

Gravity

Teacher's Guide

1.0 Summary

"Gravity" is the 9th and final Dynamica activity to be done before the Post-Test. This activity has not undergone many changes from the last school year. It should take students approximately 45 minutes to complete this activity.

2.0 Learning Goals

Driving Question: What is the effect of the constant force of gravity on the motion of objects?

This activity explores the effects of gravity on motion in many different situations, using the concepts developed in previous Dynamica activities.

Step 1: **Describing Gravity** allows students to simulate the effects of gravity on objects. It looks at the forces on objects falling, the difference between weight and mass, gravity on the moon, and horizontal vs. vertical motion.

Step 2: **Air Resistance** provides an opportunity for the students to explore the role of air resistance on the motion of falling objects.

Step 3: **Jump the Gorge** gives students some games, including Jump the Gorge, Feed the Monkey, and Cross the River, that they can win only if they understand how things fall due to gravity.

Additional Teacher Background

The simple statements that *all objects near the surface of the earth are accelerated downward at the same rate* is not as straightforward as it seems. It rests on many ideas that have been developed throughout these activities. Here are some of those ideas:

- The downward force on each object (its weight) is exactly proportional to its mass, hence the common idea that weight and mass are interchangeable. **Mass** is an inherent quality of all matter. **Weight** is the force arising from the gravitational attraction between that mass and another. Far from earth, an object would have the same mass but less weight, because gravitational attraction decreases by the square of the distance.
- The force of gravity does not depend on an object's velocity. The force on an object moving upward, or sitting still, or falling, is always the same.
- It is the **acceleration** due to gravity, and not the **force** of gravity, which is the same for all objects.
- **Uniform acceleration** means that the velocity is changing at a constant rate. That is velocity increases by the same amount every second, and the velocity-time graph is a straight line. The distance increases with the square of the time, and the distance-time graph is a parabola.

- More massive objects require more force to get them going (Newton's Second Law: $F = ma$). An object with twice as much mass needs twice as much force to make it accelerate at the same rate as the lighter object. The heavier object has more **inertia**, or resistance to change in motion.
- The reason all objects accelerate equally is this: the force of gravity on more massive objects is greater in just the right proportion to accelerate them at the same rate as less massive objects. If object A is ten times as massive as object B, the gravitational force is ten times as large; but that will cause the same acceleration, because object A has ten times as much inertia.
- The acceleration downward (the Y direction) is **independent** of motion or forces horizontally (the X direction). Thus all objects accelerate downward at the same rate regardless of their sideways velocity.
- Some students may believe that air is needed for gravity to act, and that gravity ends above the earth when there's no more air. There would be no atmosphere if gravity didn't hold it there, but the force of gravity operates through any medium, including a vacuum. There is no 'shield' from gravitational forces.
- **Air resistance** is a force that is completely independent of gravity. Objects moving through the air experience this frictional force, which changes according to their shape and increases with their velocity. The air resistance force always acts to slow them down; that is, it operates opposite to their direction of motion.
- **Terminal velocity** is the speed objects reach when the force of air resistance exactly balances the force of gravity. At that point, the **net force** on the object is zero and the velocity is constant. In the case of the hammer and the feather, both would accelerate at the same rate in the absence of air (such as on the moon). But the force of air resistance of the feather is much greater in relation to its weight, so it reaches a terminal velocity very quickly.
- **Free fall** (the experience of apparent weightlessness in a space ship or when falling without a parachute) does not mean that the force of gravity goes away. The force of gravity is the same, but all the objects around one are falling at the same rate as oneself. They offer no resistance to ones fall, so everything appears to be floating.

