On-line activities for static equilibrium labs

Below is the list of experiments (real, video based and data-based) that students can perform as labs for the invention of the center of mass, torque and static equilibrium. For each experiment we provide goals, equipment and rubrics for self-assessment. Rubrics can be found at https://sites.google.com/site/scientificabilities/rubrics

1. Observational experiment: to turn or not to turn?

Goal: To find a pattern in the directions of the forces that do not cause rotation of a rigid body

Equipment: a book, a pencil, cardboard, scissors, a sowing pin.

Rubrics for self-assessment Scientific ability to design and conduct an observational experiment B5.

a. Use the pencil eraser or the ruler to push several different points on the bottom edge of the book that you put on the smooth surface. Identify a pattern in the direction of the forces that do not cause the object to rotate. *Hint:* Draw lines on the object in the direction of the forces that the pencil eraser or ruler exert on the object.

b. Think of how you can explain the pattern you found. List your explanation(s) here.

c. Use a piece of hard carboard to cut out an irregular shaped object. Use the same procedure to find the point through which the lines of forces that do not rotate the object pass. This point is called the center of mass of your object. Then take a pin and use it to support the object at the center of mass. Did it work? If you are having trouble, read the subsection “Where is the gravitational force exerted on the rigid body” on page 220 in the textbook and repeat the experiment.

2 Observational experiment: meterstick balancing

Goal: To find a pattern in the locations of the forces that do not cause the rotation of an object around the center of mass.

Equipment: meter stick, play-dough, a marker, several identical-mass washers (or nuts).

Rubrics for self-assessment Scientific ability to design and conduct an observational experiment B7.

Place the marker horizontally on the table and secure it in place with some play-dough so it cannot roll. Place the meter stick on top of the marker so that it balances at the 50 cm mark and doesn't touch the surface of the table (if you have a stick, find its center of mass by balancing). Note: If your meter stick doesn't balance at exactly 50 cm, add either a paper clip or some play-dough to a suitable place on the meterstick so that it does. Now, place different numbers of washers (or nuts) to the left and right of the balance point. Figure out where you need to place the washers in order for the system to balance and complete the following table:

Number of washers on the left	**Distance of left washer group from the middle**	**Number of washers on the right**	**Distance of right washer group from the middle**
1	20 cm	1	
1	20 cm	2	
2	30 cm	3	
4	30 cm	3	

a. For each situation, draw a picture of the meter stick showing all of the forces exerted on it. In other words, sketch the apparatus and draw an extended-body force diagram for the meter stick, showing forces and points where those forces are exerted on the meter stick.

b. Find a pattern that relates the distances of the washers from the balance point and the magnitudes of the forces the washers exert on the meter stick. What is the relationship between the positions (as measured from the middle) of the left and right groups of washers, and the force that each group exerts on the meterstick?

3. Application experiment: balancing of the board

Goal: Apply the concept of torque to explain the outcome of an experiment.

Equipment: none

a. Watch this video [https://youtu.be/MV_2BKINOx4] and describe your observations.
b. Explain why the placement of the bob did not matter for the balancing of the board.

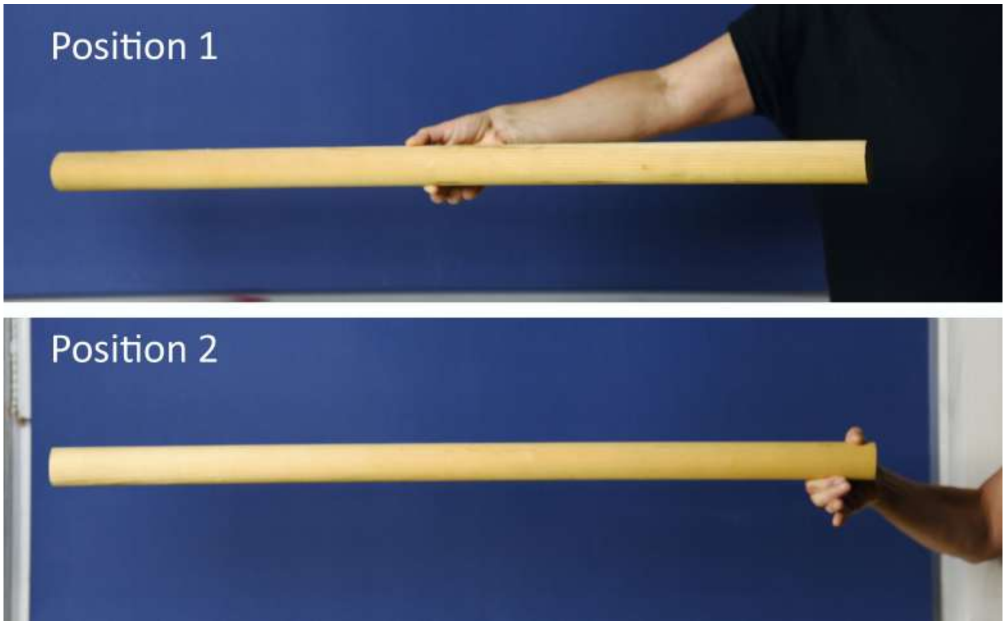
4. Application experiment: where to hold

