



## Science Objectives

- Students will explore two objects falling to Earth in a vacuum. They will modify the initial position of the drop and the elasticity of each object.
- Students will examine the object for the initial drop and for several bounces observing the position, velocity, and acceleration values.
- Students will then add air resistance to the falling objects and observe how under certain conditions, objects may reach different terminal velocities, thus falling to the ground at different times.

## Vocabulary

- gravity
- position
- velocity (instantaneous and average)
- acceleration (due to gravity)
- drag
- terminal velocity
- elasticity

## About the Lesson

All free falling objects fall to the Earth with the same acceleration regardless of size, shape, or weight. An object that falls through a vacuum is subject only to gravity. If an object falls through the atmosphere, there is an additional force called *drag* acting on the object.

- As a result, students will:
  - Describe the variables involved in a falling object.
  - Vary the air, mass, and height of an object and examine the height, velocity, and acceleration of the object as a function of time.



## TI-Nspire™ Navigator™

- Send out the .tns file.
- Monitor student progress using Screen Capture.
- Use Live Presenter to allow students to show how they manipulate variables that affect results.

## Activity Materials

- Compatible TI Technologies:  TI-Nspire™ CX Handhelds,  TI-Nspire™ Apps for iPad®,  TI-Nspire™ Software



- **Tech Tips:** This activity includes screen captures taken from the TI-Nspire CX handheld. It is also appropriate for use with the TI-Nspire family of products including TI-Nspire software and TI-Nspire App. Slight variations to these directions may be required if using other technologies besides the handheld.
- Watch for additional Tech Tips throughout the activity for the specific technology you are using.
- Access free tutorials at <http://education.ti.com/calculators/pd/US/Online-Learning/Tutorials>

## Lesson Files:

### Student Activity

- Falling\_Objects\_and\_More\_Student.pdf
- Falling\_Objects\_and\_More\_Student.doc

### TI-Nspire document

- Falling\_Objects\_and\_More.tns

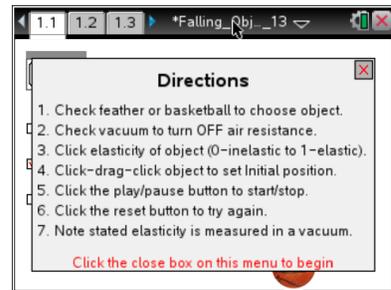


## Discussion Points and Possible Answers

Have students read the background information stated on their activity sheet.

### Part 1: Exploring the Simulation and Identifying the Variables

1. When students first open the document they will see a directions box explaining how to use the simulation. Have them look over these and then be prepared to answer any questions the students might have. *Note: The TNS file does not contain any of the analysis questions below. All questions should be recorded on the student activity sheet.*



2. Students can close the pop-up directions box when they are finished.

 **Tech Tip:** To access the Directions again, select  > **Falling Objects and More > Directions**

 **Tech Tip:** To access the Directions again, select  or **Document Tools (  ) > Falling Objects and More > Directions.**

3. Note the default settings that appear on the screen when students press the reset button . Students are to choose an object, air resistance, and elasticity value. They should move it to the height they desire and release it. Now students press the play button  to drop the object. They will need to press the pause button  to stop the object.

 **Tech Tip:** To position the object, students hover the cursor over it and when they see the hand , press click . Click  again to release.

Q1. What are the default settings for this simulation?

**Answer:** The basketball on the floor, not moving with an elasticity of 0.80 in air (“vacuum” unchecked).



4. Starting on page 1.1, have students explore the simulation. They will start with the settings given in the table below and should record their observation for each trial. As students conduct each trial, have them look at pages 1.2 and 1.3 to view the data and graph of the data.



For this first round of data collection, make sure students leave the “**vacuum**” box unchecked to create air resistance.

Object	Air Resistance	Elasticity	Observation
Basketball	Yes	0.8	
Basketball	Yes	0.3	
Feather	Yes	0.0	
Feather	Yes	0.5	

5. Now students are to try several different settings of their own.

Students should take note of what patterns they see and share.



#### TI-Nspire Navigator Opportunities

Allow students to volunteer to be the Live Presenter and demonstrate how to run the simulation.

- Q2. Note three things that you learned about falling objects from your exploration. Share these with the class on a Notes page as instructed by your teacher.

#### Sample Answers:

- The patterns as shown in the graphs are the same when in a vacuum for various drop heights, elasticity values, and objects.
- The velocities are negative, then go to zero, and then become positive.
- As elasticity increases, subsequent bounces are closer to the drop height, but are always less.
- When not in a vacuum, the objects tend to slow in their increase in velocity.
- The spaces between the points in the height vs. time get farther apart as it falls.



6. Next, students will identify the variables in this simulation, and then consider how each variable affects an object falling to Earth.