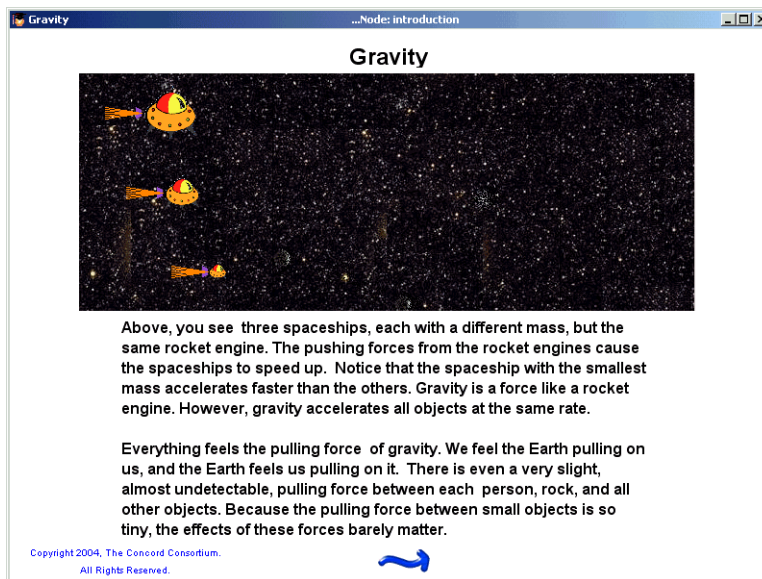
Additional Activities

Falling Filters: Drop large flat-bottomed coffee filters above a sonar ranger, and observe the distance, velocity, and acceleration graphs. A single coffee filter reaches its terminal velocity very quickly, but as more filters are nested together (or a lump of clay is put inside the filter), the velocity will increase for more of the fall. What are the forces on the filter? Do the forces change as it reaches terminal velocity? Does air resistance change if the shape stays the same? If not, why does the heavier object fall faster? This complex situation should generate a great deal of interesting conversation.

3.0 Standards Alignment

Alignment to National Math and Science Standards (NCTM or NSES)

Objective	Standards
Students will understand the difference between weight and mass.	<ul style="list-style-type: none"> Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses
Students will understand why objects with different masses fall with the same acceleration in a gravitational field.	<ul style="list-style-type: none"> Students should recognize and apply mathematics in contexts outside of mathematics.
Students will use the independence of motion and forces in the vertical and horizontal directions to understand trajectories.	<ul style="list-style-type: none"> Students should develop an understanding of properties of, and representations for, the addition and multiplication of vectors.
Students will understand how terminal velocity results from the balance of gravity and air resistance forces.	<ul style="list-style-type: none"> Students should recognize and apply mathematics in contexts outside of mathematics. Objects change their motion only when a net force is applied.

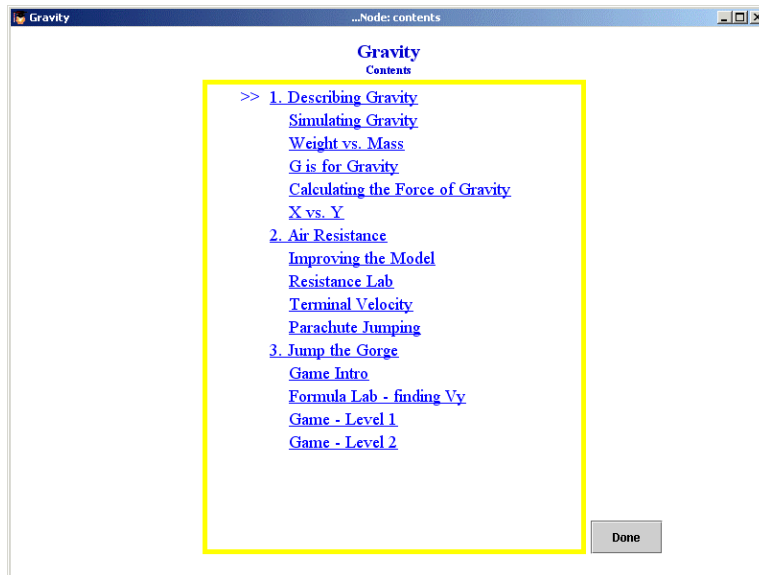


Opening Screen

4.0 Activity Sections


4.1 Table of Contents

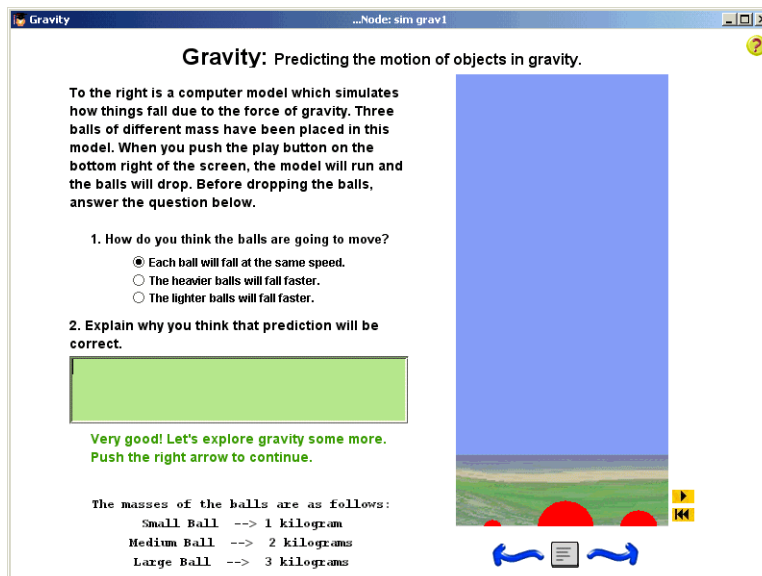
This activity has 3 sections, each with subsections. The Gravity activity should take students 45 minutes to complete.



