Bouncing Ball Lab Introduces Models and Foreshadows Future Physics Concepts

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Contents

Background

I have used this lab as an introduction to my physics classes at all levels: First year to AP. The goal of the lab is to introduce students to the role of physics in making predictions, and for me to see where they have strengths and weaknesses in lab procedures and data analysis.

I have formatted this outline using the 5E Instructional Model.

This document is sort of version 0.9, so please excuse any inconsistencies in pronouns.

NGSS standards

Science & Engineering

- HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Foreshadowing

As we progress through the year, I have students reflect on the Bouncing Ball lab when investigating the following standards apply:

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- HS-PS3-2. Develop and use models to illustrate that **energy** at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

Crosscutting Concepts

- HS-PS2-2 **Systems and System Models**: When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Student focused learning objectives

- I can develop lab procedures based on a desired outcome and using available tools.
- I can record measurements using appropriate units.
- I can plot data and apply a predictive trendline to make predictions outside the range of my data.
- I can develop a model of a phenomenon, and recognize the limits of my model.

Engage

The Challenge

Present your students with a variety of balls and a meterstick. The challenge for your students is to develop a method of determining how high their ball will bounce if dropped from 1.5 meters and from 5-6 meters (find a balcony/stairwell that you can use). I inform my students that a portion of their grade will be based on how accurate their prediction matches the results, and I encourage you to do the same (more on this later).

Explore

Introduction to Experimental Design

1) Ask your students to spend about ten- to fifteen minutes with their lab group discussing and brainstorming a set of experimental procedures. Let them know that all groups will share out experimental designs at the end of the brainstorm session.

a) You may want to remind them that the purpose of a brainstorm is not necessarily to develop all the steps of their procedures, but to come up with a skeleton of procedures, or perhaps even a couple different procedures.

2) After this, facilitate a class-wide discussion to help generate:

a) "Rules" around what is fair (e.g. you can't measure the height of a table, then place the meterstick on the table to get 1.5 meters–*but congratulate any group that develops this or similar "illegal" procedure as being creative!*)

b) ***Some*** class-wide practices (e.g. we'll all drop on the floor, and not tables, so everyone has a similar bounce surface).

c) Demonstration that there are different ways to approach the challenge.

Goals of discussion

In the class discussion, the goals are:

3) Students define the "Independent variable" as the drop height, and the "Dependent variable" as the bounce height.

4) Determine the units they will measure with (meters or cm, depending on the outcomes you desire).

5) Develop experimental "best practices." For example:

a) Collecting ten data points to plot on a graph.

b) Averaging three data points for each independent value tested.

6) During the discussion, you may find:

a) Some groups will say "bounce it from 1 meter and from 0.5 meters, then add them." I usually show two points on a graph, then draw a straight line through them and a parabola through them, and ask which trend is the best predictor.

b) Students may suggest using camera phones to record the height of the bounce—work out with your students what you will accept—but be open to accept creativity.

7) Here is where you can the level of guidance for this inquiry lab: e.g. do you want your class to develop a few procedures that all will follow, or will you be more open to letting them discover later which procedures work best. You may need a few years of working with students in your classes to determine their level of guidance they need. **Examples of 'consensus' procedures may include:**

a) Number of independent variable data points to collect (I usually like to get them thinking ten is a good ballpark).

i) If students suggest dropping from 0.5 and 1.0 m and averaging the two, I sketch a quick graph axis on the board, add two data point at "x = " 0.5 and 1.0, then ask "Is this a straight line or a curve?" Most students will respond "A line." Then I draw an "upward" parabolic curve through the points, then a "downward" parabola, and ask "Are you sure?" This helps develop the idea that the more data points we plot, the more sure we can be of the model/equation we develop (linear, exponential, power, etc.).

b) How many trials for each height (I usually suggest three, so they can see if differences are design limitations—measurement uncertainty—or poor dropping technique/observing technique.

c) Hopefully a group will bring up ***where*** on the ball the group is going to record from. Some may want to record from the top of the ball, some from the bottom. It is best not to force either way upon them, but to allow each group to determine **and record** where they will be measuring from. The location of the measurement will not affect the slope of their graph, but will affect the y-intercept.

i) Allowing for different groups to use different measuring points will allow this to be revealed in the whiteboard meeting. (Hint: If you measure from the top of the ball, how high will the ball bounce if you drop the ball from zero…and can you drop the ball from zero?)

