The Bouncing Ball

Teacher Lab Discussion

Overview

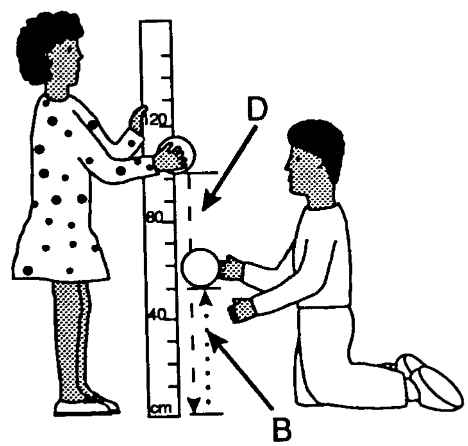
This is one of the first experiments involving two quantitative variables. Both are length variables, the simplest we can use. In this experiment we will determine the exact relationship between the height from which a ball is dropped and the distance that it rebounds. But these are not the only variables involved in the experiment. Because the other variables are clear and easy to understand, we shall use this Teacher Lab Discussion as a general introduction on how to deal with variables.

Finding All The Variables

One of the first tasks in designing an experiment is deciding what the two primary variables, the manipulated and responding, will be. The next task is to determine all the other variables that affect the values of the responding variable. A bouncing ball is one of the simplest and most familiar objects in the child's world. One can think of many variables associated with a bouncing ball.

In this experiment we have selected two interesting quantitative variables. The two variables are the release height (measured from the bottom of the ball, in cm) and the bounce height (again measured from the bottom of the ball, in cm). Figure 1 depicts a picture of *The Bouncing Ball* experiment. Suzie releases the ball and her partner, Lyle, kneeling to get a level view of the ball, measures the bounce height. Notice that both variables have been labeled on the picture. This is good experimental technique. There are other variables besides these two. One qualitative variable is the technique of releasing the ball. If one throws it down instead of just dropping it, then the bounce height will be very different. Indeed, that is the question to ask. If I change the value of this other variable, will the values of the responding variable change? In that light, it is clear that if we change the type of ball, then the bounce height will also change. So, the type of ball is another variable to consider. Is there anything else? We hope the children will see, when you ask them this, that the type of floor will make a difference. The bounce height off a soft carpet is very different from the bounce height off a hard floor. That should about cover it for *The Bouncing Ball* experiment, but each experiment will bring its own set of variables, and so an introductory discussion of variables is crucial to understanding the experiment and defining what one wants to measure. In the next two sections we shall discuss how to choose the values of the manipulated variable and how to find the correct values of the responding variable.

Figure 1



Choosing the values of the manipulated variable

The experimenter can pick any values of the manipulated variable he or she wants. However, a little common sense shows us that some choices are better than others. One goal of any experiment is to see a pattern in the relationship between the variables. We must therefore select at least three values of the manipulated variable in order to see the relationship between the variables. Also, if the values you choose are too close together you may not be able to see the pattern. For example, dropping the ball from 20 and 22 cm, there may be no significant difference in B because of the "error" in making the measurement. It is not easy to determine the maximum height of a moving bouncing ball with better than 2 or 3 cm accuracy. So then, what values of D should we pick? It is best to pick them so that they are multiples of the lowest value. If we decide that the lowest value is 10cm, then we pick 20 cm and 30 cm, or 20 cm and 40 cm for the other two. If we choose values of 10 cm, 20 cm, and 40 cm for D, then a 1 cm error in the drop height will not overlap the other drop height values and will not affect the value of the responding variable very much. Moreover, if we double D each time, then we already have a pattern, and this makes finding corresponding patterns in the responding variable that much easier. When we do the bouncing ball experiment, we like the values of D to be 40 cm, 80 cm, and 120 cm so that: (1) the children do not have to get their noses to the ground to make the measurement, and (2) they have to figure out how to measure something greater than a meter. You, however, make the choice of the values of the manipulated variable based on what you want the children to do and on your circumstances.