Q3. In the first column of the table below, list the variables that affect an object falling to Earth. In the second column of the table, describe how each variable changes the fall of the object. In the last column, indicate whether or not the variable you identified can be controlled.

Variable	How does it change the falling object?	Can you control this variable?

**Sample Answers:**

Variable	How does it change the falling object?	Can you control this variable?
Air	Slows the object	Yes
Object	None in a vacuum	Yes
Mass	None in a vacuum	No
Height	Time in air/rebound height	Yes
Elasticity	Rebound height	Yes
Wind	Depends on direction (up down, left, right)	No
Temperature	Would cause the air to be more or less dense.	No
Planet	Changes the acceleration	No
Initial Velocity	Falling time, and rebound height.	No

**Part 2: Exploring Falling Objects in a Vacuum**

Now students can compare the patterns they have already observed with those for the same objects falling in a vacuum.



7. Have students go back to page 1.1, select the basketball, **check the vacuum box**, and then set the elasticity value to 0.80. They should move the ball to a height of 2.00 meters and drop it. They should pause the simulation just after it hits the ground.



#### Move to page 1.2.

8. On page 1.2 students will find data in a spreadsheet for the object they just dropped. The spreadsheet contains the time, height, and velocity of the object as it falls and bounces.

Have students examine the data for this drop.

	time	height	velocity
1	0	2.	0
2	0.07	1.99	-0.687
3	0.14	1.95	-1.37
4	0.21	1.85	-2.06
5	0.28	1.71	-2.75
6	0.35	1.52	-3.42

Remember: The data clears each time the simulation is reset.

Q4. Answer the following:

- a. Using the data shown on page 1.2, approximately how many seconds did it take for the ball to fall 2.00 meters?

**Answer:** 0.70 seconds

- b. What was the initial velocity of the object?

**Answer:** 0.00 m/s

- c. How fast was it traveling right before it hit the ground?

**Answer:** -6.28 m/s

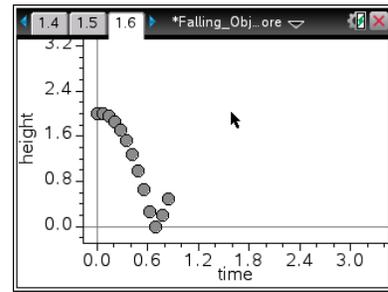
- d. Explain why some of the velocity values are positive and others are negative.

**Answer:** A negative velocity indicates that the basketball is falling to Earth. A positive velocity indicates that the basketball is bouncing upward.



Move to page 1.6.

9. Students should look at the plot of height vs. time on page 1.6. Note that the points become further apart as the object approaches the ground. Students need to explore this by first looking at the height drop at three points in the drop.



- Q5. Fill in the table below using information from the spreadsheet on page 1.2. In the first column select three points during the fall but before the bounce. Record Time 1 and Height 1 from the row *before* your selected point. Record Time 2 and Height 2 from the row *after* your selected point. Next, complete the calculations and fill in the table below using time and height data.

Data Value Row #	Time 1	Time 2	Time 2 – Time 1	Height 1	Height 2	Height 2 – Height 1

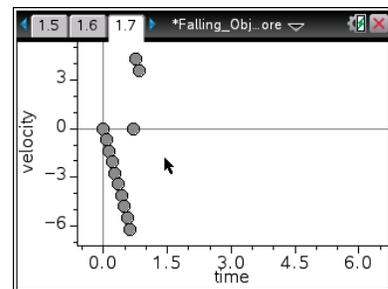
#### Sample Answers:

Data Value Row #	Time 1	Time 2	Time 2 – Time 1	Height 1	Height 2	Height 2 – Height 1
3	0.07	0.21	0.14 sec	1.99	1.85	-0.14 m
6	0.28	0.42	0.14 sec	1.71	1.28	-0.43 m
9	0.49	0.63	0.14 sec	0.987	0.266	-0.721 m

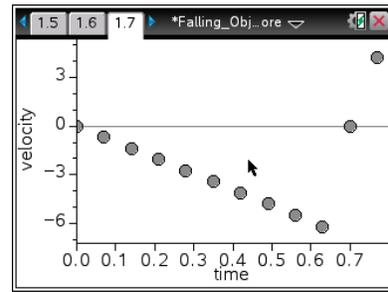
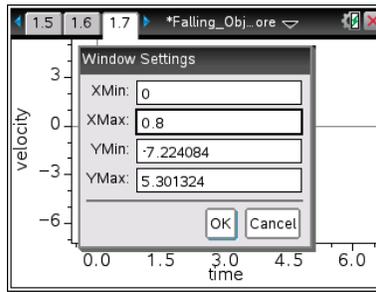
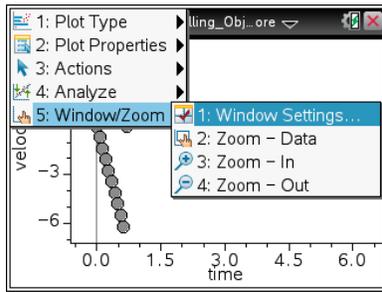
Since the time intervals are the same for the data displayed, it can be said that the object is falling a larger distance in the same time interval as it approaches the ground.