8) This is a good time to remind students that a portion of their grade is the accuracy of their prediction, as this may encourage them to focus on following procedures carefully.

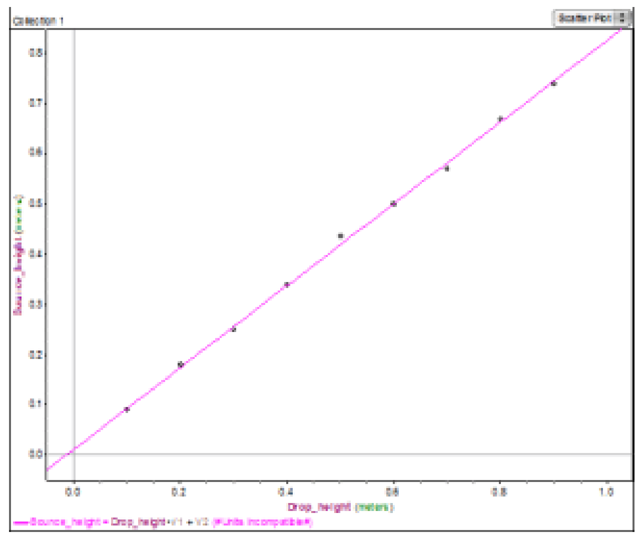
General experimental design procedures students may develop

9) Most students will develop an experiment that involves dropping the ball from 1.0 meters, 0.9 meters, 0.8, etc.

10) Three trials at each drop height ensures accuracy of measurement.

Data analysis

You will need to determine the level of scaffolding you will need to provide your students for analyzing data. Many students have not done this type of analysis before (even in 11th or 12th grade), so I advise providing them with higher levels of scaffolding than you think they will need. If you discover they didn't need it, you can provide less later, but if this lab is used as an introductory lab, proper scaffolding will allow students to see that physics experiments ***can*** work.



After conducting their experiment, each group analyses their data by plotting a graph (by hand or using a computer/calculator), then presents their analysis to the class on a whiteboard. Results include:

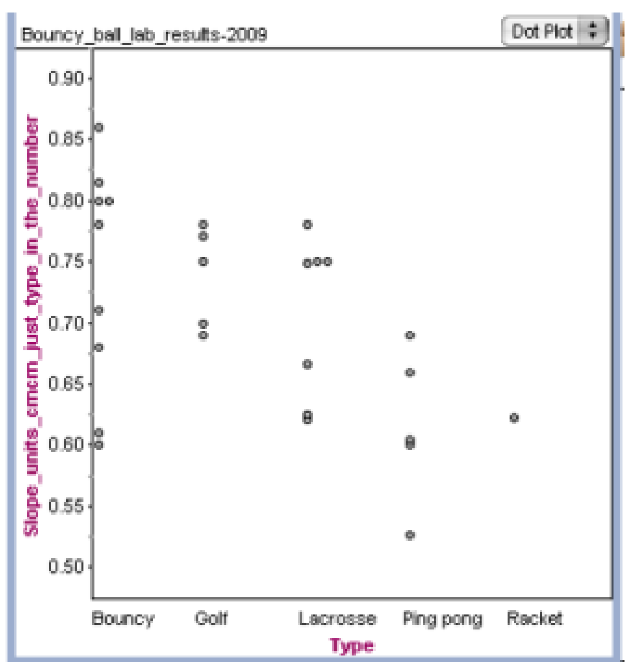
11) Shape of graph.

12) Slope of graph (with proper unit)

a) These units students may want to 'cancel out' (m/m or cm/cm), but I enforce that they must always include units with numbers (except, I guess, the units for the friction coefficient when we get to that).

13) Y-intercept (with proper units)

Graphing



To the right are a couple of computer generated graphs. The first shows one results from one student group. Most groups will generate a scatter plot similar to this.

From this graph and their best-fit line, they generate their slope and y-intercept. I always assign as their first-night homework to submit, via the internet, their slope, y-intercept, and type of ball.

