Lab 04: Force and Motion Part I   Instructor Notes

Learning Objectives

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

In Lab 03, you learned to create mathematical models from experimental data for a simple pendulum. This week you will develop mathematical models from experimental data in the study of force and motion.

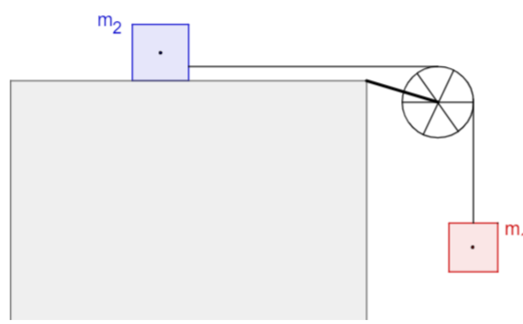
As a reminder, you will be expected to compile **Lab Records** *(Word file) created in lab this week and turned in as a group through Canvas after class. Portions of the scoring rubric, which details expectations, are provided throughout this document. The lab records must be turned in through Canvas within 24 hours from the start of lab.*

Lab Records Scoring Rubric (44 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 acceleration of a system?

Consider the situation shown to the right in which a hanging mass is attached to a block. Assume the horizontal surface to be nearly frictionless and that the string connecting the blocks doesn't stretch.



a. **Predict**. When the hanging mass is released, how do the two objects and connecting string move? Briefly describe in your **lab records** the motion of the objects relative to one another, including whether or not they undergo acceleration.

b. **Brainstorm**. In light of this scenario, consider the research question: *What impacts the acceleration of a system?* Make a list of at least two factors that could be changed in the lab setting and that might result in a change in the acceleration of the system. Record the list in your **lab records**.

c. **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 **acceleration of the system**. Use the template on the next page to communicate the design in your **lab records**.

Experimental Design Template	
Research Question	*What impacts the acceleration of a system?*
Dependent variable (DV):	
Independent variable (IV):	
Control Variables (CV):	
Testable Hypothesis: (should contain IV and DV so that it is a *testable* hypothesis)	
Prediction	

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 lab instructor checks your entire* experimental design plan before collecting any data. Be sure that your group has discussed prior to this checkpoint 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).

Be sure students know where to find the videos to use with Tracker. There are 3 available data sets so be sure to spread them out across the lab groups so different models results, which will provide for a richer class discussion during next week's lab.

Check each group's procedure. **Range of data:** Check that each group plans to use data from both extremes of the IV. Also, check that they plan to analyze more than 3-4 videos; remind them of any length vs period graphs from the pendulum lab which didn't provide a complete story given the limited data points. **Number of trials:** There is only one video provided for each IV. Therefore, more than one trial is not possible. This may seem problematic given that students will need to calibrate, include axes, and mark the falling object for tracking, all of which include random error. Students could analyze each video three times and take the average, but this would be extremely time consuming. Instead, we should recognize that the data collection using Tracker involves a measuring *technique* which has uncertainty to it that we can determine once and use for all videos. Students will determine the uncertainty of the technique in II.b. Discuss this with students at this checkpoint so there is no confusion on what to do; that is, they will do just one trial (one video) per IV value, but will add error bars to the data points later.

Check your lab records for completeness using the rubric below:

	Excellent (2)	Limited (1)	Missing (0)
Brainstorm Factors	Lists at least two factors that may impact acceleration of a system.	Only one factor is listed.	No possible factors listed.
Experimental Set-up (one 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 (one 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.** You will use Tracker to determine the acceleration of the falling mass in the videos provided on Canvas. Detailed instructions for how to use Tracker for this purpose were included in this week's pre-lab. Record all collected data in a table in your **lab records**. Be sure to use the standard metric units of meters, kilograms, and seconds.

Note: Each video opened in Tracker is opened onto 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. Close as many tabs as needed. Another option is just to close Tracker and open it up again.

b. **Determine uncertainty.** The values for acceleration were measured using a **technique** in which you had to use a calibration tool to determine 1 meter in the video, position axes on the video, and choose a point on the falling object to track. All of these steps involve randomness that cannot be repeated exactly. Therefore, the uncertainty of this measuring technique needs to be determined. As in the pendulum lab, the uncertainty is the standard deviation of at least 10 measurements for the same event (video). Although tedious, it is important that your group opens the same video and goes through all steps of calibration and analysis from start to finish at least ten times. Record all data and the resulting standard deviation (computed in Excel) in your **lab records**.

c. **Plot the data in Excel.** Produce the appropriate graph in Excel to address your research question. Remember that the IV is typically plotted on the horizontal axis and the DV on the vertical axis. <u>Plot only positive values for acceleration so the graph is easier to interpret later</u>.

d. **Insert error bars for the x- and y-axis.** The error bars for acceleration (y-axis) should be the uncertainty in the measurements of acceleration (standard deviation computed earlier of at least 10 measurements). The error bars for the x-axis should be the uncertainty in the balance used to measure the mass. Use 0.05 g for this value. You may have to convert this to units of Newtons depending on what is plotted on the x-axis. There are many different versions of Excel so use the Excel User's guide posted for this week in Canvas or use the internet if you need help with this step.

