

Newton's 2nd Law Lab

Directions and Suggestions for Teacher

Purpose:

This lab is designed to give students experience modeling Newton's 2nd Law of Motion. Students will adjust the mass of a hover puck and then measure its acceleration as it is accelerating because of a force. Once they have their graphs they will use the graph(s) to create a mathematical model and then use the model to make predictions. This lab will introduce students to one of the most important equations they will work with all year.

Virtual Part:

(<https://www.thephysicsaviary.com/Physics/Programs/Labs/NewtonsLawLabWithPredictions/>)

The virtual part of this lab could be done before students do a live version of the lab or if you have limited lab space you can have half the students working on the virtual part of the lab while the other half work on the live part of the lab.

Measuring Mass:

Students will be determining the mass of the object by reading it off of an analog dial gauge. I didn't want them to have to take the time to read a triple-beam balance, but at the same time, I didn't want to just give them the mass. I find it always is a better idea to have them have to estimate and make judgment calls when taking data.

Measuring Acceleration:

When the hovercraft is pulled across the table, a velocity vs. time graph is produced. Students will use this graph to find the acceleration of the craft while being pulled. The slope of this graph will give them the acceleration of the craft. There is an export feature that will allow the students to copy the raw data for time, position, and velocity which they can then use in an external program to find acceleration. I personally prefer them to have to manually find the slope of the velocity graph.

Working Through the Lab:

Although there are ten different possible masses for the hovercraft in the virtual program, students need not do all levels. I would not suggest less than 5 levels as it is a good practice to collect more data to have greater confidence in your results. The program will randomize the masses of the hovercrafts, so all students will get different results. Students should not refresh the website while working or it will generate new values and thus make all the old data irrelevant. Below is a sample of what potential data might look like.

Data:

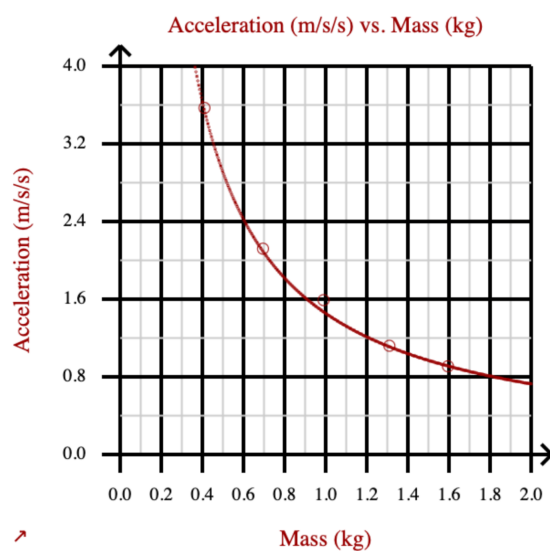
Mass (kg)	Acceleration (m/s/s)
0.410	3.57
0.695	2.12
0.990	1.59
1.310	1.12
1.595	0.909

Graphing Data:

(<https://www.thephysicsaviary.com/Physics/Programs/Tools/Graphing/>)

Once students have finished collecting data, they should graph it and find a relationship between the variables. The mass of the hovercraft (kg) is the independent variable and should be placed on the x-axis and the acceleration (m/s/s) should be on the y-axis. This graph should come out to be an inverse graph.

I prefer always having the students transfer their graph onto their lab sheet by hand.



Data Set 1

$$y = \frac{(1.454)}{x}$$

Equation:

For this graph students get an inverse relationship between the variables. This indicates to them that a larger mass will cause a smaller acceleration.

The equation for an inverse relationship is given below.

$$y = (\text{graph constant})/x$$

We want to continue to emphasize to them the idea that each of these letters has real physical significance. Looking at the axes, they should see that the y is the acceleration in m/s/s and the x is the mass in kg. So the equation becomes:

$$\text{acceleration} = (\text{graph constant})/(\text{mass})$$

We then want students to think about the significance of the graph constant. We can prompt them what could have changed other than mass that would have made the hovercraft acceleration more rapidly. Hopefully, most students will realize that if we had pulled the craft with a greater force, we would have produced a larger acceleration. We want to make sure that they realize that the force of our pull is going to be the graph constant for this equation. So the final equation is one they will use throughout the rest of the year.

$$\text{acceleration} = \text{Force}/\text{mass}$$

In this lab, the only force determining the motion of the hovercraft was the applied force from the string attached to the craft. It might be helpful at this point to have them brainstorm what would happen to the acceleration if there had been a significant amount of friction or air resistance on the craft. We can let them know that the force we would use in the equation would now be the net force on the craft.

Checking their work:

Once the students have reached the point where they have graphed and created an equation, they will then be able to check their work. They should simply hit “Finished” on the program to be brought to a form they can fill out to see if they did everything correctly. Remind students that they all will be getting different answers and that they shouldn’t worry if their answers differ from those of their classmates.

Make sure to stress that they should have graphed mass in kilograms. They will be entering their graph constant as the force that pulled their craft across the table. They will then use their equation to make a prediction on how much acceleration they will have with a certain mass for which they didn’t collect data. Again, make sure they put the mass into kg before they do their prediction.

