ACTIVITY 7

# Hooke's Law

## Math Objectives:

- Graph scatter plots
- Analyze and graph linear functions
- Calculate and model slope

## Materials:

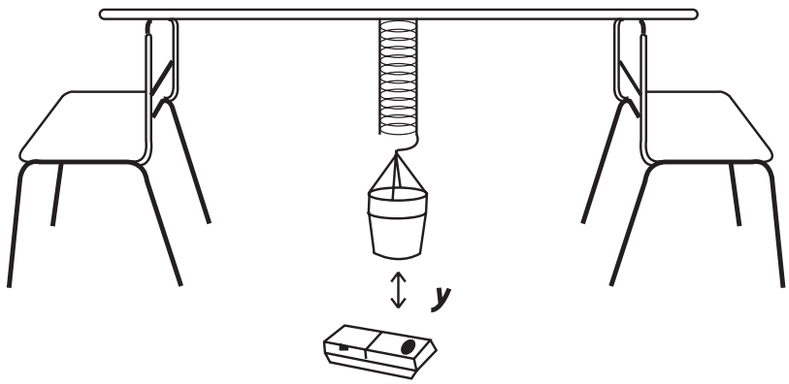
- TI-83/TI-84 Plus Family
- Calculator-Based Ranger™ (CBR 2™)
- Vernier EasyData™ Application
- Small spring cut in half (a Slinky® works well)
- Empty 4 oz plastic/paper cup (flat bottom)
- Two large paper clips or string
- Meter stick or other long stick
- Second meter/yard stick or ruler
- 30 Candies (M&Ms® and almonds work well)

### OVERVIEW

Hooke's Law, explained in its simplest form for beginning algebra students, states that the stretch on a spring is directly proportional to the force applied to the end of the spring. In this activity, the force is the weight of an increasing amount of candy added to a cup. This force is applied to the end of a spring. **See the diagram below.** The data will be collected using the CBR 2 and the EasyData App. This experiment will produce linear behavior. You will analyze the data, determine an equation of the line of best fit, and interpret the meaning of the slope. The coordinates of the graph are the distance from the cup to the floor vs. the number of candies. You will interpret the values used in your model and apply the properties of this linear model to predict future behavior/events.

**NOTE** The following activity, **Activity 8: Hooke's Law, The Rest of the Story,** uses the data collected in this activity for further investigations into linear functions. Unless you have an extended lab period or block scheduling, it is unlikely you could complete them both in an average class period. This lesson can be done without doing Activity 8, but if you plan to do Activity 8, have your students save the data into named lists for easy retrieval. Also make sure students have their worksheet from Activity 7.

**NOTE** *For more help in saving data to named lists, see Appendix E.*



## SETUP

Briefly demonstrate and discuss the data collection procedure with the class. Have students collect the data in groups of 3 or 4. Each group should do the following:

1. Place a meter stick or other long stick on the back of two chairs as shown in the diagram on the previous page.
2. Hang the spring from the stick. (A plastic Slinky® cut in half works well.)
3. Poke holes in the cup and put string or paper clips through the holes to form a handle. (You can also use an empty cream cheese or margarine container. The container you choose needs to have a flat bottom so the CBR 2 can take a reading of it. You can save valuable class time by having the handles already attached before the experiment.) Hang the cup/container on the spring with the string/paper clip handle. Make sure it is at least 18–24 inches off the floor when empty.
4. Before starting, have students measure the distance, in inches, from the top of the stick to the floor and record this on their worksheet. This measurement will be used if you choose to do **Activity 8: Hooke's Law, The Rest of the Story.**
5. Position the CBR 2 on the floor directly under the empty cup/container so you can measure the distance from the floor to the bottom of the container. Link the CBR 2 directly to the TI-84 Plus. You can use either the I/O unit-to-unit cable or the mini-USB cable.
6. The EasyData App will launch automatically if you are using the mini-USB cable. If you are using the I/O unit-to-unit cable, you will need to press the [APPS] key, scroll down to highlight the EasyData App, and then press [ENTER] in order to launch the App.