Finding the correct values of the responding variable

Good experimenters have to make sure that they have obtained the correct values of the responding variable. The easiest way to do this is to make each measurement at least twice and preferably three times. If the results are close, but not necessarily identical, then the children have done a good job. Close usually means the numbers are within 10% of each other. Thus, if one gets 20 cm, 23 cm, and 16 cm for the rebound, then one has got problems. Also, by doing each measurement at least twice the children can take turns acting as dropper and measurer (in most experiments, there should be no more than two participants on each team). This also gives the group at least two independent determinations of each data point which is a good experimental technique. Since these are usually different, a 3rd measurement is necessary.

Given three measurements, one wants to report only one number, their average. (See *TIMS Tutor 2. Averages.*) At the 3rd, 4th, and 5th grade level one can obtain this average by "eyeball." This means ordering the three numbers from low to high and taking the one in the middle as the eyeball average. For example, if D is 40 cm and the three trials for B give you 22 cm, 23 cm, and 22 cm, then 22 cm is a good eyeball average. If B is 20 cm, 25 cm, and 16 cm then the values are too inconsistent, and we do the experiment over (although 20 cm is the number in the middle). When children have learned to divide whole numbers and obtain decimal results, then the average can be calculated by hand or by using a calculator. The student should always check that the exact average they compute

Figure 2

Data Table: Experiment 1

Type of Ball: *Tennis Ball*

D, Drop Height in *cm* (units)	B, Bounce Height in *cm* (units)			
	Trial 1	Trial 2	Trial 3	Average <B>
40	*22*	*23*	*22*	*22*
80	*40*	*38*	*42*	*40*
120	*72*	*69*	*70*	*70*

Figure 3

is close to the average they get by estimating. The results of a typical experiment with eyeball averages is shown in Figure 2.

Picture, Data Table, and Graph

In the TIMS version of the scientific method, the children always start with a picture but only after a suitable period of exploration on their part, and a little class discussion on yours, to determine what all the variables are and how the experiment will be done. In other words, the children should play with the bouncing ball and discover for themselves all the interesting things that affect how the ball bounces. Then you guide them into what the experiment will be, i.e., that the manipulated variable in the experiment will be the drop height **(Question 1),** and the responding variable will be the bounce height **(Question 2)**, but that during the experiment the type of ball and the type of floor will be held fixed **(Question 3)**. It would be a disaster to come back the next day to finish the experiment and find that the tennis balls got all mixed up (say, they fell on the floor and bounced all over the place). You would have to start all over! Once they know what they are doing, they draw their pictures.

There are pictures and there are pictures. The picture should reflect what the children are doing, so that a person who looks at the picture can reproduce the experiment. The picture should also clearly identify the two primary variables. We show three pictures here. The picture in Figure 3 is by Lori, a 2nd grader at the Gladstone School in Chicago. Although the picture is lovely, there can be too much of a good thing. The “Art Bord” and all the details of the room are not germane to the experiment. None of the variables is identified. The picture in Figure 4 is by Kevin, a learning