Move to page 1.7.

10. The change in distance divided by the change in time is called *speed*. *Velocity* is speed in a particular direction. On page 1.7, observe the graph of time vs. velocity. Have students look at the plot and note the points that represent the time intervals explored above.



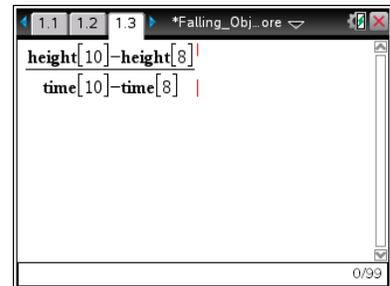
**Tech Tip:** You might want to have students adjust the Window setting so that they can focus on the drop. Press **menu** **Document Tools** () and select the **Window/Zoom** option and change the **Window Setting** for the time (x-values).



A velocity at any given instant is known as *instantaneous velocity*. The velocities given in the spreadsheet on page 1.2 are instantaneous velocities. Now students will find the average velocity for an interval and compare it to an instantaneous velocity in the middle of the interval.

11. Students will calculate the average velocity for the three intervals from the table in question 5 using the formula below and see if it is close to the velocity shown in the spreadsheet on page 1.2. Use the Scratchpad or insert a Calculator page (**ctrl** ).

$$\text{Average Velocity} = \frac{\text{Height 2} - \text{Height 1}}{\text{Time 2} - \text{Time 1}}$$



In the example shown to the right, the data value in the 9<sup>th</sup> row is selected. The data values in the 8<sup>th</sup> and 10<sup>th</sup> rows are used to determine the average velocity. On the handheld, the calculation uses the cell reference from the spreadsheet. **Height [8]** is the value in the height column, 8<sup>th</sup> row.

- Q6. Fill in the table with the average velocity you calculated and the velocity on page 1.2 for each data value selected in question 5.

Data Value Row #	Average Velocity Calculated	Velocity of Data Value

**Sample Answers:**

Data Value Row #	Average Velocity Calculated	Velocity of Data Value
3	-1	-1.37
6	-3.07	-3.43
9	-5.15	-5.49



Q7. How does the velocity you calculated compare to the velocity reported in the spreadsheet?

**Sample Answer:** very close

time	height	velocity
0.28	1.771	-2.73
6	0.35	1.52
7	0.42	1.28
8	0.49	0.987
9	0.56	0.651
10	0.63	0.266

Q8. Notice that the distance between the points on the velocity vs. time plot on page 1.7 is constant, but this is not the case for the height vs. time plot on page 1.6. What do you think this means?

**Answer:** This means that the rate of change of velocity is the constant.

Q9. Calculate the change in velocity over time using the formula to the right. Get an assigned time interval from your teacher. Fill in the table below.

$$\frac{\text{Velocity 2} - \text{Velocity 1}}{\text{Time 2} - \text{Time 1}}$$

**Sample Answer:**

Time 2 =	Velocity 2 =
Time 1 =	Velocity 1 =
Calculated change in velocity =	

$\frac{\text{velocity}[10] - \text{velocity}[8]}{\text{time}[10] - \text{time}[8]}$	-9.81
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A change in velocity over time is *acceleration*. On Earth the acceleration due to gravity is 9.81 m/s/s. Since the acceleration of a falling object is downward toward the Earth, it has a negative value.

**Move to page 1.8.**

Q10. Look at the graph of acceleration vs. time. How would you describe this graph?

**Answer:** A horizontal line, a line with a slope of zero, a constant negative value.

**Move back to page 1.1.**

Students will now explore a falling feather. Reset the simulation, and then check the box for “feather” and for “vacuum.” They are to see if they can determine the differences between the falling feather and the falling basketball in a vacuum.



Q11. a. How much longer than the basketball did the feather take to fall to the ground?

**Answer:** There is no change in a vacuum.

b. How much slower than the basketball was the feather moving right before it hits the ground?

**Answer:** There is no change in a vacuum.

c. How much slower than the basketball was the acceleration of the feather?

**Answer:** There is no change in a vacuum.

**Teacher Tip:** Assign the students various heights and have some do the basketball and some the feather. You want the kids to share their results as we move through this part. Some heights are hard to find, so pick ones that the kids can hit, or just give them a range of heights, (ie. around 1.25 meters).