## DATA COLLECTION

1. Press the [Y=] key to access the **File** menu and select **1:New** by pressing [1] or since **1:New** is highlighted, you can just press [ENTER]. This resets the program and clears out old data. **See Figure 1.**


**Figure 1**

2. The default unit of measurement on the EasyData App is meters. You will do this activity in feet. To change the units of measurement, press the [WINDOW] key on the top row of the calculator to select the **Setup** menu soft key. From the **Setup** menu, choose **1:Dist** by pressing [1] or [ENTER] since **1** is highlighted. **See Figure 2.**


**Figure 2**

3. From the **Units** menu, select **2:(ft)** by pressing [2] or by pressing the down arrow key until the **2** is highlighted and pressing [ENTER]. **See Figure 3.** When you have confirmation that you will be using feet, select **OK**. **See Figure 4.**

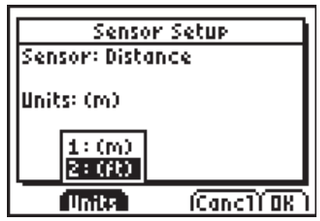



**Figure 3**

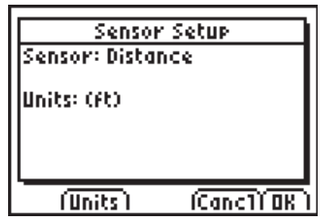



**Figure 4**

4. You will be returned to the main screen of the EasyData App. From the **Setup** menu, select **6: Events with Entry**. This will allow you to control when data is recorded by pressing a key on the calculator. **See Figure 5.**


**Figure 5**

5. This takes you back to the main screen. Select **Start**. You will hear the CBR 2 clicking as the reading is displayed at the top of the screen of the calculator. Select **Keep** to record this first data reading. It is the distance from the bottom of the empty container to the CBR 2. **See Figure 6.**

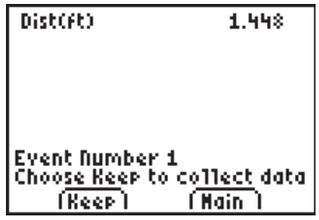



**Figure 6**

6. When the **Enter Value** screen appears, press [0], for no candies. **See Figure 7.**

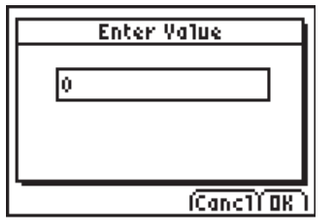



**Figure 7**

7. Slowly add 3 candies. Try to minimize the swing of the container. When the container is steady and the distance displayed at the top of the screen is stable, select **Keep** again. This time enter 3 in the **Enter Value** screen to represent the 3 candies in the cup. **See Figure 8.**

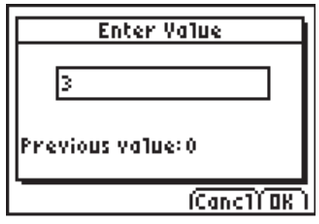



**Figure 8**

8. Continue for a total of 10 trials. Each time the **Enter Value** screen appears, enter the value of 3 more candies than the previous trial. With each recorded value, a new data point will be displayed on the graph along with the option to **Keep** or **Stop** the data collection. **See Figure 9.**

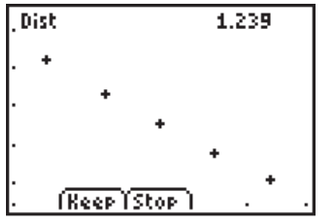



**Figure 9**

9. When finished with the trials, select **Stop**. A graph of your data points will be displayed. Use the right and left arrow keys to view the values of the points. **See Figure 10.**

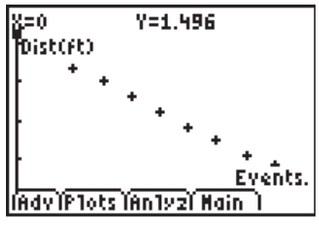



**Figure 10**

**10.** To confirm a description of the plots, press WINDOW to select the **Plots** soft key. This is a good time to review the vocabulary with your students. Identfy the **Events** as the independent variable and the **Distances** as the dependent variable. **See Figure 11.**