Figure 4

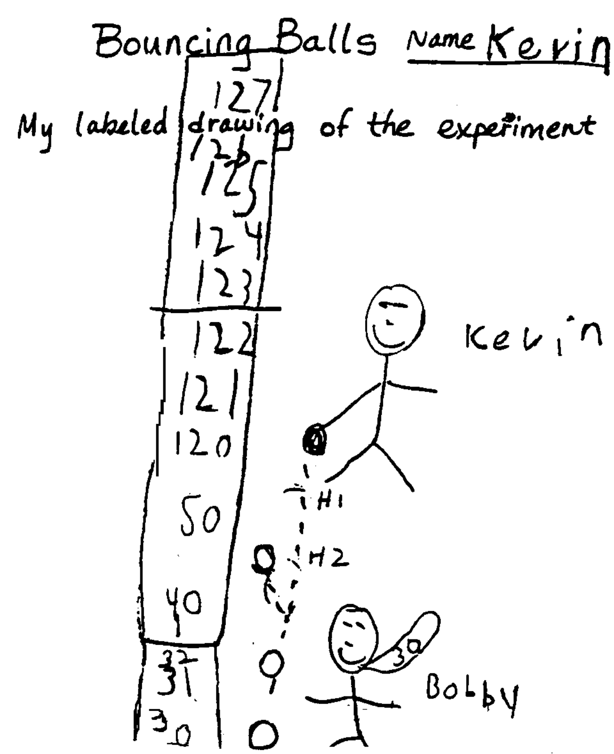
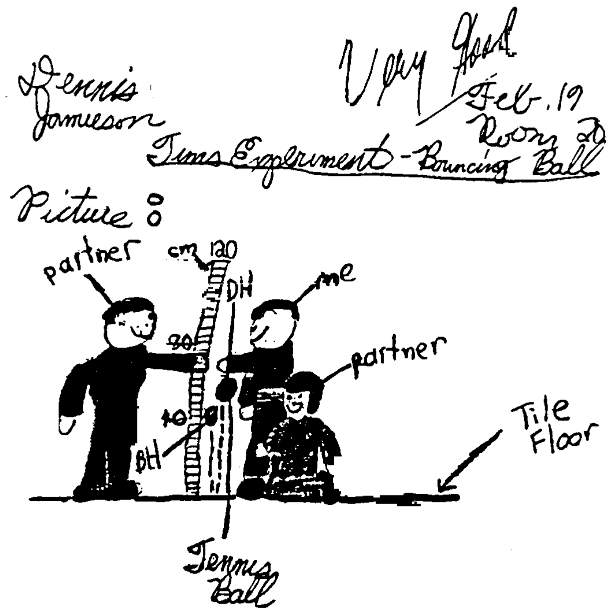


Figure 5



disabled 5th grader from the Spring Hills School in Roselle, Illinois. Although a much cruder picture than Lori's, the basics are all there: the ruler, and the symbols for the manipulated variable and responding variable. It is clear that Kevin is focused on the experiment, and that is as it should be. The picture in Figure 5 is super in every way. The drop height (DH) and bounce height (BH) are clearly indicated. The fixed variables—the ones that do not change during the experiment—are also identified. Even the values of the DH are shown as 40, 80, and 120 and still better—the units of cm are there, too. This was done by Dennis and his two partners at the Jamieson School in Chicago. If three children are working as a team it's important that all three have an active part in doing the experiment.

We want the children really to do two experiments, one with a tennis ball and then repeat the experiment with a super ball. The teachers have told us it is best if they do both experiments one right after the other. What the children should understand is that as we go from Experiment 1 to Experiment 2, we change the type of ball **(Question 4)** and that this, as they will see, changes their results quite dramatically. The data for each of Dennis's experiments is shown in Figure 6 and Figure 7. Notice the bounce height units are filled in with a vengeance. Cm are everywhere. Good! Maybe then the children will get in the habit of putting in units all the time. But units are not easy. Notice that he wrote D(H) and not D(cm). Sigh. Interestingly, the values of the bounce height are the same in Lori's and Kevin's experiment too. Of course, they all used the same drop height but they did not all use the same floor, since these schools are 20 miles apart! But maybe in schools one floor is like another—sort of a typical school wooden floor. Bring in some carpet to show what would happen when the floor does change.

Figure 6

Dennis

EXPERIMENT 1

Data Table

Type of Ball Tennis Ball

D (H)	B (cm)			
	Trial 1	Trial 2	Trial 3	Average
40	20cm	21cm	22cm	21cm
80	46cm	44cm	44cm	44cm
120	64cm	66cm	65cm	66cm

