

Lab 1.1

● Graded

Group

Luca Occhipinti

Jessica An

Kate Xue

...and 1 more

[✎ View or edit group](#)

Total Points

5 / 5 pts

Question 1

Score

5 / 5 pts

💬 + 5 pts Commendable use of making hypothesis, verifying it experimentally, and data interpretation. Keep it up !

1

Good!

2

Did you try and measure this ?

3

You have assumed a linear relationship between the drop in angle and number of swings, which leads to conclude that after 5 swings, there is a "significant drop in amplitude". The data obtained for mean number of swings is 4.6, which is actually pretty close to 5, indicating that the linear relationship is actually accurate. Good job !

4

Should be the time period in 's' and not 'swings'

Question assigned to the following page: [1](#)

Periods of a pendulum

Learning goals

By the end of this unit, 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.

Group organization

In this course you'll be working in groups on lab activities and related assignments. Negotiating group dynamics successfully is therefore an integral component of the course. To help you get to know each other, and to ensure effective collaboration and fairness, group members should discuss and write down the answers to the following questions in order to establish a "Partner Agreement."

Who are your Group Members and how do they prefer to be referred to (nicknames, pronouns, etc.)?

Luca Occhipinti, he/him - Jessica An, she/her - Kate Xue, she/her - Sean Whelan, he/him -

Take turns having each group member share one thing about themselves (where you're from, what you like to do outside of class, etc.). Keep going around until you've found one thing you all have in common that you expect no other group will have in common and record it below.

We all have white water bottles :D

Discuss with your partners your reasons for taking this course and what you're personally hoping to get out of it. How do your goals compare? Discuss how you can support each other's goals. Can you agree on a collective goal for the group (e.g. to ensure everyone gets an A, to have fun, to provide a physics study group). Establish your collective purpose and record it below.

Make sure everyone gets an A and has fun.

To complete each lab a number of distinct tasks will need to be completed by individual group members or collaboratively by the group as a whole. These tasks include, but are not necessarily limited to, setting up equipment, collecting data, taking notes, and performing analysis, and managing the group. The tasks each of you spend the most time on will also likely be the ones you learn the most about and grow the most in your ability to perform. How will you ensure each member has an equitable role and is able to be involved in all aspects of the work they're interested?

We will assign responsibilities beforehand to each member so that we can all agree to work on the tasks we want to work on and evenly distribute the work.

Question assigned to the following page: [1](#)

In []:

Set up

Click on the Code Cell below, fill in the "." as per the instruction and then run the code cell (shift-enter).

In [3]:

```
#start up

from google.colab import drive
drive.mount('/content/drive', force_remount=True)

#Fill in the "." with the directory information where your utilities file is located o
#%run "/content/drive/My Drive/Colab Notebooks/utilities.ipynb"

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

Mounted at /content/drive

Note: If you are working in Jupyter Notebook, rather than Google Colab, replace the code cell above with just the single line:

```
%run ./utilities.ipynb
```

Make sure you have the utilities.ipynb downloaded and save in the same directory this file is in.

Session I: Understanding our measurements

The focus of this unit is to evaluate whether the period of a 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. Evaluating data

Set up a pendulum apparatus with your group and, using an amplitude of 10° , make about ten measurements of the time it takes the pendulum to go through **a single period**. Utilize all group members to collect these data quickly (i.e., have everyone simultaneously measure the time with their own stopwatch). Conduct another 10 measurements of the period from an amplitude of 20° .

In the following Code cells, record your ten measurements for the periods released from both amplitudes (ten.initial and twenty.initial). Each measurement should be separated by a comma, for example, if you made the following three measurements for the 10° amplitude: 10 s, 2 s, and 20 s, the code would be:

Question assigned to the following page: [1](#)

```
ten.initial=np.array([10,2,20])
```

```
In [4]: ten_initial = np.array([1.56, 1.46, 1.8, 1.46, 1.85, 1.26, 1.53, 1.43, 1.65, 1.35])
twenty_initial = np.array([1.48, 1.38, 1.6, 1.43, 1.63, 1.36, 1.38, 1.45, 1.65, 1.61])

print("Data for ten:")
print(ten_initial)

