what are some reasonable next steps based on your t' value?

[your response here]

▼ B. Next steps

Depending on your t' value above, one or more next steps may be more logical.

For example, a small t' value means that you cannot distinguish the two sets of measurements, which may mean that the period does not differ between the amplitudes of 10° and 20° . To test this claim, you may want to measure the period from other amplitudes to build a stronger evidence base. Alternatively, the result may mean that your precision is not good enough to distinguish a difference that actually exists. To test this claim, you may want to find a way to further reduce your uncertainty and see if the effect persists.

A large (greater than 3) t' value means that you can distinguish the two sets of measurements, which may mean that we have violated the assumption that the amplitude is "small." To test this claim, you may want to measure the period from other amplitudes (smaller and bigger) to better understand what counts as "small" amplitudes. Alternatively, the result may mean that some other variable is causing these measurements to differ, such as air resistance, friction in the pivot, or some kind of mistake. To test this claim, you may want to find a way to control that other variable and see if the effect persists.

Q. With your group, decide on a claim that you wish to test that follows logically from your t' value. Briefly describe what claim you are testing, evidence for that claim, and how you will test the claim.

[your response here]

Hold a mini-conference with another group where you each

- present your claim, evidence for that claim, and how you will test the claim and
- give each other feedback on whether you are convinced of their claim and whether their experiment makes sense to systematically test the claim.

When evaluating the other group's ideas, try to be a "constructively critical reviewer": come up with alternative explanations for their evidence or ways that the results of their experiment may not effectively test the claim (e.g., the same result could support multiple explanations).

Q. Briefly describe that mini-conference, including any changes to your proposed design.

[Your list of feasible experiments here]

Q. Work with your group to carry out your investigation. Document:

- a clear description of the measurement method,
- your raw data, calculated means, standard deviations, and standard uncertainty in the means, and the associated t' values between the measurements, as appropriate, and
- your interpretation of your results and appropriate next steps.

[Your methods here]

```
1 # your analysis here
2
```

[Your interpretation and next steps here]

✓ C. Iterating and improving

Q. Find another group who performed a different kind of experiment from you and exchange results and findings. Based on both your and their results, craft a new/updated claim with evidence and propose next steps to further test the claim.

[Your experimental design here]

```
1 #your analysis here
```

[Your interpretation and next steps here]

Conduct as many new experiments as you have time for, creating new text and code cells to document your methods, data/analysis, and interpretations/next steps as you go.

✓ Lab Checkout

By the end of the lab session, document below a claim about **whether the period of the pendulum depends on the angle of amplitude** and briefly summarize your evidence (from above) that supports your claim. Present your claim to your TA or (if you are out of time), they will look over these notes to evaluate your claim.

In the checkout, they will be looking for:

- Whether the claim is supported by evidence,
- Whether that evidence is sufficient, and
- Whether it is clear that you collected the data.

[Your response here]

Reminder: Submit your group's notebook by the end of **the lab session**.

- To submit, make sure all your code and text cells have been run and the output is displayed.
- Convert your .ipynb file to a PDF using the print function or using an online ipynb->PDF converter.
- Submit your PDF to Gradescope by the end of **each lab session**.
- Only one person from your group needs to submit the file, but that person needs to **add all group members to the submission in Gradescope**.

