Labs 06 and 07: Simple Harmonic Motion Instructor Notes

Learning Objectives

- Design and conduct controlled experiments to develop mathematical models from experimental data

This is a double week lab with nothing due for two weeks! For both Labs 06 and 07 you will be expected to compile **Lab Records** *(Word file) during class and turn them in as a group through Canvas within 24 hours after your Lab 07 class. Portions of the scoring rubric, which details expectations, are provided throughout this document. This double week lab will also require the writing of an* ***individual Lab Report****. All expectations for the lab report can be found at the end of this document. The lab report is due within one week of your Lab 07 class.*

Lab Records Scoring Rubric (76 pts total)

	Excellent (2)	Limited (1)	Inadequate (0)
General Information, Neatness	1. Student names 2. Experiment name & date 3. Course and section # 4. Overall organization and neatness	A couple parameters are missing or submissions are disorganized or difficult to read.	Many parameters are missing or submissions are highly disorganized or difficult to read.

I. Design an Experiment – What impacts the period of a mass oscillating on a spring?

Consider the situation shown to the right in which a hanging mass is attached to a spring. If the mass is pulled downward and released, it will undergo periodic motion; that is, motion which repeats itself.

a. **Brainstorm**. In light of this scenario, consider the research question: *What impacts the period of a mass oscillating on a spring?* Make a list of several factors that could be changed in the lab setting and that might result in a change in the period. Record the list in your **lab records**.
Similar to pendulum: mass, spring constant, and initial amplitude.

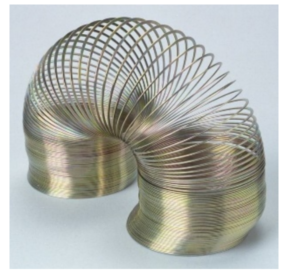
b. **Select an IV to test.** Choose one of the possible factors from your list. Design a controlled experiment to determine how the selected factor may impact the period. Use the template below to communicate the design in your **lab records**.

Experimental Design Template	
Research Question	*What impacts the period of a mass oscillating on a spring?*
Dependent variable (DV):	Period
Independent variable (IV):	One of these: mass, k, distance pulled
Control Variables (CV):	Hold mass, spring constant, or amplitude constant as well as anything else which might be considered a factor
Testable Hypothesis: (should contain IV and DV so that it is a *testable* hypothesis)	Mass affects period; spring constant affects period; Amplitude affects period

Experimental Design Template	
Prediction	As mass increases the period will also increase, etc.

Side Note

A factor your group likely included on your list is spring stiffness. There are a wide variety of springs used in everyday life applications, from the loose Slinky toy to the tight suspension springs in a car. In order to characterize the wide array of springs, it is common to talk about them in terms of their **spring constant** (k). The unit for spring constant is N/m and indicates the amount of force needed to stretch or compress a spring a certain length. Stiffer springs have larger spring constants, while less tight springs have smaller spring constants.



c. **Other details about the experiment.** Once the template is complete, details of the investigation can be planned for this factor. Given that the lab is online, you will not be able to use real equipment. However, a set of videos of various scenarios is available for your use in Canvas. Check out the collection and as a group decide which videos will be useful in addressing your hypothesis. Not all videos need to be used. Rather, make choices based on the need to provide strong evidence for any final claims. Remember that good experimental technique also involves choosing values for the IV that span the range of possible values; that is, choose values on both the low and high end as well as in the middle to fully explore any possible relationship.

Do not conduct the investigation until approved by your lab instructor!

Checkpoint 1! *Be sure your instructor checks your entire* experimental design plan before collecting data. Be sure that your group has discussed your planned procedure in term of the (1) the number of "trials" for each video and (2) range of values for the IVs (that is, which videos you will use).

Check the research design as well as the number of trials and range of data they plan to use. Review with students how to find uncertainty (which will mean they can do just one trial per video). If they plan to test distance of pull first, make sure that they read the note in section IIa about not using Tracker for this but rather using their cell phone to measure period. This will require a new uncertainty measurement of the *technique* for finding period.

Check your lab records for completeness using the rubric below:

	Excellent (2)	**Limited (1)**	**Missing (0)**
Brainstorm Factors	Lists several factors that may impact period.	Only one factor is listed.	No possible factors listed.
Experimental Set-up (only one total needed)	Includes a **screenshot** of the experimental set-up; *essential* features are included and **labeled**.	Some features and/or labels are missing.	Screenshot is missing.
Experimental Design Template (3 by lab end)	Includes a completed **design template** (contains research question, IV, DV, CV with values, hypothesis, and prediction).	A couple of the parameters are missing or provided detail is limited.	Significant number of parameters missing or include too little detail to be useful.