4.2 1) Describing Gravity

This section introduces students to the force of gravity. The model shows how balls of different mass will drop at the same velocity. Students are then asked to apply forces to the balls and answer questions about the models. In all the screens

in this activity, there is a help button available—students can click on the  icon (located in the upper right-hand corner) for context-specific help.



First subsection

Gravity: Simulating gravity with forces.

A CHALLENGE: Random forces have been assigned to the green balls. By adjusting the purple force arrows, make the green balls move in the same way as the red ones. By doing this you will simulate gravity with the purple force arrows.

If you get stuck you can push the hint button below. Each time you press the hint button the hints will become more specific, but first try to solve the challenge without using any hints.

The masses of the balls are as follows:
 Small Ball --> 1 kilogram
 Medium Ball --> 2 kilograms
 Large Ball --> 3 kilograms

Students apply forces to the green balls to match the red balls

Gravity: Explaining the difference between weight and mass.

To the right you see three different balls with three different masses. The force arrows you see represent the forces each of the balls feel due to gravity. This force of gravity is called the weight of the object. Often, the terms weight and mass are used to mean the same thing. However, weight and mass are not the same.

Weight = the force exerted by gravity on an object.

Mass = a property which describes how much matter an object consists of.

6. Using the balls to the right and the definitions for weight and mass above, describe the relationship between the weight and mass of the three balls?

The masses of the balls are as follows:
 Small Ball --> 1 kilogram
 Medium Ball --> 2 kilograms
 Large Ball --> 3 kilograms

Definitions of weight and mass

Gravity: Determining mass using forces and collisions.

A CHALLENGE: In space there is no gravity so things are 'weightless'. However, they still have mass. The three balls to the right each have a different mass. Although they are the same size, each is made from a different material. Add forces or initial velocities to determine the mass of each ball. Confused? Try the hints.

7. Drag the colors below so that the masses of the balls are ordered from lowest to highest:

low--> blue red green <--high

The exact masses for the three balls are:

1 kg; 2 kg; 3 kg ... 1 kg; 2 kg; 4 kg ... 1 kg; 3 kg; 6 kg ...

8. Describe the experiments you performed which helped you to determine the answers to the above questions.

Use force boosters to run experiments.

Drag the balls to give them a starting position.
Press and hold the "v" key to adjust a ball's initial velocity.
Press and hold the "f" key to adjust or apply a constant force.

Gravity in space

Students can experiment by setting the initial velocity of each ball and/or applying a force to each ball. The student must decide which ball has the greatest mass, which has the least and which is in between. Then the student should select the correct mass for each ball. Strategies for doing this include:

- Colliding balls using the same velocity and using your knowledge of collisions to figure out the masses of each ball.
- Setting the force for each ball so that they are equal and running the model to see in which order the balls move.

To calculate the specific masses, apply a force to each ball such that the balls accelerate at the same rate. The length of the force arrows will tell you the relative masses. If students have trouble passing the screen above, the correct answers are in the screen shot below. The blue ball has the lightest mass (1kg), the red ball is in the middle (3kg) and the green ball has the heaviest mass (6kg).

Apply force and velocity to the balls using the following instructions:

- Drag the balls to give them a starting position.
- Press and hold the "v" key to adjust a ball's initial velocity.
- Press and hold the "f" key to adjust or apply a constant force.

Gravity: Describing the relationship between weight, mass, and gravity.

To the right you see the same two balls placed in three different environments:

- in outer space, far away from anything with a large mass.
- near the Moon which has a large mass (about 70 billion, million, million kilograms).
- near the Earth which has a mass 85 times larger than the moon.

11. Gravity is the force of attraction between two objects. Explain why the balls are heaviest on the Earth, are lighter on the Moon, and don't have any weight in space far from any planets, moons, or stars.

Weight changes depending on gravity but mass remains the same.

Gravity: Determining which property best describes gravity.

GIVING GRAVITY A NUMBER: We often talk about the "gravitational force" of gravity. However, as you can see in the model to the right, where forces simulating Earth's gravity have been placed on three different balls, the gravitational force on an object depends on the mass of the object.

