Name:________________________________

Partner's Names:________________________________

Physicists Workshop 5: Projectile Motion

Goals

- Improve communication and teamwork capacities
- Gain confidence in scientific investigation, including appropriate use of equipment
- Keep careful records of observations
- Review uniform motion and uniformly accelerated motion
- Explore Galileo's claim that projectile motion can be decomposed into uniform motion and uniformly accelerated motion and that the combination is a parabola
- Review video analysis
- Use a graphing program to produce graphs, including motion diagrams and position vs. time graphs

Equipment

- Ramp made of bent aluminum u-channel
- Steel ball
- Ring stand with ring clamp
- Strips of paper with carbon paper OR aluminum foil
- Tape
- Computer, LoggerPro, network connection

Background

In the *Dialogues Concerning Two New Sciences* (*Essential Galileo*, p. 334, 356-357), Galileo claims that the curved motion of projectiles which had been previously observed was actually described by the geometric curve of a parabola, and that this motion was made up of uniform motion (in the horizontal direction) and uniformly accelerated motion (in the vertical direction). In this investigation, you will explore Galileo's claims in two ways: by reproducing a version of what he describes, and also through the use of video analysis. You will also view a series of videos (though not analyze them) which make a bridge between points Galileo makes in *Two Chief World Systems* and this work on projectiles.

General Outline

Today's activities break up into three broad sections:

1) a hands-on component that replicates Galileo's investigation and data collection
2) a related investigation using video analysis;
3) viewing (but not analyzing) a series of videos that relate both to projectile motion and also to *Dialogue on the Two Chief World Systems*, section 8.5, **Day II: Vertical Fall, Conservation of Motion, and the Role of Experiments** (*Essential Galileo* pp. 222 – 233), which is your reading assignment for Thu. Oct. 27 and will be discussed in class that day.

Galileo's Investigation of Projectile Motion

1. You will be oriented to the equipment and data collection. Make sure to take notes and ask clarifying questions. Basically, you will be gaining hands-on experience with what Galileo describes on the bottom of p. 360 and continuing onto p. 361 (in *Essential Galileo*).

2. Your vertical distances will be (all in cm): 2, 8, 18, 32, 50, and 72. If you have time, interest, and want to take on a challenge, you should also try to get (again in cm) vertical distances of 98, 128, 162, and 200 (this might involve collisions with the floor instead of the bench-top). Why these distances? Hint: divide the numbers by 2. What pattern do you notice? Given that these are vertical distances, and we saw last week something about motion in the vertical direction, what can you conclude about the time for the 2 cm trial compared to the time for the 8 cm trial compared to the time for the 18 cm trial, etc.? This might be a challenging question, so please work on it in your group for a few minutes and then consult with others as needed.

3. Now, work through the investigation. Make sure to measure vertical and horizontal distances as carefully as you can, following the protocol discussed in class. Fill out the data table below. Please note that the format of the data table is to minimize the space on this page – it is not necessarily the way that you might want to enter the data into your computer graphing program.

	required							Optional but encouraged			
Time (s) wait till 4. below to fill in											
Vertical distance (cm) set by you	2	8	18	32	50	72		98	128	162	200
Horizontal distance (cm) measured by you											

4. Since we've argued (see 2. above) that the time associated with each vertical distance increases at a regular rate, we know that the time for the 8 cm vertical fall is twice the time for the 2 cm fall, the time for the 18 cm fall is three times the time for the 2 cm fall, the time for the 32 cm fall is four times the time for the 2 cm fall, etc. The 2 cm fall time is very close to 0.064 s, which is verifiable through video analysis among other techniques. Please go ahead and fill in the Time row in the table above.

5. You now have a data set very similar to what you worked with last week. Using a computer graphing program, produce:

- a y vs. x graph (vertical distance y vs. horizontal distance x, with y on the vertical axis and x on the horizontal axis), being careful with how you enter the data into your spreadsheet or program
- an x vs. t position vs. time graph (horizontal distance x vs. time t)
- a y vs. t position vs. time graph (vertical distance y vs. time t).

You may note that your y vs. x diagram looks a bit different than what Galileo shows on p. 361. It seems that he has accounted for the fact that the ball is falling and for the fact that in his set-up, the ball is moving to the left. If you are interested, you can adjust your data to account for these: make all your distances (though not your times!) negative numbers. We can't actually have a negative distance, but this allows us to account for the fact that the ball is falling and moving to the left.

6. Include appropriate trendlines on each of your three graphs. Make sure to display the equation and R^2 value.

a) Which graph (if any) offers evidence in support of Galileo's claim that one component of projectile motion is uniform motion (in other words, constant speed)?

b) Which graph (if any) offers evidence in support of Galileo's claim that one component of projectile motion is uniformly accelerated motion?

c) Which graph (if any) offers evidence in support of Galileo's claim that projectile motion is parabolic?

Video Analysis of Basketball Shot

At the link from the Calendar page for today, you will find a file titled Basketball Shot with Analysis. Save this file to your computer (right click on the file and use 'Save link as' or 'Save target as' or equivalent). Note that this is a LoggerPro file, not a video file, so you'll just open it directly or in LoggerPro rather than using Insert: Movie. This file does have a move attached to it already, and the mouse clicking has already been done for you to save time. However, if you have never done video analysis before, you can download Basket Ball Shot without Analysis and learn from your classmates how to do video analysis using that file.

1. Play the movie, and then scroll through it slowly. You should see the dots already laid out for you. We'll concentrate on the time when the ball is in the air, before the first bounce (which is about the first 1.5 seconds, or the first 40 data rows). Copy that Time, X, and Y data into Excel or program of your choice (and don't forget to label the columns).

2. As you have before, produce:

- a Y vs. X motion diagram
- an X vs. Time position vs. time graph
- a Y vs. Time position vs. time graph

3. Include appropriate trendlines on each of your three graphs. Make sure to display the equation and R^2 value.

a) Which graph (if any) offers evidence in support of Galileo's claim that one component of projectile motion is uniform motion (in other words, constant speed)?

b) Which graph (if any) offers evidence in support of Galileo's claim that one component of projectile motion is uniformly accelerated motion?

c) Which graph (if any) offers evidence in support of Galileo's claim that projectile motion is parabolic?

Just for Viewing

At the same link from the Calendar page for today as above, you will find a series of videos under the heading **Just for Viewing** (which means no need for video analysis (and since in many cases the camera is moving, it's very difficult to do video analysis even if you wanted to).

1. Watch each video (you may need to download the video to your machine and then play it, or use a different browser).

2. As you watch (and re-watch) each video, consider how it connects to the projectile motion work you just did (if you think it does).

3. Also, keep the videos in mind as you review the reading for Thursday's class.