print("Data for twenty:")
print(twenty_initial)
```

```
Data for ten:
[1.56 1.46 1.8  1.46 1.85 1.26 1.53 1.43 1.65 1.35]
Data for twenty:
[1.48 1.38 1.6  1.43 1.63 1.36 1.38 1.45 1.65 1.61]
```

The quality of a measurement can be evaluated based on its uncertainty. Uncertainty is unavoidable when making measurements, so we need to identify and estimate uncertainties as part of any measurement process.

We use the term **uncertainty** to refer to inevitable limitations in measurements associated with the methods or tools we use to make measurements. Uncertainty should not be confused with **an error**--a mistake that should have been avoided or fixed. **Human error**, although commonly used, is incredibly vague. Don't use it. Instead, be specific. **If a human made an error, fix it.**

In a new text cell below, list as many factors as you can that may have caused the variability in your measurements of the period of a pendulum. Then, roughly rank them based on how large you expect their impact to be on your measurements. Briefly explain your reasoning (about one sentence).

[1. Reaction time 2. Not releasing the bob in a linear way, and instead giving it some motion in a third dimension. 3. Friction in the top of the pendulum. 4. Inability to see when the pendulum reached the maximum; We believe that reaction time - from seeing the ball released to pressing start and from seeing ball finish its motion to pressing stop - was the biggest cause of uncertainty. Additionally, we believe that releasing the bob not exactly in a straight line - introducing circular/3D motion - affected the period greatly. Furthermore, the friction in the pivot of the pendulum contributed to the uncertainty.]

Run the code cell below to calculate the mean, standard deviation, and standard uncertainty in the mean of your measurements of the period from each amplitude.

```
In [5]: mean_ten_initial=np.mean(ten_initial)
sd_ten_initial=standard_deviation(ten_initial)
su_ten_initial=standard_unc_of_mean(ten_initial)

mean_twenty_initial=np.mean(twenty_initial)
sd_twenty_initial=standard_deviation(twenty_initial)
su_twenty_initial=standard_unc_of_mean(twenty_initial)

print("Ten degrees: Mean = " + str("%.2f" % mean_ten_initial) + " s; Standard Deviation
print("Twenty degrees: Mean = " + str("%.2f" % mean_twenty_initial) + " s; Standard Devi
```

```
Ten degrees: Mean = 1.53 s; Standard Deviation = 0.19 s; Standard Uncertainty in the Mean = 0.06 s
Twenty degrees: Mean = 1.50 s; Standard Deviation = 0.11 s; Standard Uncertainty in the Mean = 0.04 s
```

Typical reaction time uncertainty is about 0.1 s and most stopwatches are precise to 0.01 s.

Question assigned to the following page: [1](#)

Is your standard deviation (the uncertainty in each measurement of the period) closer to the reaction time uncertainty or the stopwatch precision? Comment on what this might mean regarding the physical sources of uncertainty in your measurements (speculate!).

[Our standard deviation is far closer to the reaction time uncertainty than the stopwatch precision. This indicates that the physical sources of uncertainty - our reaction time - had a the greatest impact on the uncertainty of our data.]

Design multiple ways you could minimize the uncertainty in your measurements **with the equipment available to you here in the lab**. Briefly explain your reasoning.

[If the same person was releasing the pendulum as taking the time so that the start time is better synced up with the time the pendulum is released. Another way to reduce uncertainty is to take the measurement of a greater amount of periods - for example, 10, and divide to get the average time per period. Use a level to make sure the bob starts perpendicular to the table.]

B. Reducing uncertainty

Today, we will first consider two ways to reduce measurement uncertainty. Choose ONE of the activities below:

Option 1: Increasing the number of swings.

Why might measuring five consecutive pendulum swings in a single measurement trial reduce the uncertainty on your estimate of the period as compared to an estimate from five measurement trials of single swings?

[Every time you stop and start the stopwatch you add about 0.1 second of uncertainty due to reaction time. If you stop and start the stopwatch for 5 trials, you add $10 * 0.1\text{s}$ or 1.0s of total uncertainty across the experiment. If you just take one trial with 5 swings, you stop and start the stopwatch twice during the entire experiment, resulting in a total uncertainty of 0.2s compared to 1.0s.]



Continuing the logic, measuring 20 or 50 consecutive pendulum swings should be even better. One potential issue is that the amplitude of the swing will change over time.

How many consecutive swings do you expect would lead to a noticeable change in amplitude? Provide either a guess or calculated prediction, with a brief explanation of your reasoning.

[Our group guessed that after 30 swings, the pendulum would stop moving. This means that on average, the pendulum loses about 2% of its amplitude every swing. Thus, we estimate that 5 swings would result in a 10% loss in amplitude, which corresponds to 1.5 degree when the bob is released from ten degrees to start. We defined a noticeable change in amplitude as a 1.5 degree change in the amplitude. Thus a noticeable change would occur after 5 swings. We also defined a "swing" as the motion from one maximum to the other and back (one period).]

2

Design and implement a *quick* investigation to determine at what number of consecutive swings the amplitude of the pendulum noticeably changes. Document your investigation and results.

[First, we decided on our release angle, which we defined as 10 degrees. From there, we set up a

Question assigned to the following page: [1](#)

system to help us observe the dampening in amplitude of the bob system. Our system consisted of a ruler propped up against the metal piece hanging off of the top of the protractor. This gave us a reference point to release the ball from - so it was released at exactly 10 degrees. We also used this reference line created by the ruler for comparison, so we could see how much the amplitude was changing compared to where it was released from. We also used a protractor and another ruler to exactly measure 8.5 degrees on the large protractor. In this way, when we released the ball from the initial amplitude, it would be easier to see how many swings it took for the amplitude to drop by 3 degrees (1.5 degree on each side of the amplitude). To measure the number of swings (and define what a swing is), we counted each time the bob swung from its maximum on the right to the left all the way back to the maximum on the right (one swing = one period)]

