

✓ 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:

- Identify and quantify sources of random uncertainty in data.
- Design an experiment with sufficiently high precision to test a model, finding efficient and effective ways to reduce uncertainty.
- 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.

```
#start up
```

```
from google.colab import drive
drive.mount('/content/drive')
```

 Mounted at /content/drive

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.

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

- Groups should have 2-3 sets of data from last time, corresponding to parts A, B, C of Lab 1.1
- They'll use that data for part A in this lab

- Same groups as last time!
- If they ran out of time last week, they can take more data but they have to move quickly and catch up.
- If groups shifted at all due to add/drop, just choose data from one group/person.

✓ Session II: Model testing

Continuing from Session I, today we're looking at our measurements of the period of a pendulum under different circumstances (different amplitudes). By comparing these measurements, we should be able to come up with new questions to investigate regarding the behavior of a pendulum.

A. Comparing measurements

Use your group's data from Session I to quantitatively compare the period of the pendulum when released from the two angles of amplitude 10° and 20° and answer the following questions.

What is the t' value for the comparison between *each* of your group's pairs of measurements of the period of the pendulum when released from 10° and 20° ? You should have at least two different t' values. (Recall you did at least two versions of the measurement in Session I.)

```
# Input the raw data for the first data set
ten_first = np.array([...])
twenty_first = np.array([...])
```

```
#Calculate the mean, standard deviation, and standard uncertainty of the mean
mean_ten_first = np.mean(ten_first)
```

```

sd_ten_first=standard_deviation(ten_first)
su_ten_first=standard_unc_of_mean(ten_first)

mean_twenty_first=np.mean(twenty_first)
sd_twenty_first=standard_deviation(twenty_first)
su_twenty_first=standard_unc_of_mean(twenty_first)

# Input the raw data for the second data set
ten_second = np.array([...])
twenty_second = np.array([...])

mean_ten_second=np.mean(ten_second)
sd_ten_second=standard_deviation(ten_second)
su_ten_second=standard_unc_of_mean(ten_second)

mean_twenty_second=np.mean(twenty_second)
sd_twenty_second=standard_deviation(twenty_second)
su_twenty_second=standard_unc_of_mean(twenty_second)

t_first = t_prime(mean_ten_first, su_ten_first, mean_twenty_first, su_twenty_first)
t_second = t_prime(mean_ten_second, su_ten_second, mean_twenty_second, su_twenty_second)

print("First set of results:")
print("Ten degrees: Mean = " + str("%.2f" % mean_ten_first) + " s; Standard Deviation = " + str("%.2f" % sd_t
print("Twenty degrees: Mean = " + str("%.2f" % mean_twenty_first) + " s; Standard Deviation = " + str("%.2f" %
print("t-prime = " + str("%.2f" % t_first))
print("Second set of results:")
print("Ten degrees: Mean = " + str("%.2f" % mean_ten_second) + " s; Standard Deviation = " + str("%.2f" % sd_t
print("Twenty degrees: Mean = " + str("%.2f" % mean_twenty_second) + " s; Standard Deviation = " + str("%.2f"
print("t-prime = " + str("%.2f" % t_second))

```

Change the '2' if you want more decimal places

How did the t' value change (or not) as your uncertainty changed?

[Your answer here]

Make sure their answers represent their full dataset. No cherry-picking. Emphasize that there is no correct outcome, whatever happens happens.

What are plausible ways to interpret each of your t' values?

[Your answer here]

What are some reasonable next steps or new questions based on your set of t' values?

[Your answer here]

✓ B. Pushing the limits of a model

Be here by 30 minutes in.

Today, we will consider two ways to test models by pushing them to their limits. Choose **ONE** of the activities below.

As you complete the activity below, consider ways to most efficiently make use of all your group members. You may wish to have multiple group members setting up their own pendulum to more efficiently distribute the data collection or conduct parallel investigations. This is also a good time for one of the group members to play the "skeptic" and to check in with other groups and your TA(s) about your plan.

Option 1: Reducing uncertainty.

Why would reducing measurement uncertainty help test the limits of a model?

[Your answer here]

What might reduced uncertainty tell us about the angle dependence for the pendulum period model?

[Your answer here]

They should come up with **two** different ideas, e.g.

- measure from the turning point
- measure from the bottom
- skip the first swing
- setup and test multiple similar pendulums
- many trials
- many swings per trial
- super long string

Work with your group to generate new ideas for reducing the uncertainty in your measurements. Come up with **two distinct experiments** with distinct measurement methods. Remember that different measurement methods can have different systematic uncertainties, so it is usually valuable to try to make the measurement under different conditions. Consult with other groups for additional ideas.

[Your list of feasible experiments here]

Work with your group to systematically test both measurement methods for reducing uncertainty. In each case, document:

- a clear description of the measurement method and what source of uncertainty it is expected to reduce, and
- your raw data, calculated means, standard deviations, and standard uncertainty in the means, and the associated t' values between the measurements of the period from amplitudes of 10° and 20° .

[Your methods here]

your analysis code here: copy code from the activities above or in the previous session's notebook.

Using the results of your analyses above, reflect on any conclusions you might be able to draw or any further questions that emerge.

[Your answer here]

✓ Option 2: Pushing on assumptions.

By assumptions, we mean all the things we take for granted. For example, in the case of projectile motion, we assume that the only force which acts on the projectile is gravity and that we can treat the projectile as a point object. For many objects this may be a decent assumption, but for some objects we may find that our model breaks down.

Why would pushing on assumptions of a model help test the limits of a model?

[Your answer here]

What might pushing on assumptions tell us about the angle dependence for the pendulum period model?

[Your answer here]

Work with your group to generate new ideas for pushing on assumptions surrounding the pendulum's period. Come up with **two distinct experiments** with distinct measurement methods. Remember that different measurement methods can have different systematic uncertainties, so it is usually valuable to try to make the measurement under different conditions. Consult with other

groups for additional ideas.

[Your list of feasible experiments here]

They should test two different assumptions, e.g.

- mass doesn't matter
- angle doesn't matter
- dissipative forces are negligible
- string isn't stretching during the swing

Work with your group to systematically test multiple measurement methods for pushing on model assumptions. In each case, document:

- a clear description of the measurement method and what assumption it is expected to push on, and
- your raw data, calculated means, standard deviations, and standard uncertainty in the means, and the associated t' values between the measurements of the period from amplitudes of 10° and 20° .

[Your methods here]

your analysis code here: copy code from the activities above or in the previous session's notebook.

Reflect on any patterns you see in your results between the methods used, the uncertainty in the measurements, the validity of the assumptions, and the t' values between the measurements of the period from amplitudes of 10° and 20° .

[Your answer here]

✓ C. Iterating and improving

At least 30 minutes left.

Find another group who performed a different kind of experiment from you and exchange results and findings. Based on both your and their results, design another way to improve your investigation, either by reducing uncertainty or by pushing on assumptions. Continue improving and pushing your investigation until the end of the lab period.

[Your experimental design here]

your analysis code here: copy and edit code from the activities above

Describe all your results and tentative conclusions. Make sure any claims you make are supported by quantitative evidence.

[Your response here]

What did you uncover about the period of a pendulum through your investigations in this unit? What was the most important tool or skill that you used for this investigation?

[Your response here]

- Keep them experimenting and make it clear that they are expected to have tried to use prior results to inform continued inquiry.
- If any students want to plot Period vs. Some Parameter, let them know they can do that. Just need to import matplotlib.
- Tell them to delete the markdown cells from the Option A or B that they did **not** pursue. This makes the pdf they'll submit shorter !