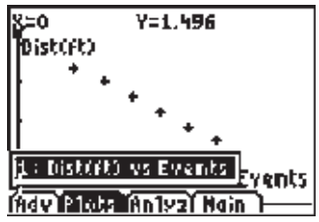



**Figure 11**

**11.** Select **Anlyz** and choose **2:Linear Fit** from the menu.**See Figure 12.**

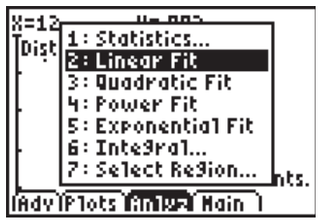



**Figure 12**

**12.** When **2:Linear Fit** is chosen, the calculator will display an equation for the line of best fit. Select **OK. See Figure 13.**

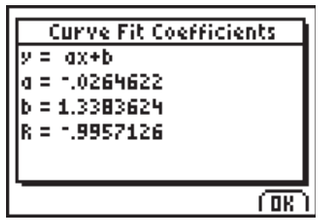



**Figure 13**

**13.** You will see the line of best fit being drawn on the screen with the data points. You can still use the right and left arrow keys to scroll through the data points. Use either the up or down arrow key to trace along the line rather than on the individual points. **See Figure 14.**

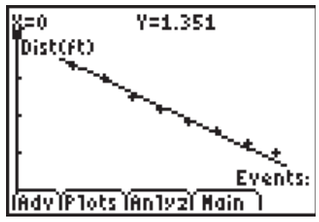



**Figure 14**

**14.** Select **Main** and then **Quit** on the next screen. The confirmation screen will be displayed telling you the lists where your data is stored. Select **OK** to exit the App. **See Figure 15.**

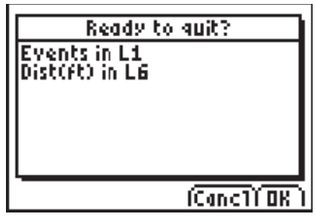



**Figure 15**

## DATA ANALYSIS

**1.** Rather than having the calculator do all the work of finding the regression equation, consider having the students use the definition of slope and their understanding of linear equations to write their own equation for the line of best fit. An additional step would be to find the equation using both methods and then compare the answers. The following directions use a combination of the knowledge of formulas and calculator computations to graph an equation of a line. The students need to know the formula for deriving the slope when given the coordinates of two points and how to use the calculator for quicker and more accurate computations. This activity is meant to build the students' understanding of slope while showing them some lesser used features of the calculator.

**2.** The exit screen of the App verified that the data values you recorded are in lists **L1** and **L6**. Under the [STAT PLOT] menu, the **Plot1** is turned on with the window set to display all the points collected. **Y1** is turned off, but the regression equation found by the App is still displayed there. You can tell when the **Y1** is turned off because the equals sign is no longer highlighted. This indicates that the equation's graph will not be displayed in the [GRAPH] window. **See Figure 16.**

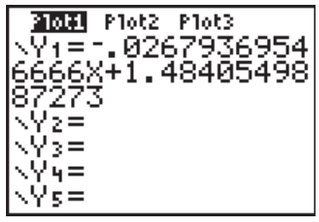



**Figure 16**

**3.** If you have already completed some of the previous lessons in this book, this may be a good time for participants to practice on their own and/or in groups. You could circulate the room and help where needed as students find their own line of best fit and compare it to the regression equation found by the calculator. You can decide how to proceed from here based on your students' knowledge and what your goals are for this lesson. Have the students link **L1**, **L6**, and **Y1**. This will allow each student to do his/her own data analysis.

★ **NOTE** *For help with linking calculators, see Appendix J.*

**NOTE** The following is a slightly different method of finding the slope of the regression equation. This method uses some of the features under the list menu. During this procedure, the student's knowledge of the definition of slope will be reinforced even though they will use technology to perform the otherwise time-consuming calculations. You may find it easiest to have the students work in groups to collect and link the data. Then they can come back together as a class while you direct them. They may need your direction because the features used in the next steps could be new to them.

