**Ball Bounce – TI-Nspire and CBR-2**

**Objectives:**

In this activity you will:

* Graph the height of a bouncing ball over time
* Graph and interpret quadratic functions
* Apply the vertex form of a quadratic function
* Determine the equation of a quadratic function that models data
* Examine the role of the parameter *a* in a quadratic function.

**Overview**

A bouncing ball is a real-world example of a quadratic function. This activity investigates how the quadratic equation, $y=a(x-h)^{2}+k$, can be used to model the behavior of a bouncing ball and how the parameter *a* impacts the graph of a quadratic function.

**You Need:**

* TI-Nspire
* CBR-2
* Cable Link
* A firm bouncing ball with a smooth surface (a tennis ball will absorb the pulses from the CBR-2)
* 3 students; one to hold the CBR-2, one to release the ball, and one to run the calculator.

**TI-Nspire & CBR-2 Set Up**

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1. Turn on the TI-Nspire. Create a new document.
2. Add Vernier Data Quest to the document.
3. Connect the CBR to the calculator using the link cable. The Tic-Tic-Tic and flashing light indicate that there is a connection. The CBR 2 will immediately begin calculating the distance between the sensor and the nearest object. This distance will be displayed on the TI-NSpire.
4. Change the Duration to 12 seconds by pressing MENU, select Experiment, select Collection Mode, select Time Based. Set Duration to 12 seconds.
5. One student will hold the CBR in the air as shown in the previous figure.
6. Identify the distance from the CBR to the ground. This distance will be used to transform the data.

Distance from CBR to Ground, *D* = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. One student will hold the ball halfway between the CBR and the floor.

**Data Collection**

1. At the same time, one student will drop the ball and the student holding the calculator will click on the Start Collection link (green arrow) to begin collecting data on the ball’s movement. (Another way to begin collecting data is to press MENU, select Experiment, and then select Start Collection).
2. The distance between the ball and the sensor will be plotted on a graph. The data will be labeled *run1*. Store the data by clicking on the Store Latest Data Set link. (Another way to store the data is to press MENU, select Experiment, and then select Store Data Set). If the run1 data is not visible, click on the run button and select run1.
3. Disconnect the CBR to the calculator by unplugging the link cable.

**Data Analysis**

To analyze the movement of the bouncing ball, you will copy the time and position data into a spreadsheet.

1. Add a spreadsheet to your document. Press doc, select Insert, select Lists & Spreadsheets.
2. Label column A by selecting the top cell in column A. Type in “time”.
3. Import the time data into column A by selecting the gray cell below the label. Type in “run1.” and then select time from the drop down menu. Hit enter and the run1.time data will populate column A.
4. Label column B by selecting the top cell in column B. Type in “pos”.
5. Import the position data into column B by selecting the gray cell below the label. Type in “run1.” and then select position from the drop down menu. Hit enter and the run1.position data will populate column B.

The CBR measured the distance from the sensor to the ball as the ball traveled away from and towards the sensor. To approximate the height of the ball above the ground, you will calculate a new variable called *h*, using the formula

*h* = *D – pos*

1. Label column C by selecting the top cell in column C. Type in “h”.
2. Select the gray cell below the label. Type in “= (value of D) – pos”. Hit enter and the height data will populate column C. Column C now contains the height of the ball over time.
3. To graph the height of the ball vs. time, add a Data & Statistics sheet to your document. Press doc, select Insert, select Data & Statistics.
4. In the Data and Statistics page, set the *x* variable to time by clicking on the Click to add variable link at the bottom of the screen. Select time. (Or press MENU, select Plot Properties, select Add X Variable, select time).
5. Set the *y* variable to height by clicking on the Click to add variable link at the left side of the screen. Select height. (Or press MENU, select Plot Properties, select Add Y Variable, select height).
6. Change the window settings to zoom in on the parabolic motion. Press MENU, select Window/Zoom, then select Window Settings.

Use the graph to answer the following questions:

1. What physical property is represented along the *x*-axis?
2. What are the units?
3. What physical property is represented along the *y*-axis?
4. What are the units?
5. Identify the vertices of the first three complete parabolas.
6. What do these vertices represent?
7. Why does the plot look like the ball bounced across the floor?

For any one bounce, a plot of height vs. time has a parabolic shape. The equation that describes this motion is quadratic: $y=a(x-h)^{2}+k$ where *a* affects the width of the *parabola* and (*h,k*) is the *vertex* of the parabola. This equation is called the *vertex form* of a quadratic function.

The goal of the next exercise is to find the quadratic function that models the highest bounce off the ground.

1. Identify the highest bounce. Find the vertex of this parabola. Record the vertex below.

 *h*= \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ *k*=\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Write a quadratic function of the form $y=a(x-h)^{2}+k$ by substituting in the values of *h* and *k*.
2. We will adjust the value of *a* until we have found the quadratic function which accurately models the highest bounce. Start by setting *a* = –1. Write the quadratic function when *a* = –1.
3. Plot the quadratic function you created above on the same graph with the bouncing ball ordered pairs. Press MENU, select Analyze, then select Plot Function. Enter your function as *f*(*x*).
4. Sketch the points representing the highest bounce and the graph of the quadratic function when

*a* = –1 on the coordinate axes below.



1. To find the equation of the parabola, use a guess-and-check method to find the value of *a*. Change the value of *a* by double-clicking on the function and typing in a new value. For each new value of *a* that you enter, view the resulting parabola. Record the value of *a* that creates a parabola which accurately fits the highest bounce.

*a* =

1. Using this value of *a,* and using the *h* and *k* values found above, write the vertex form of the quadratic function.

Use the calculator to answer the following questions:

1. What effect does the sign (positive or negative) of *a* have on the parabola?
2. What effect does increasing the size of the absolute value of *a* have on the shape of the parabola?
3. What effect does decreasing the size of the absolute value of *a* have on the shape of the parabola?
4. How would the equation change, if at all, with a different bounce of the parabola?
5. Would you expect your classmates to have the same value of *a* for their trials or do you think the value of *a* would vary? Explain your answer.
6. Find the value of *a* from the other groups of students in your class. How do these values compare to your value of *a*?
7. What conclusion can you make about the value of *a* for a quadratic equation of a bouncing ball?

**Further Explorations**

1. Find the quadratic equation that accurately models the second-highest bounce?
2. Using what you discovered about the value of *a* in a quadratic equation for a bouncing ball, write the equation of a parabolic ball bounce with a vertex of (7,0.48). Assume the data was measured in meters.
3. If a ball that was more bouncy or less bouncy was used this time, would it affect the value of *a* in the equation. If so, describe how.