```
In [8]: # your analysis code here: copy code from the activities above
data = np.array([5,4,4,5,4,5,5,6,4,4])

mean_data=np.mean(data)
sd_data=standard_deviation(data)
su_data=standard_unc_of_mean(data)

print("Mean: " + str("%.2f" % mean_data) + " swings, Std. Dev: " + str("%.2f" % sd_data)
Mean: 4.60 swings, Std. Dev: 0.70 swings, Std. Uncertainty of the Mean: 0.22 swings

[Mean: 4.60 swings, Standard Deviation: 0.70 swings, Standard Uncertainty of the Mean: 0.22 swings]
```

Option 2: Swings versus trials

Why might measuring five consecutive pendulum swings in a single measurement trial reduce the uncertainty on your estimate of the period as compared to an estimate from five measurement trials of single swings?

[Your answer here]

How many repeated trials do you expect you need to match the uncertainty from a single measurement of five consecutive swings? Provide either a guess or calculated prediction, with a brief explanation of your reasoning.

[Your prediction and explanation here]

Design and implement a *quick* investigation to test your prediction for the number of repeated trials needed to match the uncertainty from a single measurement of five consecutive swings. Document your investigation and results.

[Your design here]

```
In [ ]: # your analysis code here: copy and edit code from the activities above
```

[Your results and findings here]

C. Iterating and improving

Question assigned to the following page: [1](#)

Using your results and those of other groups and your other ideas about how to reduce uncertainty, carry out another investigation to precisely measure the periods of your pendulum from amplitude angles of 10° and 20° using what you now believe to be the **most precise, accurate, and efficient method**. You should be able to efficiently achieve an ultimate precision better than 0.005 s.

In the space below, jot down your methods and results, including:

- a clear description of how you measured the period, including any on-the-fly changes as you implemented the procedures,
- your raw data and calculated means, standard deviations, and standard uncertainties in the mean for your measurements of the period of the pendulum from amplitudes of 10° and 20° ,
- a qualitative evaluation of the extent to which each of your methods affected the quality of your measurements, and
- suggestions for what you could do to reduce the uncertainty further.

[Firstly, since our lab group concluded that there is a noticeable change in amplitude after about 4.6 swings, we will measure the time the pendulum takes to oscillate 4 periods, then divide by 4 to get the average period. Furthermore, we will have the same person who is releasing the pendulum measure the time so as to reduce any uncertainty caused by reaction time. Finally, we will have someone else watching to make sure that for all trials only linear motion is occurring and the pendulum is not moving into the 3D (circular motion).]

```
In [15]: # your analysis code here: copy and edit code from the activities above
data2 = np.array([1.685, 1.685, 1.680, 1.6625, 1.6675, 1.6775, 1.680, 1.6625, 1.6725, 1.6725])
data3 = np.array([6.67/4, 6.67/4, 6.65/4, 6.64/4, 6.67/4, 6.66/4, 6.65/4, 6.64/4, 6.68/4, 6.68/4])

mean_data2=np.mean(data2)
sd_data2=standard_deviation(data2)
su_data2=standard_unc_of_mean(data2)

mean_data3=np.mean(data3)
sd_data3=standard_deviation(data3)
su_data3=standard_unc_of_mean(data3)

print("Mean: " + str("%.3f" % mean_data2) + " swings, Std. Dev: " + str("%.3f" % sd_data2) + " swings, Std. Uncertainty of the Mean: " + str("%.3f" % su_data2))
print("Mean: " + str("%.3f" % mean_data3) + " swings, Std. Dev: " + str("%.3f" % sd_data3) + " swings, Std. Uncertainty of the Mean: " + str("%.3f" % su_data3))
```

Mean: 1.674 swings, Std. Dev: 0.009 swings, Std. Uncertainty of the Mean: 0.003 swings

Mean: 1.666 swings, Std. Dev: 0.005 swings, Std. Uncertainty of the Mean: 0.001 swings

10 Degrees --> Mean: 1.674 swings, Std. Dev: 0.009 swings, Std. Uncertainty of the Mean: 0.003 swings.

20 Degrees --> Mean: 1.666 swings, Std. Dev: 0.005 swings, Std. Uncertainty of the Mean: 0.001 swings

Submitting

Save your notebook with all your answers to the questions, modified code cells, and output from each code cell.

Go to File -> Print -> Print to PDF.

Submit the **PDF of your notebook** by uploading it to the Gradescope assignment. Make sure all students' names are listed at the top AND you link all students in Gradescope (ask your TA if you're not sure how to do this).

Question assigned to the following page: [1](#)