Figure 7

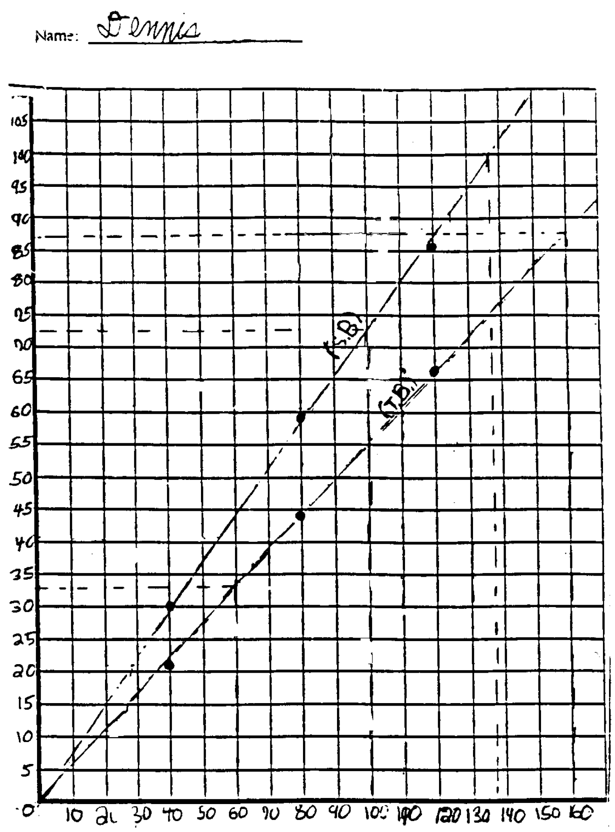
EXPERIMENT 2

Data Table

Type of Ball Superball

D (H)	B (cm)			
	Trial 1	Trial 2	Trial 3	Average
40	30cm	31cm	30cm	30cm
80	61cm	58cm	59cm	59cm
120	86cm	86cm	86cm	86cm

Figure 8



We asked the children to tell us why it is a good idea to carry out three trials for each value of D **(Question 5).** Kevin's answer is perfect: "We check it to make sure." Why do we take an eyeball average for B **(Question 6)**? Again, we let Kevin answer, "It is closest to all the numbers."

The children are asked to place both sets of data points on the same sheet of graph paper. This is a common experimental technique because it gives the scientist or mathematician an easy way of comparing the results. If we placed each experiment on a different graph, then one is constantly moving one's eyes back and forth trying to figure out the scale, etc. We show Dennis's graph in Figure 8. Notice that he had to skipcount by 5's and 10's in order to get all the data points on the graph and leave room left over at the ends. Of course, the manipulated variable goes on the horizontal axis **(Question 7)** and the responding on the vertical **(Question 8)**.

The next two questions **(Question 9, Question 10)** are very important. Oftentimes one data point is a gift. You do not have to do the experiment because logic alone is enough to tell you its value. In this case the point (0,0) is the gift. Why? Because if D = 0 then the ball cannot bounce, it just lies there on the floor, and so B = 0, too. Equally important is to realize that the curve must pass through (0,0). It is a perfect point—subject to no experimental error. So, as you can see, Dennis correctly forces the curve through (0,0). In **Question 11** we ask if the curve is a straight line. Nothing in science is perfect. This is the real world, not a mathematical artifact. So the data points will never (or rarely) lie on a perfect straight line. Yet by fitting the data Dennis finds that he does get a straight line, even though there are data points which miss each line. This idea of fitting a line is discussed in the *TIMS Tutor 2. Basic Quantitative Foundations.* Dennis does a good job, as did Lori and Kevin. Our only complaint is that Dennis's line is a bit sloppy. Putting a ruler down and drawing a solid line is the best technique. But let's not be too petty. This is an A-1 graph.

Comprehension Questions

We start with a bit of a vocabulary lesson by asking if D and the type of ball are quantitative or qualitative variables. In **Question 12**, D is a quantitative variable because it takes on numerical values, while in **Question 13** the type of ball is a qualitative variable because it doesn't take on numerical values.