Equipment: a thick stick or plank that is about 1 m to 1.5 m long.

Goal: Apply the concept of torque to explain the outcome of an experiment.

Equipment: a thick stick or plank that is about 1 m to 1.5 m long.

Find a thick stick or a plank that is about 1.0-m to 1.5-m long. Hold the plank in two positions as shown in the photos below.



a. In which position is it more difficult to hold the plank?

b. Draw extended body force diagrams for both situations (the plank is the system). What forces are exerted on the plank? How does the force diagram help explain why it is much more difficult to hold the plank in position 2 than in position 1? Assume that your hand is in contact with the plank at two points where the fingers are touching the plank.

5. Application experiment: finding the mass

Goal: to apply conditions of static equilibrium to solve a practical problem

Equipment: meter stick, a small object of known mass, tape.

Rubrics for self-assessment Scientific ability to design and conduct an application experiment D1-D7.

You have a meter stick (or a plank) of unknown mass and a small object of known mass (about 100 g) that you can fix onto the meterstick and a scale (a kitchen scale). If you have a plank, you need to also have a length measuring device. Design an experiment to determine the mass of the meter stick using your knowledge of static equilibrium.

a. Draw a picture of the experimental set-up.

b. Describe the procedure in words.

c. Apply the concepts of equilibrium to develop mathematical representations that can be used to predict the mass of the meter stick. Then predict its mass using your mathematical representations.

d. Use a scale to measure its mass and compare the result to the predicted value.

e. How can you explain the difference between the predicted and measured value?

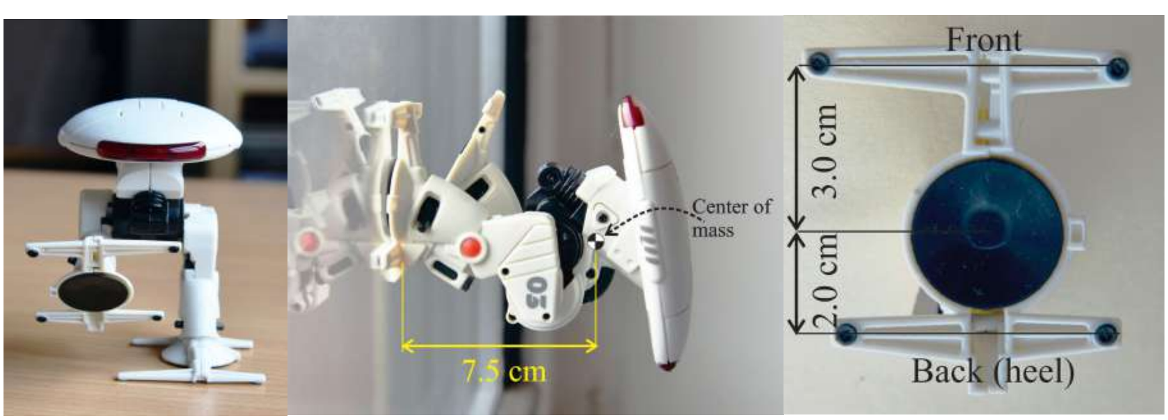
6. Application experiment: finding the center of mass

Click on the link below, watch the experiment and answer the questions.

http://islephysics.net/pt3/experiment.php?topicid=13&exptid=116

7. Application experiment: Window climbing robot

A 0.150-kg toy robot can climb up a window (see the figures below) using suction cups on its feet. The center of mass of the robot is shown on the photo in the middle, and the details of its foot on the photo on the right.



a. Propose a simplified model of the robot that will allow you to determine the forces that other objects exert on the robot when it is in the position shown on the photo in the middle (the robot is at rest). Draw a sketch of the model. (*Hint*: Note that the robot's right foot is not touching the window; also note that the front part of the left foot is not touching the window; replace the forces exerted on the suction cup with a single force in the center of the cup).

b. Determine the forces that other objects exert on the robot when it is in the position shown on the photo in the middle. Indicate any assumptions that you made.

c. The robot in the middle photo is facing upward. Discuss how the forces exerted on the robot will change if the robot is facing downward and then determine these forces.

d. In which case is it more likely that the suction cups will detach from the window: when the robot is facing up or when it is facing down? Explain.