II. Developing a Mathematical Model

a. **Conduct the experiment.** Use Tracker, if possible*, to determine the period of the oscillating spring-mass system in the videos provided on Canvas. Detailed instructions for how to use Tracker for this purpose are included in this week's lab folder on Canvas. Record all collected data in a table in your **lab records**, using standard metric units (m, kg, s). ***If you are investigating the distance the mass is pulled down before release for its impact on the period, the mass will move too quickly in many of the videos and Tracker will not be able to take appropriate measurements. When testing this IV, use a cell phone as a stopwatch instead. Be sure to follow best practices to reduce error.**
Note: Each video opened in Tracker is opened into a new tab. At some point, Tracker will run out of memory. When this happens, right click on an individual tab below the video pane and either save or just close the tab. If you save it you can pull it up again in Tracker so that is recommended.

b. **Determine uncertainty.** The values for period will be measured using one of two *techniques*; that is, either using Tracker or using your cell phone as a stopwatch. Both techniques have uncertainty which must be determined and then included as error bars on your related graph. Use the procedures used in previous labs to determine this value. Be sure to record enough detail so someone can follow what you have done, along with all data and the resulting standard deviation (computed in Excel) in your **lab records**. Remember, you are determining the uncertainty of a *measuring technique*. This value can be used for all experiments that involve the same technique.

c. **Plot the data in Excel.** Produce the appropriate graph in Excel to address your research question. Remember that the IV is plotted on the horizontal axis and the DV on the vertical axis.

d. **Insert error bars for the x- and y-axis.** The error bars for period (y-axis) should be the uncertainty in the measurements of period determined earlier. The error bars for the x-axis should be the uncertainty of whatever is plotted on that axis. See the excel data file provided with the videos to obtain these values.

e. **Conduct a curve fit.** Use the trendline function in Excel for your graph and be sure to check off the boxes to put the equation and R^2 value on the graph. Remember that the purpose of the fit is to smooth out the random error attributed to each data point while providing a mathematical description for how the two variables under study co-vary; that is, how the DV is related to the IV. Try different fits (curves) to be sure you are selecting the one that passes through the most points. Do not make the final decision based on R^2 values alone as sometimes they are close in value and a better fit may not be the one closest to 1. If you aren't sure on this, consult with your instructor.

f. **Save all data and the graph.** These should be saved in your lab group's folder on One Drive as well as on your own computer(s). Cut and paste the data table and the graph, which includes the final selected trendline, mathematical model, and R^2, into your **lab records**.

g. **Claim, conditions, and assumptions.** Write a claim next to your graph based on what it indicates to you. Include conditions with the clam as well as your assumptions. Refer to Pre-Lab 06, if needed.

h. **Consider the mathematical model provided by Excel.** Rewrite the equation in terms of the axes from the graph; that is, replace x and y in the equations by physics variables which represent the IV and DV in your experiment. Record this new equation in your **lab records**. Include a short description about the relationship between the IV and DV as indicated by the experimental model; that is, what does the model tell you about the behavior of the system when the IV increases or decreases in value?

i. **Consider the constant(s) in the mathematical model.** Remember that the model describes a *real* system. In your **lab records**, describe what the constant(s) in the mathematical model may physically represent in terms of the lab setting. Hint: Use dimensional analysis to determine the units that the constant(s) must have for the equation to hold.

Checkpoint 2! *Have your instructor check your graph, mathematical model, and claim. While waiting for this checkpoint, check your lab records for completeness using the rubric on the next page. If time remains while waiting, jump to step j on the next page.*

Check the **mathematical model and their general conclusion** (be sure they are consistent). One of the main learning objectives of this course is for students to learn how to determine a mathematical model from a graph. If students have an incorrect model, please spend time with them to help them better learn how to do this process. Check their experimental design as well, including number of trials, range of data, etc. Recall that the main objective of the pre-lab was to give the students practice understanding experimental **assumptions** so ask them about what assumptions they are making in this experiment. One assumption is that any movement in the x-direction as the mass oscillates up and down doesn't significantly impact the vertical motion.

j. **Repeat the experiment**. Conduct a separate experiment for each remaining possible factor. Follow the previous instructions and be sure to include all necessary information in your **lab records**.
Although there is no checkpoint after the next two experiments, it wouldn't hurt to monitor students' progress to be sure they are on the correct path. Also, this is a two week lab. Students should at least get two variables tested during the first week.