The comprehension questions are heavy on reading the graphs. You might assign a few for the lab period. Let them take one home for a homework assignment and save one as a test question. It is important that the children show how they found their answer by drawing lines right on the graph. Dennis does this very well. We shall use his data in our answers. **Question 14** is an interpolation problem: how high will a tennis ball bounce that has been released from 60 cm? The children should start at D = 60 cm, move up to the tennis ball graph, and then over to find B. The children will also need interpolation skills to read the answer off the vertical axis. Dennis gets B = 33 cm. The children should then check their prediction. This is what science is all about: the power and ability to learn a lot from a little bit of data. In **Question 15** the children have to extrapolate, so the curve has to be extended in order to determine the bounce height when the release height is 160 cm. Make sure when the children plot the data that the drop height values go out to at least 160 cm. Dennis's data gives a value of B = 87 cm. And again the children should check it out. Notice both this value of D and D = 120 cm require the children to go beyond the end of the meterstick. Make sure that they do not raise the meterstick but simply add another to it, or tape a small ruler to the end.

In **Question 16** we go the other direction: predicting the drop height from an observed bounce height. Say that you see a ball bouncing to a height of 55 cm. From where was it dropped? Easy. Start at B = 55 cm, go over to the tennis ball curve and drop down to find D = 100 cm. For Dennis's data this point is particularly convenient since the curve goes right through it. We will not always be so lucky. When the children check their prediction they should drop it from 100 cm and see how close to 55 cm the ball bounces. **Question 17** is a chance for the children to express in words what they have been finding mathematically in the previous three questions. The pattern is that as D gets bigger, B gets bigger, too. And the pattern is a straight line.

We now look at Experiment 2. But first we ask in **Question 18** why redo it? The answer should be, "because we want to see what happens when we change the type of ball." And indeed things do change, as they can see by noticing the steeper graph. We give the children practice working off the super ball graph in the next two question. In **Question 19,** the drop height is 1 meter, and, using Dennis's data, the value of B is about 72 to 73 cm. **Question 20** is a real challenge. A value of B = 2 m = 200 cm is not on their graph, so they cannot use extrapolation. Instead, they have to use their heads. Here is where doubling and tripling comes in. Point out to the children that when they doubled the drop height, the bounce height doubled too. Well, almost, and that is good enough. For example, when D went from 40 cm to 80 cm, B went from 30 cm to 59 cm; so, if I find the answer from the graph for B = 100 cm, I can double the answer to get the answer for B = 200 cm. As we showed on the graph when B = 100 cm, D = 138 cm. So, when B = 200 cm, D should equal 138 cm $\times$ 2 = 276 cm. Yes, this is hard but doable for students who know their multiplication by twos. Point out also that when D went from 40 cm to 120 cm it tripled; and, lo and behold, B went from 21 cm to 66 cm for the tennis ball, and from 30 cm to 86 cm for the super ball. Both sets of values are triples.

In **Question 21** the children have to look at both curves to get the answer. A strange ball found on the playground rebounds to 18 cm when dropped from 50 cm. Is it more like a tennis ball or a super ball? The children can plot the data point and see which curve it is closer to. In this case, the strange ball is more like the tennis ball. Still, looking at the idea of what happens when we change the type of ball, Olga's ball in **Question 22** is not as lively as a tennis ball so it would have to lie in Region Z. What about a different surface? We ask in **Question 23** what would happen to the data if a soft rug is used. The graph shows two choices. Since, from a given D, the ball would not bounce as high, the lower curve, Curve Y, is the correct choice. Have a rug on the side for them to check, if they cannot see the answer from their own experience or from common sense. In **Question 24** we look at a clay court vs. a grass court. If the ball bounces higher on clay, then Curve X must be the correct curve.

The next question requires formal operational skills; or, if you wish, proportional reasoning. These are very important questions for students because the sooner the proper reasoning seed is planted, the more quickly it will grow. **Question 25** is the easiest.

You can fill in the table in one of two ways. The children can treat it as a concrete operational problem and plot the (30 cm, 40 cm) data point, put a curve through it and (0,0), draw the straight line and read off D = 80 cm when B = 60 cm, and B = 75 cm when D = 100 cm. Or they can use formal operational skills and note from their experiment that doubling D doubles B! When B goes from 30 cm to 60 cm, D must go from 40 cm to 80 cm! Likewise, going from 40 cm and 100 cm is a factor of 2.5; therefore, B must be 30 cm × 2.5 = 75 cm.