**4.** It will be helpful to have **L1** and **L6** next to each other in the display. To accomplish this, press [STAT] [ENTER] to access the Stat List Editor and position the cursor so the name **L2** is highlighted. Press [2nd] [DEL] to access the [INS] (insert) command. **See Figure 17.**

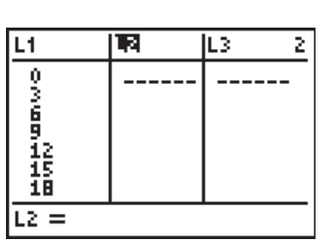



**Figure 17**

**5.** A blank column will be inserted to the right of **L1**. Press [2nd] [6] to have **L6** appear at the bottom of the screen. **See Figure 18a.** Press [ENTER] to see **L6** fill in the blank column. **See Figure 18b.**

★ **NOTE** *For more help rearranging the order of the lists displayed, see Appendix B, section 4.*

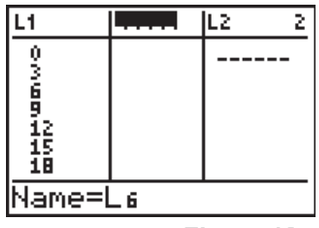



**Figure 18a**

**6.** We already know the differences in the **X**-values of any two consecutive points is three because the number of candies increased by three for each trial. The goal for this next set of calculator commands is to use the calculator to determine the differences in the **Y**-values of the data points collected in the activity and then use that difference to find the slope.

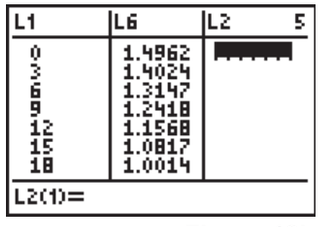



**Figure 18b**

**7.** Give **L2** a command that will calculate the difference between two consecutive values in **L6** and put that difference in **L2**. To do this, use the up arrow key to highlight **L2**. Press [2nd] [STAT] to access the [LIST] menu and arrow over to the **OPS** menu. Select **7: ΔList. See Figure 19.**

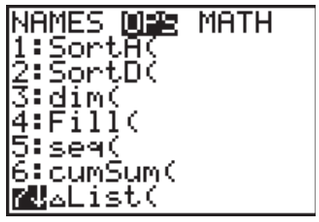



**Figure 19**

**8.** You will see this command displayed at the bottom of the Stat List Editor window. Press [2nd] [6] to type in **L6** and close the parenthesis. **See Figure 20.**

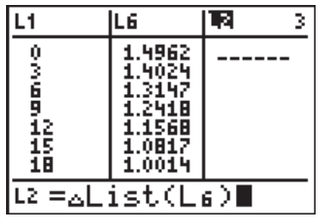



**Figure 20**

**9.** This will give the differences in the **Y**-values of your data points that were stored in **L6**. Press [ENTER] to see **L2** filled in with these differences. **See Figure 21.**

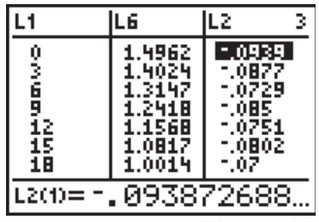



**Figure 21**

**10.** Because the change in the **X**-values is always three, you can divide each difference by three to find the slope for the individual segments between any two consecutive points listed in **L6**. Position the cursor to highlight **L3** and define it to be **L2/3**. **See Figure 22.**

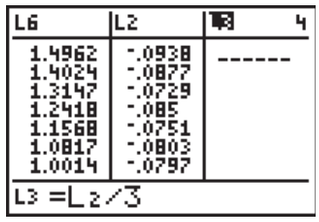



**Figure 22**

**11.** Press [ENTER] to see **L3** filled in with these slopes. **See Figure 23.** Discuss with your students why these differences, although very close, are not exactly the same. This is a good time to discuss the difference between theoretical events and actual data collection. Point out how human error affects data collection and that the CBR 2 helps to cut down on that type of error. Discuss the factors that could contribute to human error if the measurements were taken by hand with a yard or meter stick. Examine how much variation there is between any two entries in **L3**. Is .005 of a foot a significant error?