Check your Lab Records for completeness using the partial rubric below:

	Excellent (4)	Limited (1-3)	Missing (0)
Data Table (3 by lab end)	Organizes **measurements** into a neat table, **labels** values, **units** included.	Some measurements are missing; labels/units missing.	Data table is missing.
Estimation of Uncertainties (for each of 2 techniques used)	1. Provides **uncertainty estimates** for each type of measurement. 2. **Describes** *how* uncertainties were determined.	Several uncertainty values or the description of how uncertainties were determined are missing.	A significant number of uncertainty values or description is missing.
Graphs with Error Bars (3 by lab end)	1. Includes **graph**; labels axes (units) 2. Includes **x and y error bars** (indicates if too small to be seen).	Labels with units are missing; some error bars are missing or are incorrect.	Graph is missing.
Trendline Equation(s)	Trendline **equation** and **R^2 value** are included on all graphs, as warranted.	Trendline equation or R^2 is missing for some graphs.	Trendline equation and R^2 are missing on graphs.
Claim, Conditions, and Assumptions (next to each of 3 graphs)	1. A **claim** about the **relationship** between the IV and DV is included next to the graph. 2. **Conditions** of claim are included. 3. **Assumptions** are included.	Claim is incorrect, conditions of claim are not included, or assumptions are missing.	Claim, conditions, and assumptions are all missing.
Mathematical Model(s)	Experimental mathematical model(s) are stated in terms of appropriate variables, with units included on all constants and coefficients.	Mathematical models are left in terms of x and y rather than appropriate variables; or units are missing.	The mathematical models are missing.
Tables and Figures are Labelled	All templates, tables, graphs, etc. are labelled using standard headers w/numbers, such as, "Fig 1. Graph of T vs Mass".	Several labels on data tables, graphs, or other figures are missing.	A significant number are missing.

III. Scientific Research Community

Scientists build on the work of others. They often include the findings of other researchers in synthesizing their own data and in generating claims. Checkpoint 3 models this process.

Class Checkpoint 3! *Each group will share their findings with the class during this checkpoint. Your instructor will show you where to type both of your experimental models into a chart on One Drive in preparation for this checkpoint. Once all groups have submitted their entry, your instructor will bring the class back together for a class discussion. If you find yourself waiting for other groups to submit their entry, check your lab records for completeness using the rubric on the next page and then start answering the questions in the next section.*

A file will be posted on One Drive that includes the grid below. Students should access the grid and fill in their line according to group number. The first row is from the Data and Analysis Instructor Excel file.

Group	Model 1	CVs for Model 1	Model 2	CVs for Model 2
1 (Kathy)	$T = (2.85\ kg^{0.5})/\sqrt{k}$	$m_{on\ spring}$ = 0.2015 kg, d_{pull}=0.05 m	$T = (2.3603\ s/kg^{0.5})\sqrt{m}$	k = 7.05 N/m, d_{pull}=0.05 m
2				
3				
4				

Lead a whole class discussion.

1. **Start the discussion around Model 1**. Discuss any similarities among the student models and reconcile, if possible, any differences. A common error is that some groups do not use Kg and m as their units. Ask the students if the resulting relationship makes physical sense.
2. **Move to Model 2.** Repeat the above for the second model.
3. **Combining Models 1 and 2.** It may be too hard for students to see how these two models can be collapsed into one model $T = 2\pi\sqrt{\frac{m}{k}}$. You may have to show them the theoretical model and then discuss with them whether or not it fits. The argument below has been cut and pasted from the Data and Analysis Instructor Excel file. Both are great matches to theory as you can see.

   Model 1: $\mathrm{T} = 2.85/\sqrt{k}$ where C = 2.85
   $\mathrm{C} = 2\pi\sqrt{m} = 2\pi\sqrt{0.2015\ kg} = 2.82$ Great match!

   Model 2: $\mathrm{T} = 2.3603\sqrt{m}$ where C = 2.3603
   $\mathrm{C} = 2\pi/\sqrt{k} = 2\pi/\sqrt{7.05\ N/m} = 2.366$

   Great match!
4. **Things to keep in mind.** Students' models will vary from what was provided in the Instructor's Excel file. The purpose of the conversation during this checkpoint is to get students to recognize that the models should be close to $T = 2\pi\sqrt{\frac{m}{k}}$.
5. **Remind students.** End this checkpoint by reminding students that they will be asked to share the models/outcomes of at least two different groups in their lab reports. They should cut and paste the completed table of all students' data into their lab records (or somewhere else is fine) so they have it for later use.

