**Center of mass lab:**

Assemble a dynamics track, a force sensor, a wood block, and a motion detector as shown in the diagram below. The track should be supported only by the force sensor and the block. The block should be at least 30 cm from the end of the track. Place the motion sensor on the end of the track closest to the wood block. Level the track.

Start LoggerPro. Open the “Center of mass finder” file.

Stack two dynamics tracks and an iron weight on top of each other as shown. Each cart and weight should have a mass of approximately 500 g for a total mass of 1.500 kg. The “Center of mass finder” file has a box for entering the total mass of your weights. Make sure this reads 1.500 kg (or the correct total mass of your three objects). Place the stacked carts and weight above the wood block. Zero the force sensor and the motion detector.

Motion detector

Force sensor

cart

cart

weight

track

block

Click collect and give the carts a gentle push in the direction of the force sensor. The screen should display four graphs. The top graph shows position as measured by the motion detector as a function of time. If the track is level this should be a straight line with positive slope. The bottom graph displays force (measured by the force probe) as a function of position (measured by the motion sensor). The two graphs in the middle convey information about the center of mass of the system but they must be calibrated, which we do next.

Look at the lower graph, the graph of position as a function of force. It should run through the origin since we zeroed the force sensor and motion detector. It should also be a straight line since the force sensor has to support more weight as the carts get closer to it. The relationship is linear because the torque on the system is balanced but don’t worry if you don’t understand this point. It is enough for us to observe experimentally that the relationship between the force on the force probe and the position of the position of the three objects is linear. We will use this linear relationship to calibrate the middle two graphs on the screen.

The motion detector only reads the position of the object nearest to it. The force probe will measure the position of the center of mass of the objects on the track. To do this the computer must be told the exact relationship between the force that is read by the force probe and the position that is read by the motion detector. That relationship is displayed on the bottom graph.

Look at the position vs. force graph (the bottom graph). Identify the region where the position and the force are both increasing in a linear way (where the graph is a straight line of nonzero slope). Highlight a segment of the graph in this region. Click on “linear fit” (the “R =” button). You should get an equation for the best fit line.

Enter the slope of the best fit line in the box labeled “Slope dx/df”. Enter the intercept of the line in the box labeled “Intercept x”. The “center of mass finder” should now be calibrated.

Check the calibration:

1. Place the three stacked objects (two carts and a weight) on the track, at least 30 cm from the motion sensor. Estimate where you think the center of mass is located. Click collect. Check the position reported in the “Position” and the “CM position” graph. Record your estimate and the two readings below.
2. Now carefully move the weight and one cart 20 cm closer to the motion sensor. Move the remaining cart 40 cm farther away from the motion sensor. What do you believe this did to the position of the center of mass? Will the readings on the “Position” graph and/or the “CM position” graphs change? Click collect. Record the readings from the two graphs below. (Did they agree with your predictions?)
3. Based on your results above, does the “Position” graph (the top graph) do a good job of reporting the position of the center of mass of objects on the track? Does the “CM position” graph?
4. Discuss your predictions and results with your classmates and your instructor.

You now have a device for tracking the center of mass of an object or a group of objects. You are to conduct a series of investigations into the behavior of the center of mass of a system of two or three objects.

Investigation #1:

Two carts, different masses, level track.

Separate your two carts and place the weight on the back of one of them. You should now have a 1.0 kg cart and a 0.5 kg cart. (The exact values of the masses are unimportant as long as they are different and the total mass is correctly indicated on the “Center of mass finder” screen.)

Place the 1.0 kg cart at rest in the center of the track with the 0.5 kg cart nearer to the motion detector. Click collect and give the 0.5 kg cart a push toward the 1.0 kg cart. Allow them to collide.

1. Can you identify the time of the collision by looking at the “Position” graph (as measured by the motion sensor)?
2. Is there anything special about that time on the “CM position” graph? Describe the CM position graph before, during, and after this time.
3. Measure the slope of the CM position graph before and after the collision. How do the two values compare?
4. Look at the “CM velocity” graph (you may need to change the scale to see details of what happened at the time of the collision).
	1. Is there anything special about the CM velocity graph at the time of the collision?

Note: The CM velocity graph is inevitably “bumpier” and less smooth than the CM position graph. Average values may be needed for interpretation. Depending on how stable your track is, the CM velocity graph might be especially bumpy at the time of the collision. This is because the collision may have caused the track to vibrate and that vibration can be detected by the force sensor. Physicists refer to this as “a disturbance in the force.”

* 1. Use this graph to measure the average velocity of the Center of Mass before and after the collision. How do they compare?

Note: the velocities before and after the collision will not be exactly the same due to friction and other factors. The question here is whether the collision itself caused a change in velocity that was not seen elsewhere. So to decide whether a change in velocity was *significant* it might be necessary to compare the velocities at two other times, both before or both after the collision. The key question then becomes whether the collision caused a change in velocity that is more significant than changes in velocity at other times.

* 1. Are any differences in velocity that you observe in part b more significant than differences in velocity you observe when there is no collision?
1. Repeat this experiment several times with variations in the positions and velocities of the carts. For example, you could try starting with the less massive cart at rest, with the more massive cart closer to the motion detector, or with both carts initially in motion. Try several variations with these two carts. Record your observations below. Share your results with classmates and your instructor.

Investigation #2: What if the weight is not on a cart?

Two carts (same mass), weight with same mass as a cart, level track.

Try repeating the experiments of investigation #1 but with the weight resting somewhere on the track. In this case the carts may collide with each other but one of them will also collide with the weight.

1. At a time when the two carts collide with each other, is there anything special about the CM position graph?
2. At a time when the two carts collide with the weight, is there anything special about the CM position graph?
3. Why might your answers to parts a and b be different? Discuss your results with your classmates and your instructor.

Investigations #3, #4, #5, and so on…

Invent your own investigations. Here are some things to think about. What if there were three carts of equal mass? What if there were multiple collisions? Why did we bother to level the track in the first place? What would happen if you conducted these experiments on an inclined plane? What would happen if one of the carts was being pulled horizontally by an external force (such as a weight on a pulley)?

As you design your experiments, keep in mind that the CM position and CM velocity graphs will only be accurate if the total mass on the track is correctly identified in the Total Mass box. If you add objects such as pulleys you can either (a) simply consider them to be part of the system and add their masses to the Total Mass or (b) attach them to the track, place two carts and the weight above the block, go back to page 1 and recalibrate your CM finder.

Record your observations on the following page(s). Have fun.

Investigation #3:

Investigation #4, etc.: