COMPILATION: Unit 8 - Uniform Circular Motion Lab. Part 1

Part 1: paradigm labs that use some version of a mass, string and a tube.

Date: Fri, 19 Apr 2002
From: "Park, Nicholas" <ParkN@CFBISD.EDU>
Subject: UCM Lab -- Help!!

Yes, I'm only now on Unit VIII... and today was the 2nd 90-minute period spent on the UCM lab. The trouble is that there is no consensus on the results -- on group found that speed is prop. to length, another found speed is prop. to L squared, another found speed squared is prop. to L, and another found speed to the 5th power is prop. to length!!! I checked their control of variables and their calculations, and all appeared to be in order.

In my last two classes, the students re-ran the lab as a whole class, and got data that looked linear, with only the slightest hint of a downward concavity -- not enough to be convincing. I don't see how I can get any conclusions from this; I guess I could just derive the relationship theoretically, and chalk it all up to error, but that doesn't sit well with me (or them)...

Date: Mon, 22 Apr 2002
From: Chad Dorsey <dorseyc@LINK75.ORG>

Nicholas Park brings up his troubles with the Uniform Circular Motion (UCM) lab he's doing. A group of modelers in Maine this summer had similar troubles during a session trying to work the bugs out of this lab. In the end, our troubleshooting session had us wanting to shoot the cause of our troubles...

Has anyone had any luck with creating an incarnation of this lab that is anywhere *near* reliable? I personally haven't even covered circular motion because of the troubles with this lab (and because of time, but that's a whole other story...)

Date: Mon, 22 Apr 2002
From: Lou Turner <louturn67@AOL.COM>

I just read about another teacher being frustrated in getting good results for finding the relation between variables in UCM. So I am repeating an approach that I posted maybe 5 years ago.

The pre-lab discussion identifies the relevant variables as F, M, R, and T. My objective is to decide if the force acting on the object varies directly or indirectly as each of the variables M, R, and T. For example, I have the students make a stopper move in a circle at a convenient radius, say 40 cm, and measure the time it takes to make one revolution. I ask the students to then double the radius and keep the mass and time the same. It is not necessary that the time be exactly the same, but it is important that the time be approximately the same as before. It usually takes my students two trials to get close to the same time. For the student doing the twirling, her responsibility is to decide if the force increases, decreases or stays the same when the radius is changed from R to 2R. She does this by judging the force she exerts on the string in the two cases. The fact that the force increases means that the force varies directly as R. The other two variables are investigated in the same manner.

The students with only a small amount of care can tell me that F varies directly as M and inversely with T. The exponents are then determined by dimensional analysis. The equation must be

F = k*M^x *R^y/T^z

Since the units on both sides of the equation must be the same, and the units of force are kg*m/s^2, this means that x = 1, y = 1, and z = 2. I then find k by using the Sargent-Welch apparatus that allows the measurement of F,M, R, and T with good accuracy. Many of my students get close to 40. In the postlab discussion I state that the experts know that k = 4*pi^2, and then it is easy to write the equivalent equation containing the speed of the object.

Date: Tue, 23 Apr 2002
From: Sean McKeever <educonic@YAHOO.COM>

I too experienced the same difficulties with the UCM Stopper-Mass lab. In fact, it has been one of my pet projects to solve this issue since I started working at PASCO. Thanks to some ideas from other teachers combined with my own, we have a solution. You can try to recreate this on your own, if you have the time and patience.

Basically, you need to use a motor to spin an arm with a pulley in the center. Hang a force sensor directly above the pulley and run a string from the sensor through the pulley and out to the edge of the arm. There you can connect masses of various amounts. The force sensor will measure the centripetal force directly.

Perform three experiments:

1. Force vs. mass (change the mass on the end of the string)
2. Force vs. velocity (change the voltage supplied to the motor; a photogate measures the velocity)
3. Force vs. radius (move the force sensor vertically)

The shapes of the graphs are beautiful and we achieved experimental results with about 1% accuracy. I know not everyone will be able to afford this solution, but even if you could buy/create one for your classes and collect the data together, it would be far superior to the stopper-mass lab. We'll have this product ready for next school year.

Date: Tue, 23 Apr 2002
From: Jeff Steinert <jsteinert@auburnschl.edu>

I have had excellent success with the following approach to the UCM Lab:

We use the traditional setup with a stopper on the end of a length of fishing line threaded through a short glass or plastic tube with a 100 or 200 gram mass on the bottom end to provide the centripetal force. Students investigate only the relationship between velocity and radius while holding the Net Force (Fe/o on the 100 or 200 gram mass) and mass of the stopper constant. It is extraordinarily important that data is collected for a wide range of radii (we use from 1.5 m down to 0.15 m, marking the line with a small piece of tape to keep the radius constant). Students time the period using 10 or 20 revolutions, calculate the velocity using 2piR/T and plot v vs. R. As long as a sufficient range of radii have been used, they find that v^2 is directly proportional to R. It is extremely important to be sure that students can count the revolutions at the shortest radius. Using a smaller hanging mass (100 g) with the smaller mass stoppers makes this easier (I suggest no more than about 5:1 for the hanging mass:stopper mass ratio).

In the post-lab discussion, someone always notices that the slope has units of acceleration (m/s^2). If no one volunteers it, I will ask the class to see if they can find an independent method of determining the acceleration. Again, someone always suggests using Newton's 2nd Law (a=Fnet/m). This gives them a value to compare with the slope of their v^2 vs. R graph. Since groups have different mass stoppers, there is a range of values for slopes/accelerations. Only one group had a % Diff > 5% this year! Of course, suggesting the stopper is accelerating also opens up an excellent discussion about how its velocity can be changing even though it does not change speed.

Their conclusion, therefore, is that

a = Fnet/m = v^2/R

where

v = 2piR/T.

Rearranging and substituting leads to

Fnet = mv^2/R = m 4 pi^2 R/T^2.

The advantage of this approach, in my opinion, is that it vastly decreases the number of trials each group needs to perform, requires them to apply a previously derived model to evaluate their results and gives uniformly excellent results. What do you think?

Date: Tue, 23 Apr 2002
From: Richard McNamara <richmcn@EARTHLINK.NET>

Sean McKeever wrote:
<< I too experienced the same difficulties with the UCM Stopper-Mass lab [... due to] differences between the weight which the string supports and the actual centripetal force on the stopper. >>

I have a different approach, which I've had a great deal of success with. Instead of a discovery type of experience, it's more of a validation experience.

We start by examining the motion map for an object traveling along a circular path at a constant speed. Using a compass and protractor the students complete the following steps:

1. They start by drawing a circle with a radius of more than 5cm, but small enough to fit on a standard sheet of paper. (They chose their own radius)
2. Since it's traveling at a constant speed the dots should be at equal distances along the path. Students can pick an angle between 5 degrees and 45 degrees and mark the positions half way around the circular path.
3. (After letting the dry ice fly off a circular path along a tangent line back in Unit IV), it doesn't take much Socratic discussion to identify that the velocity at each point should be perpendicular to the radius. They can choose any length greater than 5 cm and must draw a velocity vector for each point on the motion map.
4. Picking three points in a row from anywhere on their motion map, I have them use the protractors to draw the velocity of the third point and subtract from it the velocity at the first point. Just as when we first determined the direction of acceleration vectors back in Unit III, we assign the delta velocity arrow to the middle position dot of the three selected at the beginning of this step.
5. We redraw that delta velocity arrow at the middle point and examine its direction.

At this point I poll the class to see which way each individual's delta velocity points. Lo and behold, they all point toward the center of the circles even though their circles are all different sizes, with different dot spacings and different length velocity arrows.

Using similar triangles from the original motion map and the velocity vector addition, we use ratios to show that since:
delta x/ r is proportional to delta v/v and dividing both sides by delta t, we end up with the formula for centripetal acceleration.
We discuss the basis for this new equation and question how valid it might be. They readily admit that without data we can't use this equation, so we design an experiment to confirm the relationship.

The lab we use is a pendulum with a twist. First, the end of the string is attached to a force sensor. The string then passes through some type of tube or holder to keep the forces along the axis of the force sensor. We use energy relationships to determine the velocity at the bottom of each swing. We can change the velocity by changing the from which we release mass.

I have students draw a force diagram for the object at the bottom of its swing. Two forces show up: the upward pull of the string on the object and the downward pull of the earth on the object. They shouldn't be equal. By putting in the new equation for centripetal acceleration and solving for the force of the string, we get:

Fstring/object = (m/r)*velocity^2 + Fearth/object.

Students collect data on Force Sensor reading vs. Velocity. The graphs form top-opening parabolas with non-zero intercepts. By test-plotting Force vs Velocity Squared, we get linear plots with non- zero intercepts. The kids easily identify that the intercept is the weight of the object. Each group is assigned a different string length, so we do synthesis of the results and plot slope of the equations vs. radius. The graph is a hyperbola so we test plot slope vs. 1/r. The resulting graph is linear with a negligible intercept. The slope is the mass (assuming all groups used the same mass.)

I believe this approach has several advantages:

1. It shows students that we can extrapolate existing models to new situations, but it still requires data to validate any new relationships.
2. Students believe that a centripetal force is a new type of force separate from the other types we've seen up to this point (gravitational, normal, frictional, tensions, etc.) Since the centripetal acceleration here is the difference between the two existing forces,
3. This approach reinforces Newton's 2nd Law.

This lab doesn't require as much from the students in the way of experimental design but it does have other advantages.