IV. Final Wrap-Up – Responses not to be included in lab records

The purpose of this double week lab was to develop experimental mathematical models to describe the behavior (period) of a mass-spring system. **The questions below provide guidance on how to synthesize your results for the discussion section of your lab report.** Your group should discuss your responses to these questions while in lab, but any notes from the discussion should be kept separate and not included in the lab records due after lab 07 (second week of the double week lab).

a. **Summarize your findings into a general claim.** Combine the findings from all experiments into a few sentences (not just an equation) that address the research question, "What affects the period of oscillation of a spring/mass system?" That is, indicate whether or not each tested IV impacts the period. For any that have an impact, describe the relationship.

   Students should be able to recognize that period decreases with increasing mass; period increases with increasing spring constant; and period is not affected by amplitude (distance of the pull).

b. **Identify conditions for your claim.** Your hypothesis was tested under certain circumstances (or conditions) and therefore your claim is valid for those conditions. State the conditions of your claim for which you know the claim holds. For example, one should always indicate the range of IV values tested since someone who tested values outside this range may have data that supports a different, or slightly different, claim. Given the nature of the online labs, you may not have much more to say for this one. The general rule of thumb is to state the testing conditions so that others investigating the same hypothesis can better compare their findings to yours.

c. **Consider the evidence that supports your claim.**
   The data collected during lab provides the evidence to justify your claim. The questions below serve as a guide for evaluating the evidence that supports your claim.

   1. Evaluate the data and any observed patterns or trends
      i. *How confident are you in the numbers obtained for each measurement?* Be sure to comment on the ranges of uncertainty (variation) for these measurements.

      ii. Explain in a few sentences how the mathematical model was determined and how it led to your claim.

      Both fits should be power law fits, $y = Ax^B$. For the mass as the IV, $A = 2\pi/\sqrt{k}$ and $B \approx -0.5$; for the spring constant, $A = 2\pi\sqrt{m}$ and $B \approx 0.5$. Students may struggle with these.

      iii. *How confident are you in the mathematical model provided by Excel?* That is, comment on how well the trendline passes through the set of plotted data points. Cite the R^2 value as well and discuss what this value indicates to you.

      Students should cite the R^2 value and indicate that values closest to 1 should provide more confidence in the suggested trend line.

      iv. Cite the claims (model(s)) from at least two other groups. Discuss how their findings support or refute your own general conclusion stated above.

   2. Connect your claim to theory or other scientific knowledge
      i. Find the theoretical equation for the period of oscillation for simple harmonic motion through Google, your textbook, or by asking your lab instructor.

$$T = 2\pi\sqrt{\frac{m}{k}}$$

ii. Discuss the similarities and differences between **each** of your experimental mathematical models and the theoretical model. Identify what may account for these differences.

The students have two mathematical models (d_{pull} should have been shown not to have an impact) and need to put them together to get the theoretical model. They may have difficulty doing this and may need some guidance here. Class Checkpoint 3 should have covered this.

iii. Consider the numerical value (coefficient) in one of your mathematical models. What does it represent according to the theoretical model? Calculate what this number should be according to the theoretical model and compare it to the value provided in the model from Excel. How do they compare? What may account for any differences? **Repeat** for your other mathematical model.

The constant should represent either $2\pi\sqrt{m}$ when k was the IV and the constant should represent $2\pi/\sqrt{k}$ when mass was the IV. Again, students may struggle with this and need some support. See Data and Analysis Instructor file for additional guidance.

d. **Suggest improvements.** If given the opportunity to repeat the investigation, either using video or actual equipment in a lab setting, what could be done to improve the collected data? You may wish to discuss flaws in your experimental design, how you might employ better controls, issues you experienced collecting data in today's lab, and so on.

This ends today's lab. There is no final checkpoint but please consult with your instructor if you have any questions or concerns. Remember to submit your **group combined lab 06 and 07 records** within 24 hours of the end of today's class. See the next page for instructions on the **individual lab report** due in one week.

Requirements for the Simple Harmonic Motion Report (done individually, submitted through Canvas)
Although most students are able to conduct reliable scientific investigations and draw reasonable conclusions, many struggle putting together a report that provides sufficient evidence that completely supports stated conclusions. Read this section carefully as it will help guide your writing. The rubric that will be used in grading your report can be found in a separate document on Canvas.