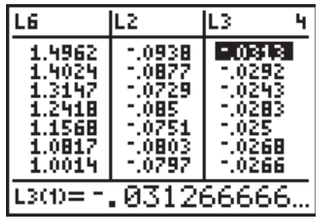



**Figure 23**

**12.** Guide the students to the understanding that the average of **L3** would serve as a close approximation for the slope of the line of best fit for all the points in the plot. Press [2nd] [MODE] to access [QUIT] and return to the home screen. Have the calculator find this average and store it in **M**. To do this, press [2nd] [LIST] and arrow over until **MATH** is highlighted. Select **3:mean(** from the list. **See Figure 24.**


**Figure 24**

**13.** Press [2nd] [3] to access **L3**. Complete the command by typing [)] [STO▸] [ALPHA] **M** [ENTER]. **See Figure 25.**

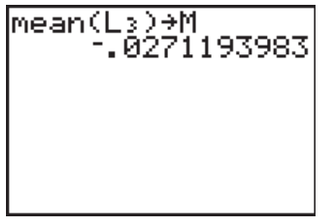



**Figure 25**

**14.** Next, identify the **Y**-intercept. Return to the graph and trace to the first data point. **See Figure 26.**

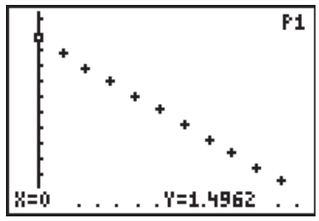



**Figure 26**

**15.** Press [2nd] [MODE] to [QUIT] and return to the home screen. The calculator keeps the **X**- and **Y**-values from the last point you traced in its memory until you trace to a new point. Store the **Y**-value from first data point in the **B** variable. The keystrokes are as follows: [ALPHA] **Y** [STO▸] [ALPHA] **B** [ENTER].
**See Figure 27.**

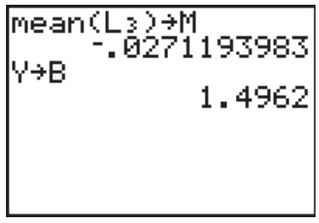



**Figure 27**

**16.** Next, check to see if these values for **M** and **B** are a close fit to the data. Go to the [Y=] window and press [ALPHA] **M** [X,T,Θ,n] [+] [ALPHA] **B** to type in **MX+B** next to **Y2. See Figure 28.**

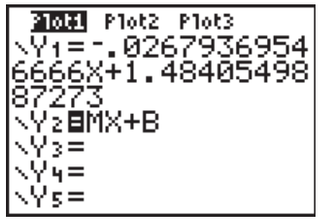



**Figure 28**

**17.** Press [GRAPH] to see how closely this equation fits the points. In the example shown, it looks like a great fit. Press [TRACE] and use the left and right arrow keys to scroll through the data points. **See Figure 29.**

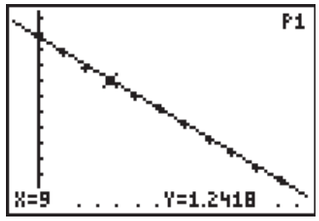



**Figure 29**

**18.** Next, press the up arrow. Your cursor will jump to the middle of the line and display the coordinates of the points on the line of the regression equation instead of the individual points from the lists. The upper left corner of the screen tells you the location of the equation you are tracing. In this example, it is tracing **Y2**. **See Figure 30.**

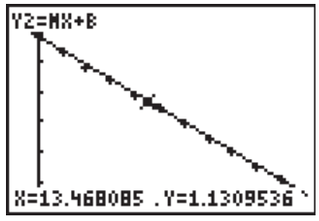



**Figure 30**

**19.** To compare how closely the regression equation you found matches the one the calculator found, graph them both at the same time. To distinguish between the two lines, use different graph styles. Go back to the [Y=] window and turn on **Y1** by positioning the cursor on the equal sign and pressing [ENTER] to highlight it. Leave **Y1** with the default style, but use the left arrow key to highlight the slash icon in front of **Y2**. Repeatedly press [ENTER] until you see the symbol shown in the screenshot on the right. The symbol looks like a ball with a line to its left. **See Figure 31.**