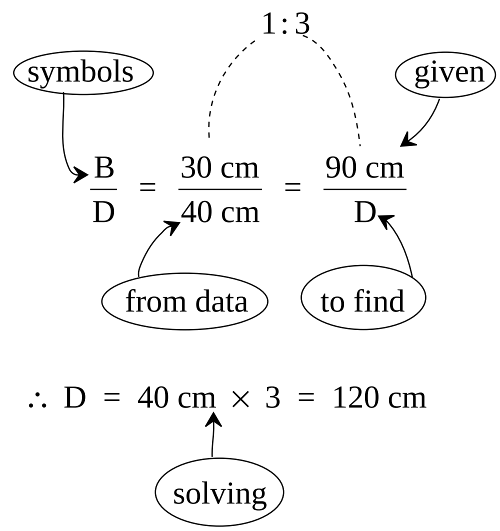
If the children are going to understand proportional reasoning, they are going to have to deal with ratios and equivalent fractions. **Question 26** is an attempt to deal with both of these ideas. The children plot the data from Question 25 and find three ratios. The answers they should get are:

$$D = 20\text{ cm};\ \frac{\text{B}}{\text{D}} = \frac{15\text{ cm}}{20\text{ cm}}$$

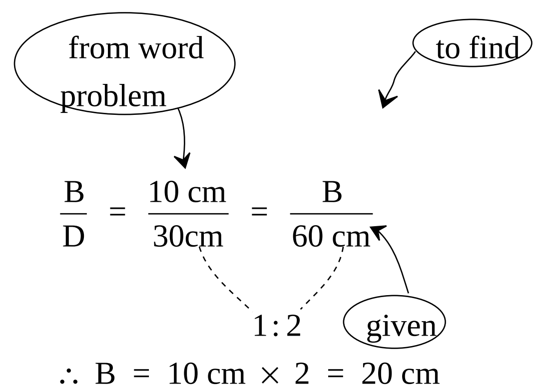
$$D = 40\text{ cm};\ \frac{\text{B}}{\text{D}} = \frac{30\text{ cm}}{40\text{ cm}}$$

$$D = 80\text{ cm};\ \frac{\text{B}}{\text{D}} = \frac{60\text{ cm}}{80\text{ cm}}$$

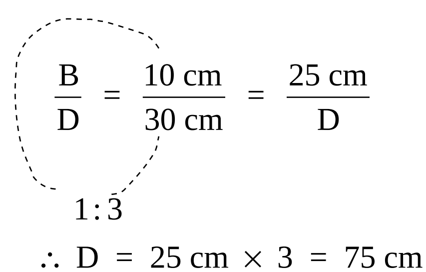
These ratios are identical. How can you tell? Let them use their calculators to find the ratio, and they will see that in each case it comes out 0.75. So, we have established that a straight line through (0,0) produces a constant ratio. This is the first step in becoming proportional-reasoning-literate. The next step is to use that ratio to solve a problem. We ask them to find D when B = 90 cm. We describe in greater detail how to set up proportional reasoning problems in the *TIMS Tutor 8. Simple Proportional Reasoning.* The steps are to set up the problem in symbols, get the ratio, put in what is asked and what is given, and solve for the unknown. We show the technique below: we picked the ratio as 30 cm /40 cm because 30 goes into 90 three times.



Question 27 is similar to Question 26, but the data is read from a word problem:



For part two of the question:



Lastly, in **Question 28** we check on how the children might pick the values of the manipulated variable. Clearly, Table V is the correct answer.

Summary

This is a long experiment chock-full of marvelous ideas. It deserves a full week—or even longer. You might want to come back to the proportional reasoning questions later in the year. But setting up the experiment, finding all the variables, extrapolating, interpolating, and checking their predictions is prototypical for almost all the experiments to follow. It is a big experiment with big ideas, so give it your best shot.

Materials per Team

- 1 meterstick and a centimeter ruler
- 1 tennis ball
- 1 super ball
- masking tape