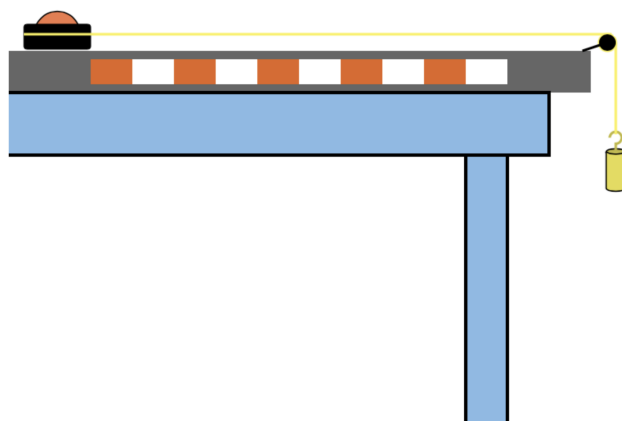
Make a graph of acceleration (m/s/s) vs. mass (kg) to determine the relationship for an object with pulled with a constant net force. Use the equation of your graph to determine the acceleration of a 65 gram hover puck subjected to the same constant force.	Enter Your Answer Below Don't Enter Units Name: Force (N): acc for 65 g (m/s/s): Return Submit
--	---

I would normally offer a small amount of extra credit added to the lab grade if they get all their answers correct. I would have them show me their completion certificate so I could record that they earned the extra credit. If a student doesn’t get everything correct, you can have them redo the lab by refreshing their page if time permits.

Live Part:

I always suggest a live lab counterpart to any virtual lab that you do with your students. This lab is never easy to get good consistent data in a live setting without having a pretty expensive lab set up to help you eliminate most friction and to get a good reading on your acceleration. In my introductory physics class, I would often just have one lab station set up in the room and I would have lab groups take just a single trial worth of data and then we would share the data with the class to produce a graph and find our relationship.

All of the live setups I have ever used have involved some type of pulley system to create a gravitational force that then is applied to the craft moving across the table. A picture of such a system is shown below.



Anyway, here are some suggestions for things you can do with the live part of your lab.

1. The Hanging Mass:

- a. Don't make the hanging mass too large or your accelerations with the smaller masses for the hovercraft will be so large, they will be hard to measure.
- b. If you want to match the type of relationship that we got in the virtual part of the lab, don't change the mass of the hanging object during the live part of the experiment.
- c. Make sure to change the value of the hanging mass from kg to N to get the expected value for your graph constant.

2. The Hovercraft:

- a. I purchased a hovercraft like this from Five Below.

- b. The problem with using this hovercraft is that it will not do so well if you tape too much mass onto it. If you don't add enough mass between trials, you will not see much change in acceleration.
- c. Rather than using a hovercraft, I have seen people use an air track with a slider. Again, adding mass to the slider will make it harder for it to hover and thus you will not get great results.
- d. Using a small car that is designed to carry masses might be the best option, but depending on the quality of the car, friction will definitely make your results less than ideal.
- e. Although you might not get great results, it is still very instructive to work through the live part of the lab and to talk about all the reasons why your live results were not as good as the virtual results.

3. Measuring Acceleration

- a. You will have a lot of options you can use to get acceleration and the one you want to go with will be determined by your budget or what is available in your school.
- b. The least expensive method would be to use the stopwatch on your student phones to time how long it takes the car to accelerate through a certain distance. Then use the formula $\Delta x = v_i t + 0.5at^2$ to calculate the acceleration. Make sure the car starts at rest. These accelerations will only be as accurate as the student's timings and for high accelerations, don't expect too much accuracy. Even though it is least accurate, this will be the simplest and cheapest way to get acceleration.
- c. You could have the students use the cameras on their phones to record the motion of the moving object and then use motion tracking software to graph the motion of the car. This will allow them to get the acceleration more accurately than simply timing it.
- d. Students can use the microphone to time the car also. When the hanging mass hits the ground it will make a noise and if they make a "Go" noise right at the moment of initial release, they should be able to get a good wave form that will show the moment of release and the moment the acceleration stops. Then use the formula $\Delta x = v_i t + 0.5at^2$ to calculate the acceleration. Make sure the car starts at rest.
- e. If you have motion sensors or pocket labs with range finders, you can get graphs of the car's motion and then use these to calculate acceleration.
- f. Again, don't expect the best results in this lab, but do the live lab anyway and use it to help students brainstorm about errors and how the errors can be minimized.

Conclusion:

I personally like to have students write out a conclusion by hand after they are done with the entire lab (live part and virtual part). Some things you can have students include in the conclusion.

1. Restatement of the purpose.

- a. This is a great way to open the conclusion
- b. It helps to reinforce the reason we were doing the lab.

2. Brief Summary of the steps

- a. I don't want too much here but I do want students to transition from the purpose to the results with a sentence or two summary of the steps.
- b. This part of the conclusion should paint with a very broad brush what type of data we were collecting and what remained constant when collecting data.

3. Results

- a. I want students to clearly state what type of relationship existed between the two variables we were examining.
- b. I want them to clearly explain what this means in simple to understand terms.
- c. Basically, they will be making sense of the equation they have discovered in the lab.

4. Error

- a. They should talk about their percentage of error from the lab (you can have them do this for the live part or the virtual part or both).
- b. They should brainstorm at least one possible source of that error and how it can be minimized if they redid the lab.

5. Limitations to the model

- a. Whenever possible I want them to think about when the mathematical model for the lab would break down and no longer apply.
- b. For instance, with this lab, the equation we got only applies if we make sure we are using the net force and not just the applied force. If there is friction and/or air resistance, the applied force alone will not allow us to find the acceleration of the object even if we know its mass.

Going Further

If you have the time, you could challenge the students with the following types of things.

1. How would your graph change if we collected our data with a greater applied force? You can ask them to sketch a new curve on the graph in a different color that would show how the graph would have been with a larger applied force and in a third color for a smaller applied force.
2. You can have the students look up the mass of a certain car and also the 0 to 60 mph time for that car. They could then use the equation that we developed to approximate the maximum net force for that car. We could have different students find the net force for different cars to see which cars have the greatest net force. Students should add the mass of a typical person onto the mass of the car to get a better approximation of this maximum net force.