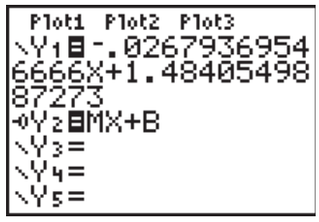



**Figure 31**

**20.** Press [GRAPH]. **Y1** is graphed using the default graph style. After **Y1** is completely graphed, you will see a small ball marking the trail as **Y2** is graphed. This feature makes it easy to see how closely your graph matches the graph found by the calculator. **See Figure 32.**

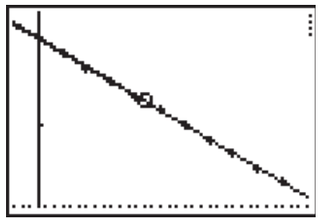


**Figure 32**

**21.** If you will be doing Activity 8, it is a good idea to save the data from **L1**, **L2**, and **L6** into named lists. Running the EasyData App will overwrite any data that was saved in unnamed lists as will many other Apps and programs. Name **L1**, **HSEQ**; **L2**, **HDIF**; **and L6**, **HOOKS**. **See Figure 33.**

★ **NOTE** *For help with naming lists, see Appendix E.*

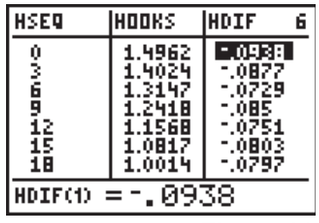



**Figure 33**

**NOTE** If you run the EasyData App again to collect another set of data, the previous data is overwritten. The EasyData App will run with no probe connected if you want to use it to view your graph. A screen confirming that no interface is connected will be displayed. Select **None** to continue without a probe. **See Figure 34.**

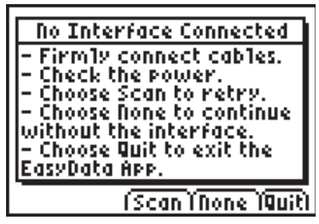



**Figure 34**

**22.** When the main screen is displayed, select **Graph** to view the plot from the last time data was collected. **See Figure 35.**

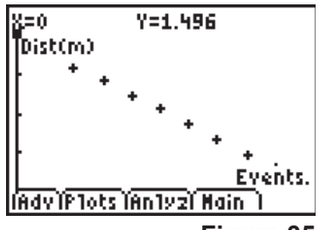



**Figure 35**

## WORKSHEET ANSWERS

Answers will vary on problems not listed.

**2.** Number of candies

**3.** Distance from CBR 2

**4.** Difference

**5.** Difference between 2 consecutive elements in **L6**.

**6.** **L2/3** calculates the slopes of each segment and the average is a close approximation for slope of the whole line.

**7.** Negative; As the number of candies increases, the distance decreases.

**8.** Less change. . . so less steep

**11.** Answers will vary, but they should match the slope in 9 or 10 when multiplied by 3.

**13.** The change in distance per change in candies.

**15.** **a)** y = m (10) + b
**b)** 12 = mx + b

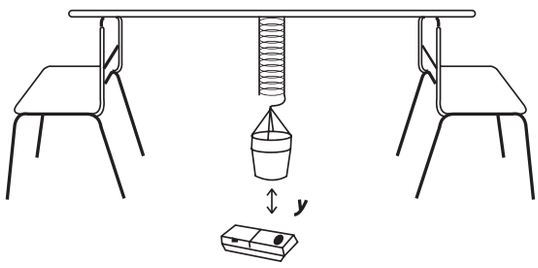
ACTIVITY 7

Name: _____

# Hooke's Law

## Math Objectives:

- Graph scatter plots
- Analyze and graph linear functions
- Calculate and model slope




## Materials:

- TI-83/TI-84 Plus Family
- Calculator-Based Ranger™ (CBR 2™)
- Vernier EasyData™ Application
- Small spring cut in half (a Slinky® works well)
- Empty 4 oz plastic/paper cup (flat bottom)
- Two large paper clips or string
- Meter stick or other long stick
- Second meter/yard stick or ruler
- 30 Candies (M&Ms® and almonds work well)

