Lab 05: Force and Motion Part II **Instructor Notes**

Learning Objectives

- Construct knowledge through the creation of a mathematical model using experimental data
- Identify limitations of the experiment; describe impact on the interpretation of data or claims
- Synthesize all gathered information and make a data-driven claim

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. This week's 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 before next week's lab.*

Lab Records Scoring Rubric (50 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. Complete the Experiment – What impacts the acceleration of a system?

In Lab 04, you began an investigation to address the research question, *What impacts the acceleration of a system?* Lab 05 will wrap up the investigation by testing a second factor.

a. **Lab records.** Today's lab records will also be submitted as part of the lab report, much like what was done previously with the pendulum lab. Therefore, this first step is to get your lab records together. Pull up a copy of Lab Records 04 and resave it as Lab Records 05. Remove your responses to the wrap-up questions but keep everything else from the testing of the first IV last week. Begin recording in this same document your work as you investigate a second facor.

b. **Design an experiment to test a second IV.** Design a controlled experiment to determine how the selected factor may impact the **acceleration of the system**. Use the template below 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	

c. **Conduct the experiment.** Use Tracker and the provided videos on Canvas to conduct the experiment to test the second possible factor. Consult the pre-lab 04 instructions on how to use Tracker, if needed. 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.

d. **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. For the acceleration, only plot positive values (magnitudes) so the graph is easier to interpret.

e. **Insert error bars for the x- and y-axis.** The error bars for acceleration (y-axis) should be the uncertainty in the measuring technique (i.e. Tracker) determined last week when your group computed the standard deviation of 10 measurements taken from a single video. The error bars for the x-axis should be the uncertainty in the balance used to measure the mass, which was 0.05 g.

f. **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.

g. **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**.

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

Class Checkpoint 1! *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.* See next page for details for instructor.

Lab 05 allows students the opportunity to gather data on one remaining IV and then compare two models for the behavior of a system for two circumstances: (1) under a changing applied force (with constant system mass from lab 04) and (2) a changing system mass (with a constant applied force). The discussion. 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 rows below correspond to Data Sets 1, 2, and 3 as shown in the instructor Excel file (distributed to instructors during Lab 04).

Group	Model 1	CVs for Model 1	Model 2	CVs for Model 2
1	$a = (2.8985/kg)F + 0.074$ m/s^2	m_{system} = 0.3404 kg	$a = (0.15\ kg\ m/s^2)\ m^{-0.8}$	$F_{hanging}$ = 0.096 N
2	$a = (3.1418/kg)F - 0.103$ m/s^2	m_{system} = 0.3404 kg	$a = (0.043\ kg\ m/s^2)\ m^{-1.5}$	$F_{hanging}$ = 0.096 N
3	$a = (3.1881/kg)F - 0.035$ m/s^2	m_{system} = 0.3404 kg	$a = (0.089\ kg\ m/s^2)\ m^{-1}$	$F_{hanging}$ = 0.096 N
4				
5				
6				

Lead a whole class discussion.

1. **Start the discussion around Model 1**. There is a lot of similarity but the constants have different signs. Ask students what the constants are doing to the magnitude of the resulting acceleration. They should agree that the acceleration is either being positively influenced or negatively influenced by something. It could be random error but all groups that have the same data sets should be consistent here, suggesting the presence of another force. See step 2.
2. **Show videos.** Show the students the videos of the set-ups for each data set.
   a. The video for **Data Set 1** shows a cart that is sitting on the air track, which is turned on but has no hanging mass attached, start to drift forward towards the pulley. This indicates a positive tilt to the air track such that the force of gravity is also contributing to the acceleration, hence the positive C in the Model 1 equation.
   b. The video for **Data Set 2** shows the cart start to drift backwards away from the pulley. This indicates a negative tilt to the air track such that the force of gravity is working against the acceleration, hence the negative C in the Model 1 equation.
   c. The video for **Data Set 3** shows a cart that is sitting on the air track, which is turned on but has no hanging mass attached, remain stationary. This indicates no tilt to the track such that the force of gravity contributes nothing to acceleration, hence the very, very small C in the Model 1 equation. I wish it were closer to 0 but these are the videos provided to us.
3. **Move to Model 2.** The above discussion suggests that Data Set 3 provides the easiest model to consider first here since it doesn't include the extra force due to the tilt of the track. Looking at Model 2 for Data Set 3, it should be clear that $a = (0.089\ kg\ m/s^2)\ m^{-1}$ has the form of $a = C_1 m^{-1}$, which students should recognize as F=ma since the coefficient C_1 has the units of N (recall that 1 N = 1 kg m/s^2). This also suggests the C_1 in the model should be the force on the system. For data set 3 the force of the hanging masses is 0.096 N which is very close to the coefficient of 0.089 N, suggesting no additional forces (although friction of the air track could explain any other differences). For the other two models it won't be as close given the additional force from the tilt of the track.
4. **Move back to Model 1.** This model has the form $a = C_2 F + C_3$. This suggests the C_2 is 1/m_{system}. In the case of Data Set 3, we have 1/m_{system} = 1/0.3404 kg = 2.94 kg^{-1}. We aren't far off! Again, any differences could be random error in the experiment as well as friction with the air track, which we were not able to measure.

5. **Things to keep in mind.** Students' models <u>will vary</u> 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 Newton's Second Law (F=ma). But take it one step further! Newton's Second Law is really $\sum F = ma$ and in this situation we could logically write $\sum F = F_{hanging\ mass} + F_{tilt} + F_{friction} = ma$.

6. **Remind students.** End this checkpoint by reminding students that they will be asked to share the data 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.