There is something that is the same for all objects falling due to gravity, and you can use the data tables to the right to figure it out. When you run the model, data will be collected every second for each ball.

12. Which value remains constant and is the same for all three balls?

- Time (t)
- Force (F)
- Mass (m)
- Acceleration (a)
- Velocity (v)

YES! So, it's best to refer to gravity by the acceleration of objects. When referring to the "acceleration of gravity", we know that number will be the same for all objects near Earth.

t	F	m	a	v
0.0	9.8	1.0	9.8	-0.0
1.0	9.8	1.0	9.8	9.8
2.0	9.8	1.0	9.8	19.6
3.0	9.8	1.0	9.8	29.4
4.0	9.8	1.0	9.8	39.2
5.0	9.8	1.0	9.8	49.0
6.0	9.8	1.0	9.8	58.8

t	F	m	a	v
0.0	29.4	3.0	9.8	-0.0
1.0	29.4	3.0	9.8	9.8
2.0	29.4	3.0	9.8	19.6
3.0	29.4	3.0	9.8	29.4
4.0	29.4	3.0	9.8	39.2
5.0	29.4	3.0	9.8	49.0
6.0	29.4	3.0	9.8	58.8

t	F	m	a	v
0.0	19.6	2.0	9.8	-0.0
1.0	19.6	2.0	9.8	9.8
2.0	19.6	2.0	9.8	19.6
3.0	19.6	2.0	9.8	29.4
4.0	19.6	2.0	9.8	39.2
5.0	19.6	2.0	9.8	49.0
6.0	19.6	2.0	9.8	58.8

t = Time (sec) F = Force (N)
 m = Mass (kg) v = Velocity (m/sec)
 a = Acceleration (m/sec²)

Acceleration remains constant and is the same for all three balls.

In the screen above, students should examine the data charts to answer the question; the correct answer is "Acceleration." If the student answers incorrectly, he or she should reset the model and try another answer.

Gravity

Collect data every 1 seconds. Reset Lab Clear Lab

Collect data for: (t)ime (sec) (m)ass (kg) (F)orce (N)
 (V)elocity (m/sec) (A)ccel. (m/sec²) (D)istance (...)

Show properties in the: x dir y dir both x and y

	m	Fy	Ay	formula
	5.0	2.0	0.4	

Create a formula -> **Fy =** Calculate


To create a formula, choose a property from the drop down menu that you will calculate. Then, type the formula in the green box and press the calculate button. Below are some examples:
*mass times velocity is written -> m*v*
*one-half mass times velocity squared -> 0.5*m*v^2*
force in the x direction divided by mass -> Fx/m
[Click here for more details about writing formulae.](#)

In the forces activity you learned how to calculate a force by using mass and acceleration. Gravity is no different. Run the experiment above and write the formula for the force of gravity (Fy) in the formula box.


In forces you learned that $F = m \cdot a$, so in this situation the force of gravity is equal to the mass times the acceleration in the Y direction ($F_y = m \cdot A_y$). Type $m \cdot A_y$ in the formula box and press the calculate button.

Calculating the Force of Gravity Lab

The following screen is the “Calculating the Force of Gravity” subsection of the first section of the Gravity activity. Students explore gravity in this lab environment and track data on the table. Use the checkboxes above the data table to select the columns viewed on the table. Students can write the equation for the force of gravity (Fy) or view the graph of motion by flipping the switch in the left corner of the screen.

Click on the  button in the upper right corner of the screen to open the following instructions:

Message X

 **Welcome to the Dynamica Lab!**

Using this lab involves setting up experiments, collecting data, writing formulas, and graphing results.

To set up an experiment:

- Drag the ball to a starting location.
- Drag any number of velocity boosters and force daemons from the gray palette.
- Press and hold "v" to adjust the velocity of the ball or a velocity booster.
- Press and hold "F" to apply a force to the ball or set up a force daemon.
- Right click on the ball, velocity booster, or force daemon, to change other properties.
- To delete a booster or daemon, click on it, and then hit delete.
- To change the duration of the applied force from a force daemon, click on it and press 1-9.
- Click on the scale "1 block = ... meters" to change scales.

To collect data:

- If necessary, change the data collection time interval above the table.
- Select which properties to collect by checking (or unchecking) the boxes.
- To focus on only the x or y axis, click either "x dir" or "y dir".
- Press play to start collecting data.

To write formulas:

- Type a formula into the green box at the bottom of the table.
- Press the calculate button to compute that formula for each row of the table.

To see graphs:

- Flip the gray switch down toward "graph".
- Select a property from the menu to graph.
- Click on the "Auto Scale" button to adjust the axes of the graph to fit your data.