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. In order to reduce the time spent on this step, consult the list of possible fits provided at the end of

Pre-Lab 03, which include linear, exponential, and power (square root, inverse, square, and so on). If you aren't sure how to tell which fit is best, consult 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. **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?

h. **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. Recall that 1 N (Newton) is equivalent to 1 kg m/s^2.

***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.*

It is probably best to ask students to share their screen or pull up their Lab Records from One Drive during this checkpoint. (1) Make sure that they have used standard metric units of m, kg, N and s or their models will not match those of others in class. (2) Check their models to see if they make sense (since they are using provided data, you can check the provided excel file to quickly see if they have something really off here), (3) check their claim relative to their graph, and (4) be sure their mathematical model has appropriate variable names (such as a, F, and m).

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

	Excellent (4)	Limited (1-3)	Missing (0)
Data Table (for one IV)	Organizes **measurements** into a neat table, **labels** values, includes **units**.	Some measurements are missing; labels/units missing.	Data table is missing.
Estimation of Uncertainties	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.
Graph with Error Bars (for one IV)	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	Trendline **equation** and **R^2 value** are included on graph.	Trendline equation or R^2 is missing.	Trendline equation and R^2 are missing.
Claim (next to graph)	1. A **claim** about the **relationship** between the IV and DV is included next to the graph. 2. **Conditions** of claim are included.	Claim is incorrect or conditions of claim are not included.	Claim is missing.

Mathematical Model for Acceleration of a System	Experimental mathematical model is stated in terms of appropriate variables, with units included on all constants.	Mathematical model is left in terms of x and y rather than appropriate variables; or units are missing.	The mathematical model is missing.

There is no final checkpoint for this lab as the questions below have been used before and students should be getting better at this. You will, of course, be asked to grade their responses in their lab records so possible answers have been provided below for instructor use.

III. Final Wrap-Up

The second factor will be tested in next week's lab. The wrap-up questions below will help document your ideas after completing the testing of one factor. Include all answers in your **lab records**.

a. **Summarize your findings into a general claim.** Your group developed a mathematical model from experimental data. The model describes the behavior of a system's motion (acceleration) in terms of a variable (IV). Summarize what your group learned in terms of whether or not this factor impacts the acceleration of a system, and if so, describe *how* it affects the acceleration.

   System mass matters. As system mass increases while keeping the force constant, the acceleration decreases.
   Or
   Force on system matters. As force increases while keeping system mass constant, the acceleration decreases.

b. **Identify conditions for your claim.** Your hypothesis was tested under certain circumstances (or conditions) and therefore your claim is valid for those conditions. <u>State the conditions of your claim for which you know the claim holds</u>. 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.

   Students should state the range of IV values used in their experiment. They may also, but not necessary, indicate other conditions such as data was collected in Cincinnati (in case they are worried about g), holds for an almost frictionless surface (air track), etc. If we had been face to face for lab, more conditions outside of the range of IV values would have been expected.

c. Consider the evidence that supports your claim.
The data collected during lab, as well as known scientific knowledge or theories, can both be used to justify your claim. For today's lab we will only consider the data your group collected during lab. The following questions serve as a guide for evaluating all 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. They should comment on the size of the error bars on their graphs. Smaller (relative) error bars indicates more confidence.

   ii. Explain in a few sentences <u>how</u> the mathematical model was determined and <u>how</u> it led to your claim. Use your best judgement here. Ideally, students should indicate that a curve was fit to data plotted in Excel and that Excel provided an equation of the fitted curve (many students think the equation is for the data points and do not consider that it is an equation of the estimated curve). Again, ideally, students should indicate something about how an equation was provided by Excel and that they changed the x's and y's to variable names that made more physical sense for their situation.

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. Look at students' graphs for this one. Students should mention being more confident if their trendline passes through most of the points with few outliers. They should also comment on the R^2 value (closer to 1 means a better fit).

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. Students will likely have a wide range of responses and accept anything that is reasonable. With Tracker, there are lots of places for error when setting up the calibration, axes, and identifying a place on the bobs to track. Also, the videos could be improved such that the vertical meter stick in the background is actually parallel to the path of the falling masses. The camera angle could be improved such that a larger section of the fall could be included in the analysis (we estimate about 10% error due to parallax if full path is included in analysis). Obviously, all of this could be improved by conducting the investigation using real equipment in a lab setting.

Check your lab records for completeness using the rubric below:

	Excellent (12)	**Limited (6-11)**	**Missing (0-5)**
Responses to the Final Wrap Up Questions	Thoroughly addresses questions and provides evidence, if requested, for the following: a. Summarizes general claim (2 pts) b. States conditions for claim (2 pts) c. Cites evidence that supports claim (6 pts) 1. Evaluates data and observed patterns i. Discusses confidence in measurements ii. Explains how model was determined and how it led to the claim iii. Discusses confidence in Excel trendline and model d. Suggests Improvements (2 pts)	Some of the question responses are missing, are not complete, or are incorrect.	A significant number of question responses are missing or are incorrect.

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 lab records** within 24 hours of the end of today's class.