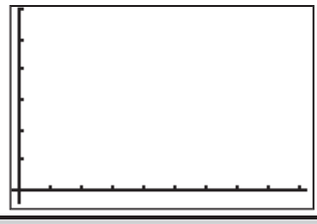
## OVERVIEW

In this activity, you will create a situation that produces linear behavior by observing a spring being stretched as you add candies to a cup attached to the spring. You will then apply the properties of a linear function to develop a model for your motion. Finally, you will interpret the values used in your model. Your teacher will outline the procedure for you. Use the results of the activity to fill in the blanks below.

## SETUP

Work in groups of 3 or 4 to do the following:

1. Place a meter stick or other long stick on the back of two chairs as shown in the diagram.
2. Hang the spring from the meter stick.
3. Hang the cup/container on the bottom of the spring. Make sure that when the cup is empty, it is at least 18–24 inches off the floor.
4. Use a ruler or a second yardstick to measure the distance, in inches, from the top of the stick to the floor and record it here. _____ This measurement will be used if you choose to do Activity 8.
5. Position the CBR 2 on the floor directly under the empty cup/container so you can measure the distance from the floor to the bottom of the container. Link the CBR 2 directly to the TI-84 Plus. You can use either the I/O unit-to-unit cable or the mini-USB cable.
6. The EasyData App will launch automatically if you are using the mini-USB cable. If you are using the I/O unit-to-unit cable, you will need to press the [APPS] key, scroll down to highlight the EasyData App and then press [ENTER] in order to launch the App. Follow the procedure outlined by your Teacher.
7. While still in the EasyData App, select **Anlyz** and select **2:Linear Fit**. Record that equation here. _____
8. Link **L1**, **L6**, and **Y1** into each student's calculator.
9. Set up a scatter plot in **Plot1** with **L1** and **L6** and sketch the graph of your data points here.



**10.** Before continuing, name three new lists in which to store and protect your data for use later. Store **L1** in a list named **HSEQ**, **L2** in a list named **HDIF**, and **L6** in a list named **HOOKS**.

| Number of Candies, L1 | Distance from the bottom of the cup to the floor/CBR 2, L6 |
|---|---|
| 0 | |
| 3 | |
| 6 | |
| 9 | |
| 12 | |
| 15 | |
| 18 | |
| 21 | |
| 24 | |
| 27 | |
| 30 | |

*For recording purposes, round all decimals to the nearest hundredth.*

**1.** Fill in the chart with the numbers from your calculator. Follow your teacher's directions to find your own regression equation.

**2.** What physical property is represented along the **X**-axis of the graph? _____

**3.** What physical property is represented along the **Y**-axis? _____

**4.** What is the mathematical meaning of the symbol delta, ∆? _____

**5.** Fill **L2** by using the command **∆List(L6)**. Describe the meaning of the values this formula will generate and put into **L2**. _____

**6.** Define **L3** to be **L2** divided by 3 and then calculate the average/mean of the numbers in **L3**. Explain why. _____

**7.** Consider your trend line for the distance to the floor vs. the number of candies.
Is the slope positive or negative? _____ Why? _____
_____

**8.** What kind of slope would you predict for a stiffer spring than the one you used? _____
_____

**9.** What is the regression equation you found to fit the data? _____

**10.** What was the regression equation found by the calculator? _____

**11.** For every set of three objects you put in the container, the distance from the CBR 2 decreased by _____.

**12.** What is the mathematical definition of slope? _____

**13.** Describe, in your own words, the meaning of slope in relation to this activity. _____
_____

**14.** Use the TRACE or TABLE buttons to find the following:

**a.** How far from the floor would the cup be if 10 candies were used? _____

**b.** How many candies are in the can if it is 12 inches from the floor? _____

**c.** How many objects would it take until the container hits the floor? _____

**15.** Write the equations that you used to answer questions 14 a–c.

**a)** _____ **b)** _____ **c)** _____

**NOTE** You will need this worksheet to do Activity 8.