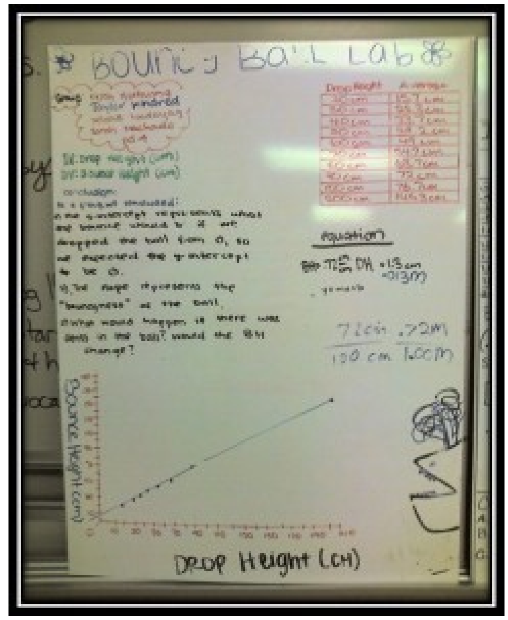
The second one shows the magnitude of the slope of each type of ball. By collecting this data from their homework, I can present the results of all classes when I start with the first class the next day. This helps to let students identify outliers and to see the trend for each type of ball.

Explain

Board meeting

In the "Board meeting," the class develops the meaning of each of these concepts. This takes careful work by the teacher. The goal is to have students develop the wording, not have the teacher provide it.

> *During the Board Meeting, student gather either as one complete circle, or, my preference is to have a 'fishbowl" consisting of one representative from each group gathered as an 'inner circle' to discuss the results, and everyone else gathered behind them to take notes on conclusions. I find the fishbowl method provides for more authentic conversations (with only 7-10 participants) and frees up the reps from needing to take notes of their discussion.*

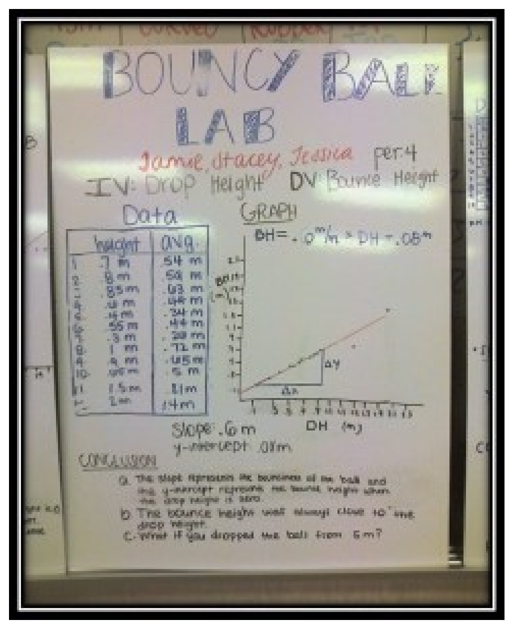


Generally, the first step is to ask the students to focus on what is similar in all the group results. Some seem almost to 'obvious' that students won't mention them, and the teacher needs to craft wording carefully to prompt the students to off these similarities. Similarities might include:

- All the data shows a straight line.
- All lines are sloped upward.
- All start at (or near) (0,0).
- The slopes are all less than one.
- The y-intercepts are all close to zero.

You may find that some group's results don't match the rest of the class. A few possible differences that may arise include:

- Data doesn't look like a straight line, and some students with good math skills may apply a curve fit to it.
  - This presents a good opportunity to discuss the rationale for collecting a large number of data points. If the group fit a curve to fewer points (especially if they only chose three points), you can re-introduce the discussion from Step 7)a)7)a) above.



Each group then determines a predicted bounce heights. In determining their bounce height, students are encouraged to use both their graph (find 1.5 m on the horizontal axis, go up to the line, then go over to the vertical axis) and their equation (input 1.5 and find the answer). However, this is also a place to encourage students to see there are often more than one way to solve a problem!

Once we finish the discussion, we are ready for the testing!

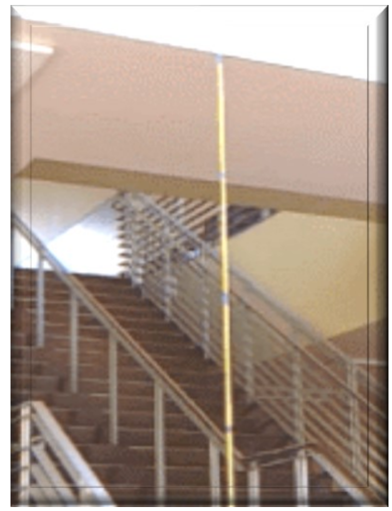
Extend

Testing:

1.5 meter challenge

- I have two metersticks taped together, and each group brings up their ball for the test.
- After testing, students find that their prediction matches their results, usually within 10%. (Depending on the level of your class, you can have them calculate a "percent error" or simply have them calculate their prediction as a percent of their actual.)