- The lab report must be a Word file smaller than 10 MB.
- It must be submitted through Canvas before your next lab class.
- The lab report must include the following three components:
  - **Cover Page** – Each lab report must have a cover page. It should include the individual student name, date of submission, course number and section, and title of the report.
  - **Part I - Discussion and Conclusion: This section is to be written individually by each student.** The details can be found at the blue arrow below.
  - **Part II – Your group's Lab Records 05 should be included at the end of your lab report.** This section should be the actual lab records already submitted by your group. It will NOT be graded as part of your lab report but you will earn points for including it. It is here so your instructor and anyone else who reads your report can look at the data tables and graphs. Rather than have you redo these for your lab report, it is much easier just to include it at the end of your individual discussion like this. Please be sure to keep all names on the lab records included here. Also, you may make small changes to this section if it will help clarify things for the grader, such as including Table or Figure numbers that were inadvertently left off when your lab records were submitted.

Requirements for Part I: Discussion and Conclusion

Many of the requirements for this section have already been discussed with your lab group, but all responses should now be written in your own words in the conversational format of a lab report. Each report, once submitted, will go through a plagiarism prevention service in Canvas. It will automatically compare your report to all other submissions in the system (this goes back years). Although Part II (lab records) will obviously show up as matching your lab partners' reports, this section should not show up that way (your instructor can check this). *Please do not copy and paste the list of requirements below into a Word file and fill it out like a worksheet. This will cause your plagiarism matching percentage to increase dramatically. Rather, write it as a thoughtful essay or argument using multiple paragraphs.*

a. **Research question.** Remind the reader what research question was investigated in this lab. Tell the reader which variables (IVs) were tested to address the research question.

b. **Evidence.** This section of the report discusses the **evidence** which supports, or even refutes, your claim. This is a multi-part discussion so be sure each is addressed in light of all IVs.

   i. Evidence (data) collected by your group

   1. Discuss how each of the experiments your group conducted led to a separate claim about a given IV. Be sure to refer to the graphs located in Part II (which should be a repeat of your combined Lab Records 06 and 07) in your discussion. Use Figure numbers on the graphs so you can refer to them by number.
   2. Discuss how each of the experiments supported essentially the same final experimental mathematical model. Be sure to let readers actually know what that model is here as well.

3. Indicate the **conditions** for which your experimental mathematical models hold.
4. Discuss how the conditions of your models limit the **generalizability** of your results.

ii. **Evidence (models) provided by other groups**

The experimental models of other groups can be used as further evidence for the validity of your model. Discuss the models of at least 2 other groups and describe how their outcomes support (or refute) your models. Be sure to cite these groups using their group number.

iii. **Scientific theory as evidence for your model**

1. State the scientifically accepted (theoretical) model for the period of an oscillating spring/mass system.
2. Discuss for the reader <u>how</u> well your experimental models fit with the same theoretical model. As part of this discussion, be sure to indicate whether or not there is consistency between the **constants** in both experimental models with the theoretical model as well as the **relationships between the variables** in these models. Even those factors that did not impact the period should be discussed here and compared to what is included in the theoretical model.

c. **Confidence in claim(s).** This section of the report should discuss for the reader the level of confidence you have in your outcomes. This is a multi-part discussion so be sure each is addressed.

i. Discuss what makes you confident, or causes you to lack confidence, in the **actual data measurements** your group collected for both experiments. Again, refer to any Tables or Graphs in Part II using their table or figure number.

ii. Discuss what makes you confident, or causes you to lack confidence, in the **trend lines or mathe-matical model provided by Excel** for each of the IVs.

iii. Discuss how the outcomes of at least **two other groups** add to or subtract from your confidence in your claim(s).

iv. Discuss how the **theoretical model** adds to or subtracts from your confidence in your claims. Be descriptive even if you feel you are slightly repeating something written earlier in the report.

v. Errors will affect your final claims and the confidence you have in them.

1. Discuss which **errors** (random and/or systematic) may have been present in the investigation.
2. For each error mentioned, discuss <u>how</u> it may have impacted your experimental models. You may refer to the theoretical model in your discussion to help you know how the error may have affected your own model.

vi. Discuss what **assumptions** were made during the experiment. Also, discuss **how** your final claim(s) would be affected if the assumptions were not true.

d. **Future Work.** Discuss how you might improve your experimental design if you were to repeat the experiment. This <u>could</u> include a discussion about how you might reduce random and/or systematic error, what other variables you might test (if warranted), what equipment you might use instead of what was provided to you, how you might extend the conditions for which your model holds, etc. Not all of these need to be included in your discussion, but rather these are provided to get you thinking about this. Be logical in this discussion as related to your own experiments rather than mention everything you can possibly think of here.

e. **Grammar usage, reference citation, and written as an essay**.

It is important to proofread your writing and to correct mistakes in spelling, grammar, and punctuation. When referencing the work of others, use the APA style. Also, as indicated earlier, the report is to be written as an essay rather than an outline or as if filling in a worksheet.