Unit 1: Pendulum for Pros

**Course-wide Learning Goals:**

By the end of the three-course intro lab sequence, students should be able to:

1. Collect data and revise the experimental procedure iteratively, reflectively, and responsively,
2. Evaluate the process and outcomes of an experiment quantitatively and qualitatively,
3. Extend the scope of an investigation whether or not results come out as expected,
4. Communicate the process and outcomes of an experiment, and
5. Conduct an experiment collaboratively and ethically.

### Objectives:

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

* Conduct an experiment to confidently evaluate whether the angle of amplitude affects the period of a pendulum
* Identify sources of statistical uncertainty, instrumental precision, and systematic effects
* Decide what and how much data are to be gathered to produce reliable measurements given the set of concerns above
* Define and calculate the mean, standard deviation, and the standard uncertainty in the mean of a set of data
* Compare measurements with uncertainty by calculating the difference in units of uncertainty
* Propose and carry out follow-up investigations or revisions in light of the data and model, particularly to improve the reliability of the data

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| **Instructor Time Stamp: 45 min. maximum 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:

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| **Lab Instructions** | **What do you expect your students will do? List as many possibilities as you can think of.** | **How will you react and/or facilitate?** |
| 1. **Thinking about measurements**   As a class, individually 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. Record your measurement for the period on the board. Do this again, this time recording the time for the bob to move through a single period starting from its lowest position. Record this measurement as well, keeping the two data sets separate. |  |  |
| 1. **Making pictures** Work in pairs to invent a way to **graphically** **compare** the period of the pendulum in the two cases, using the data that the class collected. There is more than one way to do this, so be creative! Sketch your pictures on a board and briefly describe how you came up with the representation and what it tells you.   We will have a group discussion about everyone’s inventions. |  |  |
| 1. **Quantifying our pictures** Now that you have created a graphical representation of the pendulum data, a decision needs to be made concerning which measurement method is the most reliable (i.e., consistent). Invent a **quantitative** procedure for calculating a ‘reliability index’ for each of the methods to determine how **reliably** they measure the pendulum period.   The goal, once again, is to be creative. Write down your procedure and calculate the ‘reliability index’ for each group using the class’ data. The only rules are that:   1. You use the data collected from Part I and the graphical representations. 2. Each measurement set gets a single ‘reliability index’. 3. The same procedure must be used for each data set to determine its ‘reliability index’ and make a fair comparison. 4. A small ‘reliability index’ implies that the measurements are more reliable. |  |  |

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| **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.

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| **Lab Instructions** | **What do you expect your students will do? List as many possibilities as you can think of.** | **How will you react and/or facilitate?** |
| 1. **Initial investigation**   Write down a plan for a high-precision measurement of the period of a pendulum at amplitudes of 10 degrees and 20 degrees. Include a clear description of how you will determine the uncertainty in your measurements. Use the earlier discussion and even the 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 at the end of Activity I. What does the comparison mean or suggest? |  |  |
| 1. **Quantifying comparisons**   Now that we have a statement about the reliability of a data set and high-precision measurements of the period of a pendulum, we want to determine whether the period of the pendulum is the same at 10 degrees and 20 degrees, or if one is systematically different from the other.  Work with your group to come up with a way to **quantitatively compare** the period of the pendulum at each amplitude. Focus on inventing a method to quantify how **distinguishable** the two data sets are. To get started, come up with a list of features of the data that are important to consider in making this comparison.  Then move on to inventing a quantitative index. Here are some guiding ideas:   1. A small index should imply that the data are not very different (indistinguishable) while a large index should imply that the data are very different (distinguishable). 2. Your method should work for many data sets, not just the two we’re working with.   We will have a group discussion about everyone’s inventions. |  |  |
| You will provide these sketches on the front white board of these distributions for students to extend their quantitative comparisons to general distributions. Use these sketches to develop your responses above. |  | What additional information might your students request about this sketch? |

**By the end of Week 1, students need (at minimum) to have completed this activity and arrived at t’ for the statistic to compare two measurements. They will practice statistics in the pre-lab.**

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| **Lab Instructions** | **What do you expect your students will do? List as many possibilities as you can think of.** | **How will you react and/or facilitate?** |
| 1. **Revised and improved investigation** Based on your interpretation of your initial data set, write a plan for improving the quality of your measurements. Discuss your results and your plan with other groups. Feel free to modify your plan based on this discussion, recording in your notes any changes that you make. In your plan, include a short discussion about *why* you chose that method.   Perform your revised measurements and analysis. In addition to comparing the results at 10 and 20 degrees, evaluate whether your improved measurement plan led to improved measurements (e.g. are your uncertainties in your measurements smaller this time?).  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. |  |  |

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| **Activity III: Extend the Investigation** |

**Instructor Time Stamp: At minimum, the final 30 minutes of Week 2 should be devoted to this activity. Some students may move on earlier than others, which is okay!**

In the previous activity, you evaluated whether the period of a pendulum depended on the angle of amplitude. This week, we want to delve deeper into understanding this process.

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| **Lab Instructions** | **What do you expect your students will do? List as many possibilities as you can think of.** | **How will you react and/or facilitate?** |
| 1. **Evaluating uncertainty**   As a class, we will discuss all the different methods students used to improve their uncertainty in the previous activity. What was the main source of uncertainty in the measurement? Based on this discussion, describe the best ways you can reduce the uncertainty in the measurement of the period of a pendulum. |  |  |
| 1. **Uncertainty in the amplitude dependence**   Many students found that the period of the pendulum was different at the two angles. Work with other groups of students to come up with possible explanations for why these two measurements were different. 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 come up with a convincing argument one way or another? For example, 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 all of 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.) |  |  |

**Please review the instructor summaries on your own after going through this lab activity to ensure you are prepared for the lab. The instructor materials provide information for how to facilitate these activities as well as common issues that past students have run into.**