6 meter challenge



- To test the 5 or 6 meter challenge, we go out to an area with a stairwell where students can line up to observe the height of the bounce. This presents an opportunity to discuss parallax ("whose eyes are most 'lined up' with the bounce height?"). Finding a good location for this challenge is important, since you need a location where students can line up along the stairs so at least a few are near where the different ball types will rise to.
- I hang a tape measure with every meter marked off with blue tape, and every half-meter marked off with another color. This allows students to see where they line up on the tape, as they are likely to be too far away from it to be able to read the numbers.
- About half the groups find their prediction is not close to their results (their prediction is too high).
- Generally, it's the balls with low density that have the worst results (usually a student notices this in the discussion, but be ready to prompt it if it does not come out).

Evaluate

Concluding discussion

- The first question I ask when we have our concluding discussion is "*Would it be fair for me to grade you based on the 1.5 m drop?*" The class generally says "**Yes!**" since they all got A's on it.
- My next question is "*Would it be fair to grade you on the 5 meter drop?*" The answer has at least half the class responding with a resounding "**No.**"
- I inform them that their accuracy grade will only be based on the 1.5 m drop, and that those who got 90%+ accuracy get an A on the accuracy portion of their score.

Moral of the story: **Physics works.**

- We then address the meaning of the **slope** and **y-intercept**:
  - Since balls that "bounce high" have high slopes, we define the **slope** as the "bounciness" of the ball. Be careful with wording, as students will want to talk about a ball that "bounces high," and not "bounces high from a given drop height."
  - The **y-intercept** is "how high the ball will bounce if dropped from 0 m."
  - This leads to discussion of **experimental design**: Most students get a y-intercept close to zero, but some students get a significant positive y-intercept. Usually, on examination of their procedures, it becomes clear that they were measuring from the top of their ball, and thus it physically impossible to drop from 0.0m–but there is still a mathematical y-intercept.

- We then discuss why the five meter challenge wasn't successful. Students bring up different ideas:
  - The floor outside is different (one year, after this variable was raised, I had a group to go back out and test the floor to determine this is not a problem).
  - Air resistance must be playing a role.
  - More energy is lost when the ball falls further.
  - Most of these are left to "*we'll come back and look at this lab when we address these concepts later in the semester*," but some can be resolved right there. I had one group who went out with their ball and a meterstick to check to see if the floor was different, and proudly came back to say it was not.

Follow up quiz/assessment

I usually provide a sample of data and ask students to make predictions based on it. One of my favorite is plotting the college tuition trend over the past 50 or so years [link to be added]. The private school average is about linear during this period, but the public school average is not. I ask them to predict the price of college when they go to college, and the price when 'their kids' go to college, and ask which they are more confident about. I also ask the to determine the year when, according to the graph, college was free. These questions are great at reinforcing that models have limits. (When I taught in Catholic schools, I would ask 'How much did Jesus have to pay for college? The answer is he got paid around $1.2 million ☺.)

Pedagogy and discussion about the lesson

What I value most about this lab:

- It starts physics by presenting students with a challenge that they can *successfully* complete.
- It lets me see who is having difficulty with graphing *before* I get to the "real physics."
- It introduces data analysis without introducing new physics concepts. It allows students to use their own language, which sometimes allows me to say "*Many terms often mean something different in physics than in everyday language. Let's leave the physics terms out of our discussion until we have defined them in class.*"
- It creates a foundational experience that we can return to throughout the year.

Generic data table

In my physic classes, we do a lot of labs. Students are encouraged to create their own data tables, but many aren't so "linearly" inclined, and have difficulty creating neat tables. I created a generic data table they can use on any lab.

IV:	DV:					
	Average	Trial 1:	Trial 2	Trail 3		

Credits

I would like to thank the American Modeling Teachers Association (AMTA) and Arizona State University for their work in designing and training teachers in the use of a rich curriculum that develops thinkers rather than memorizers. This lab is based on an AMTA introductory lab.

Clipped and modified from my blog post: **http://trampleasure.net/lee/index.php/994**