The rubric below ends what needs to be included in the lab records for this week. Once satisfied your lab records are complete, start addressing the Final Wrap-Up questions in the next section. The answers will be extremely useful in writing the individual lab report so you may wish to record your group's responses in a separate Word file that is not part of the lab records for this week.

Check your lab records for completeness using the rubric below:

	Excellent (2)	**Limited (1)**	**Missing (0)**
Experimental Set-Up (from lab 04)	Includes a screenshot of the experimental set-up; essential features are included and labeled.	Some features and/or labels are missing.	Screenshot is missing.
	Excellent (6)	**Limited (3-5)**	**Missing (0-2)**
Experimental Design Template (for both IVs)	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.
Data Table (for both IVs)	Organizes **measurements** into a neat table, **labels** values, includes **units**.	Some measurements are missing; labels/units missing.	Data table is missing.
Estimation of Uncertainties (includes info from last week)	1. Provides **uncertainty estimates** for each type of measurement. 2. **Describes** *how* uncertainties were determined (include info from last week).	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 both IVs)	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 (for both IVs)	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 both graphs)	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 (for both IVs)	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.
	Excellent (4)	**Limited (2-3)**	**Missing (0-1)**

Tables and Figures are labelled	All design templates, data tables, graphs, etc. are properly labelled using standard headers with numbers, such as, "Figure 1. Graph of Period versus Mass".	Several labels on data tables, graphs, or other figures are missing.	A significant number are missing.

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

The purpose of this lab was to develop experimental mathematical models to describe the behavior (acceleration) of a system in a *real* lab setting. **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 for this week.

a. **Summarize findings into a general conclusion.** Your group developed two mathematical models from experimental data. Each describes the behavior of a system's motion (acceleration) in terms of another variable (IV). Write a sentence or two as a general summary of what your group learned in terms of what factors impact, or do not impact, the acceleration of a system. For those factors that have impact, describe *how* each affects the acceleration.

An example of a claim could be: As mass increases, while holding the applied force constant, the object's acceleration decreases. (Students MUST indicate force is constant for this relation).
An example of a second claim could be: For a constant system mass, as the applied force increases, the acceleration increases. Again, students MUST indicate that system mass is constant.

b. **Cite the evidence that supports your claim.**
The data collected during lab, as well as known scientific knowledge or theories, can be used as evidence to justify your claim. The questions below 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.

      Students should discuss the size of the error bars when answering this question. Large error bars indicate a lack of confidence in the actual measurements.

   ii. Explain in a few sentences how <u>each</u> mathematical model was determined, what the model is, and how it led to your claim.

      Students should discuss that a curve was fit to their plotted data and then state their models. They should then describe how these models (either the equation or graph) indicate the relationship between the IV and DV for their experiments (that is, how it led to their claim).

   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.

      As in prior labs, students should discuss how well the trendline fits the data and the presence of any outliers. They should also comment on the R^2 value with values closer to 1 indicating a better fit.

iv. Cite the data and claims from at least two other groups. You may wish to include the chart that was filled out by all groups and then refer to it, as needed. Discuss whether the data of at least two other groups supports or challenges the findings of your group and how that impacts your level of confidence in your claims.

   Ideally, students would include a group's model (claim) which has the same sign of C3 as their model from Lab 04 and one with a different sign. If so, they should discuss how one supports and one challenges their model. Groups may not do this, however, so be flexible.

2. **Connect your claim to theory or other scientific knowledge**
   In the lecture part of your physics course you learned about Newton's Second Law (F=ma). The questions in this section serve as a guide to compare and contrast both of your experimental models to Newton's Second Law.

   i. Describe how each of your experimental models supports Newton's Second Law. Also, as part of this discussion, be sure to consider any numerical values (constants) in your experimental model and how Newton's Second Law provides physical meaning to these numbers.
   Student responses should be similar to what was discussed in Checkpoint 1.

   ii. Describe any differences between your experimental models and Newton's Second Law. Identify what may account for these differences. Student responses should be similar to what was discussed in Checkpoint 1.

c. **Consider other possible factors.** Are there any other factors not tested that might impact your response to the research question regarding what affects the acceleration of a system? If so, what are they and how might they be investigated? What new research question could you ask? If not, explain why you believe you have investigated all possible factors.

d. **Suggest improvements.** If given the opportunity to repeat the investigation, what could be done to improve the collected evidence (data), or strengthen your interpretation of the evidence, which support your general conclusion? You may wish to discuss flaws in your experimental design, how you might employ better controls, address assumptions, and so on.

e. **Consider a hypothetical scenario.** A physics student claims that Newton's second law ($F = ma$) can be used to predict the net force necessary to obtain a desired acceleration. What relationship, correlational or causal, exists between net force and acceleration if mass is constant? Explain.
   The relationship between force and acceleration is causal if the system mass is held constant.

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. See the next page for instructions on the individual lab report due in one week.

Requirements for the Force and Motion Lab Report (done individually and 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 <u>three</u> 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 <u>individually</u> 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 <u>end</u> 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 <u>will</u> 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 05) 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 <u>thoughtful essay or argument using multiple paragraphs</u>.*

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 both IVs.

   i. Evidence (data) collected by your group

   1. Discuss how each of the 2 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 Lab Records 05) in your discussion. Use Figure numbers on the graphs so you can refer to them by figure number.
   2. Discuss <u>how</u> each of the two 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 two 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 this lab.
2. Discuss for the reader <u>how</u> well both of your experimental models fit with the same theoretical model, that is, Newton's 2^{nd} Law (F=ma). 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.

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 mathematical model provided by Excel** for each of the 2 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.

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.