AP Physics Lab 10- Exploring Torque: An Open Inquiry Investigation

College Board Big Ideas:
3.F.1.1 The student is able to use representations of the relationship between force and torque.
3.F.1.2:The student is able to compare the torques on an object caused by various forces.

In this investigation we are going to continue exploring angular systems in which objects *rotate*. Every idea in the linear system will have an analogous idea in the angular system. For example, in the linear system we have velocity. Linear velocity tells you how far an object travels in a straight line every second. In the angular system we have *angular* velocity which tells you how many times an object rotates every second. There are many other concepts we could discuss, but today's investigation is an exploratory lab specifically dealing with the concept of *torque*.

Torque Now let's look at the same ideas but in the angular system. The analogous idea of force in the angular system is called *torque*. A torque is a "force" that makes an object want to *rotate*. Think of it as a rotational force. The equation for torque is written as:

$$\tau = Fr$$

τ is the torque on an object (in Newton-meters, N·m)
F is the force acting on an object (in Newtons, N)
r is a perpendicular distance [explained below] (in meters, m)

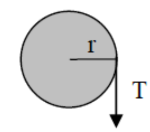

FIGURE 2 – Rope acting on a pulley

Many students think that, ***r***, stands for "radius" but that is not always the case. This can lead to much confusion on torques. It is much better to think of, ***r,*** as the distance from a chosen reference point to the point at which the force, ***F,*** is acting. Let's say you have a pulley with a rope wrapped around it. You pull on the rope which gives the rope a tension, **T**. **See Figure 2.** In this case the chosen reference point is the center of the pulley. It was chosen there because that is the point at which the pulley is rotating. Notice how the distance, ***r***, is shown; from the reference point to where the tension is acting.

Another thing you have to remember is that when you plug in for ***F*** and ***r*** they have to be perpendicular to each other. **See Figure 3a.** If they are not perpendicular then you have to either find a component of ***F*** that is perpendicular to ***r*** or vice versa. In this lab we will only deal with ***F***'s and ***r***'s that are already perpendicular. So, this idea will be left up to your instructor in your lecture to delve into.

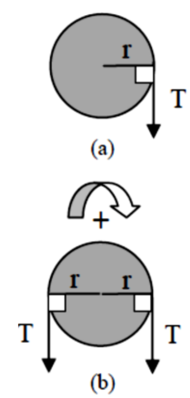

FIGURE 3 – Torques acting on an object

Net Torque The equation for Newton's 2nd Law in the angular system is very similar in form to the one for the linear system:

$$\Sigma\tau = I\alpha$$

$\Sigma\tau$ is the net torque on an object (in Newton-meters, N·m)
I is the moment of inertia on an object (in kg·m^2)
α is angular acceleration of an object (in radians/s^2)

The ideas work out the same as well. In **Figure 3a** there is one torque acting on the system (in this case, $\tau = Tr$). If you apply a *single* torque to an object it will *rotate*. And according to Newton's 2nd Law for the angular system, the object *has* to *angularly* accelerate. This is so because if there is *only one* torque acting on an object then there *must* be a net torque and therefore an angular acceleration. This is the same idea discussed perviously for the linear system.

If there are *two* torques acting on an object then the object might or might not angularly accelerate. If the two torques are *equal* but pointing in *opposite directions* then they cancel out and the *net torque is zero* and the object will *not* accelerate. **See Figure 3b.**

Center Of Mass In the past, when drawing free-body diagrams, you probably have been just arbitrarily drawing in a weight vector at any particular location. In dealing with torque we can see that the location of the force is important. So, now you have to be more careful in which place you draw your weight vector. You should be drawing it at the *center of mass* of your object. Let's say we have a meter stick. Its mass is uniformly distributed throughout itself so we would say that its center of mass is at the exact center of the meter stick. This is where we would place the weight vector of the object. **See Figure 4a.** Now, let's say that we slap on a hunk of heavy, sticky goo on one end of the meter stick. The mass of our "combined object" is no longer uniform. There is now more mass on the right side of the object. So, its center of mass would be shifted to the right (the average location of its total mass).

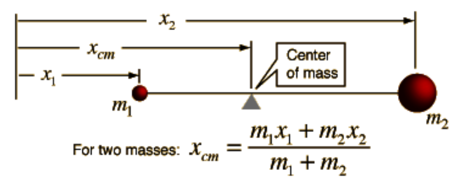

FIGURE 4 – Centers of Mass for meter sticks

Lab Investigation: In this inquiry-based lab you will be exploring the concept of torque. The following suggestions are only to guide you through the investigation, but please feel free to modify the methods and extend your investigation beyond the minimal suggestions. Create a data table to suit your data set.

Materials: meter stick or any other lever arm, fulcrum of choice, masses, string, digital force probes, rubber bands, various objects, digital scale

Part 1 - Center Of Mass: In order to find all the torques on an object, you have to include the torque due to the weight of the object. Depending on the reference point that you choose, the weight of the object might have a torque. The location at which the weight of the object acts is at the center of mass of the object. So, the first thing you may want to do is the find the center of mass of the meter stick.

Part 2 - Single Torque: Design an experiment to investigate the presence of a single torque on the system.

Part 3 - Net Torque: So far there has only been one torque acting on the ruler. Now you will be dealing with a system that has multiple torques acting on it. Explore!

Q1. How many forces are acting on the meter stick? Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well.

Q2. How many torques are acting on the meter stick? Why this is number different than the number you wrote for the answer to **Q1**?

Q3. In what directions are the torques acting (Counterclockwise or Clockwise)?

Q4. What is the net torque acting on the meter stick? How do you know this by looking at the meter stick?

Q5. Calculate the *weight* of each mass assembly. (Make sure you are using units of kilograms for *mass*.) Put these values in data table. Remember you are to determine how many torques you have, either clockwise or counterclockwise.

Q6. Measure the distance, ***r***, (in meters) for each torque. Remember, ***r*** is defined as the distance from your chosen reference point (i.e., fulcrum) out to where your force is acting. Place these values in the table

Q7. Calculate the torques, $\boldsymbol{\tau}$, and put these values in the chart. Also, put these values in for the total torques since there is only one torque per side. Calculate a percent difference between these totals. If you got a value greater that 5% then you are doing something wrong. Go back and check your data.

Part 4 – Center of Mass as Torque: For this section you will be moving the fulcrum away from the center of mass. This will cause the weight of the meter stick to have a torque.

Q6. How did you know where to place the mass/masses to balance the stick? Explain in detail using torques.

Q7. Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well. Describe the torques acting on the stick.

Q8. Calculate the weights that are causing the torques on the stick and place these values in the appropriate places in the data table.

Q9. Measure the distance, ***r***, for each torque. Place these values in the data table.

Q10. Calculate your torques and total torque. Calculate a percent difference between your total torque values. If you got a value greater that 5% then you are doing something wrong. Go back and check your data.

Part 5 – Multiple Torques on a Side: Remove the masses currently on the meter stick. Place fulcrum at 60 cm. Add an extra mass of 200 g at 90 cm. Add an extra mass of 100 g to balance the system.

Q11. Draw a diagram of the meter stick showing each force vector acting on it. Place each vector in the approximately correct location as well. Describe the torques acting on the stick.

Q12. Calculate the weights that are causing the torques on the stick and place these values in the appropriate places in the data table.

Q13. Measure the distance, ***r***, for each torque. Place these values in the data table.

Q14. Calculate your torques and total torque. Calculate a percent difference between your total torque values. If you got a value greater that 5% then you are doing something wrong. Go back and check your data.

Please self-assess your lab using the rubric/checklist