8. Testing experiment: box of crackers

Goal: To invent the "tipping over" explanation and test it experimentally.

Equipment: box full of crackers, protractor, length measuring instrument.

Rubrics for self-assessment Scientific ability to design and conduct a testing experiment C1-C5, C7-C8.

a. Place a full box of crackers on a flat but rough surface, such as a wooden desk. Its center of mass is at its geometric center. Place the box so that the tall side is upward. Tilt the box a little and release it. Tilt the box at larger and larger angles. Eventually, the box tips over. Use your knowledge of static equilibrium to devise an explanation why the box tips over. Then use the explanation you devised to predict the exact angle at which the box tips over.

b. Conduct the experiment and record the outcome. Did it match the prediction?

c. Then remove some crackers from the box and make a new prediction. Conduct the experiment and record the outcome. Did it match the prediction?

d. What is your conclusion about the conditions for the stability of equilibrium?

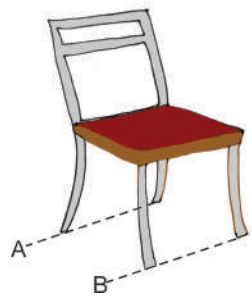
9. Application experiment: tilting chair

Goal: to apply conditions of stability of the static equilibrium to solve a practical problem.

Equipment: chair, length measuring instrument, protractor.

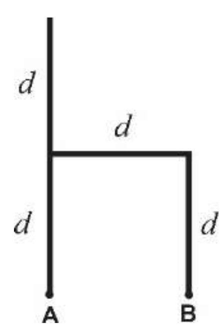
Rubrics for self-assessment Scientific ability to design and conduct an application experiment D1-D7.

a. Obtain a simple chair (see the figure below) and try to tip it over by slowly tilting it either around axis A or axis B. In which case do you need to tilt the chair at a larger angle to tip it over? Estimate both angles.



b. Explain the outcome of your experiment qualitatively using physics arguments.

c. Assume the following simplified model of a chair (the figure below shows a side view). All parts of the chair are made of the same board. Determine the tipping angle for tilting the chair around A and the tipping angle for tilting the chair around B.



d. Compare the result that you got in **c.** with the outcome of your experiments with the real chair and explain any discrepancies between the two.

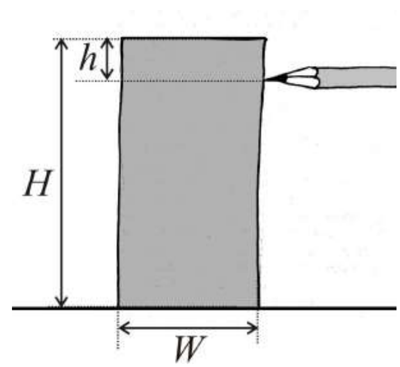
10. Application experiment: tilting block

Goals: a) Explain real life phenomenon using your knowledge of static equilibrium;

b) Evaluate mathematical representation for a physical quantity.

Equipment: A solid block (such as a wooden block), a pencil, length measuring instrument

While searching through the literature for simple experiments that will allow you to determine the coefficient of static friction, you came across the following method:



Using a pencil, exert a force in a horizontal direction on a wooden block (height *H*, width *W*) and try to tip the block over. Start at the top of the block and move down in small increments (see the figure on the right and watch the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-8-6-4]). At some point you will reach a distance *h* where the block will not tip but rather slide forward. Repeat the procedure several times to determine the distance *h* where this transition happens, as precisely as possible. The coefficient of static friction between the block and the supporting surface is determined by the following mathematical representation:

$$\mu_s = \frac{W}{2(H-h)}$$

a. Obtain a block and run the experiment described above.

b. Evaluate the mathematical representation given above. Then derive the representation.

c. Why does the result not depend on the mass of the block? Explain.