### Part 3: Falling Object in Air

Now students will see how falling objects behave when they are not in a vacuum. Objects not in a vacuum are subject to air resistance. They should have observed that objects like a basketball and a feather are different, yet in a vacuum they have the same acceleration due to gravity. In this section, students will observe the same falling objects with air resistance.

12. Assign individual students or teams of students an object to drop and an initial position. This drop will NOT be in a vacuum. Have students record their assigned values below. Recall that they should pause the simulation just after it hits the ground. If students start again, be sure to reset the simulation.

Your assigned object: \_\_\_\_\_

Your assigned height: \_\_\_\_\_

**Teacher Tip:** Assign the students various heights and have some do the basketball and some the feather. You want the kids to share their results as we move through this part. Some heights are hard to find, so pick ones that the kids can hit, or just give them a range of heights, like around 1.25 meters.

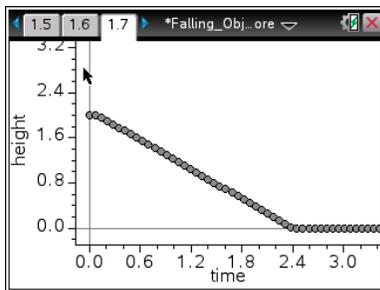
Q12. How long did it take your object to fall to the ground? Compare this with others in the class having similar heights.

**Answer:** The feather will hit after the ball in air when dropped from similar heights.

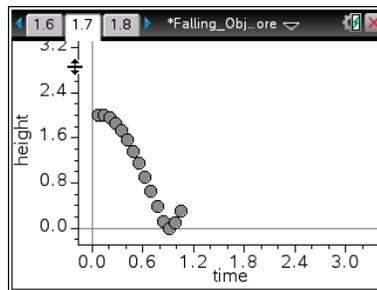


13. Have students look at the spreadsheet and the plot of height vs. time on page 1.6, and compare it to the plot for the objects dropped in a vacuum. Have them share their results with the class.

**Possible results:** The feather graph seems like a straight line now and the basketball does not seem very different but it does hit the ground later.



**Feather**



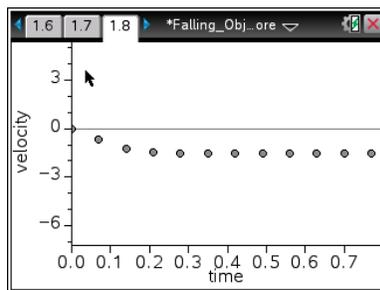
**Basketball**

time	height	velocity
0.56	1.14	-3.53
9	0.63	-4.1
10	0.7	-4.31
11	0.77	-4.47
12	0.84	-4.59
13	0.91	0

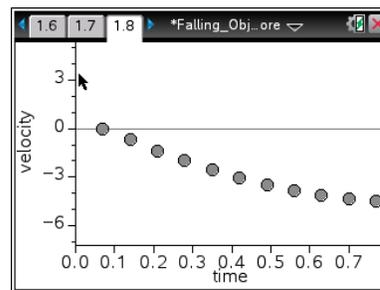
A13 = 0.91

14. Now have students look at the velocity vs. time plot on page 1.7. What do they see? Have them share their results with the class.

**Possible results:** They both are curved now, while they were straight lines in a vacuum. The feather hits a constant velocity very quickly, while the basketball seems to be approaching this constant value (depending on the height dropped from).



**Feather**



**Basketball**

time	height	velocity
0.14	2.96	-1.24
4	0.21	-1.49
5	0.28	-1.55
6	0.35	-1.56
7	0.42	-1.56
8	0.49	-1.56

A8 = 0.49

**Feather**

time	height	velocity
0.63	1.96	-4.31
11	0.7	-4.47
12	0.77	-4.59
13	0.84	-4.68
14	0.91	-4.75
15	0.98	-4.8

A15 = 0.98

**Basketball**



Q13. Terminal velocity is the constant speed that a falling object reaches. When air resistance is a factor, objects may reach different terminal velocities, and therefore, fall to the ground at different times.

- a. Determine the terminal velocity for a feather.

**Answer:**  $-1.56 \text{ m/s}$

- b. What is the acceleration of the feather when it reaches its terminal velocity?

**Answer:** 0

- c. Why?

**Answer:** If the velocity is not changing, there is no acceleration.



#### TI-Nspire Navigator Opportunities

Allow students to volunteer to be the Live Presenter and demonstrate their results for particular questions/Scenarios.

Use Quick Poll to check for answers to some of the questions in the Student document during the course of the activity.

## Wrap Up

When students are finished with the activity you may collect the individual files and examine their results or collect the Student Activity Worksheet. If you added some questions to the document, you can add this to their Portfolio and discuss the results as you Review.

## Assessment

- Analysis questions are written into the student worksheet. These could be added to the tns file as Exam or Self-Check questions.
- Have the students analyze a particular setting for a second drop (after the bounce) with an assigned initial height and elasticity value.