OK

Gravity ...Node: xVy

Gravity: Looking at the effect of sideways motion on gravity.

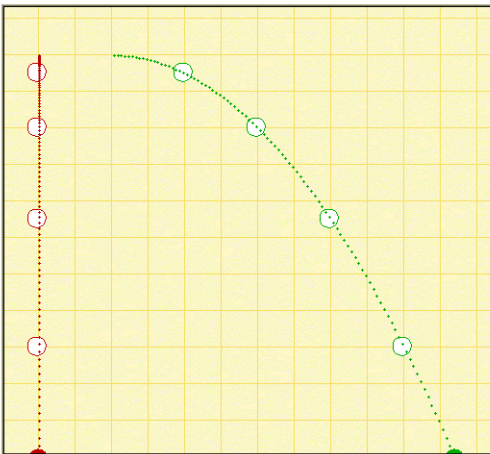
In this model, both balls will fall downward due to gravity. However, the green ball has been given an initial horizontal velocity. Before you run the model, answer the following question.


14. What do you predict will happen when you run the simulation?

Both balls will land at the same time.
 The ball moving sideways will land first.
 The non-sideways ball will land first.

Try running the simulation several times to test your prediction. Give the green ball a different horizontal velocity each time.

15. Very good! It looks like your prediction was correct. Explain why that is true.





Final subsection X vs. Y is a review of Force in 2D.

4.3 2) Air Resistance

This section asks students to think about how computer models of gravity are different than the real world. For example, so far in the activity, students have been investigating the force of gravity while ignoring other forces such as air resistance.

Gravity: Comparing the model to a real experiment.

Let's try a real life experiment and see how it compares to our computer model.

Try the following experiment:

- 1) Get up from your seat.
- 2) Hold a hammer in one hand and a feather in the other. (You may substitute a pen and a flat piece of paper if necessary.)
- 3) Drop them both at the same time.
- 4) Then answer the following questions.

17. Describe what happened when you did your experiment.

18. To the right you see a computer simulation of how these objects fall due to gravity. Run the model. Does it match your experiment? Describe the differences between the motion of the objects on the computer and the motion of the objects you dropped.

The hammer and feather example

Gravity: Determining the factor not considered by the model.

To the right you see two people dropping a hammer and a feather. One is an astronaut, dropping a hammer and feather on the moon. The other is a student, dropping a hammer and feather here on Earth.

19. One of the hammer/feather drop experiments to the right matches the computer model better than the other. Which one?

Moon Earth

20. Why does that environment match the computer simulation better? (Hint: Why does the astronaut need to wear a suit?)

The hammer and feather on the moon (official NASA footage)

Gravity: Using the Resistance Lab

STUDYING THE EFFECTS OF AIR RESISTANCE: To the right is a "laboratory" of sorts. This will allow you to try many different scenarios. You can drop either a hammer or a feather, and choose whether or not you want air resistance to be a factor. By choosing the "Planet X" environment you get a planet that has just as much mass as the Earth but no air, so the force of gravity is the same but there is no air resistance.

Data for five different properties of the falling object will be collected and graphed. You can choose the property to graph by selecting that property from the menu located just above each graph.

Run several experiments to become familiar with the "lab", and press the next arrow to continue.

Environment: Earth (with air) Planet X (no ...)

Item: Hammer (1 ...)

Environment: Earth (with air) Planet X (no ...)

Item: Hammer (1 ...)

	<-a	1	a->
9.8	0.0	9.8	
9.8	0.2	5.25	
9.8	0.4	2.82	
9.8	0.6	1.51	
9.8	0.8	0.81	
9.8	1.0	0.43	
9.8	1.2	0.23	
9.8	1.4	0.12	
9.8	1.6	0.07	

Acceleration (m/sec²) separate combined Acceleration (m/sec²)

Students choose Earth or Planet X, feather or hammer, for each model.

Gravity: Exploring the effect of air resistance on velocity.

The effect air resistance has on velocity or distance is more subtle than its effect on acceleration. To better compare these graphs, you can overlap them by clicking on the switch between the graphs. After dropping a hammer on the Earth and Planet X, answer the questions below.

26. Compare the velocity graphs from the two environments and describe how air resistance affects the velocity of a falling object.

27. Now compare the distance graphs. How are they different?

Environment: Earth (with air) Planet X (no ...)

Item: Hammer (1 ...)

Environment: Earth (with air) Planet X (no ...)

Item: Hammer (1 ...)

	<-a	1	a->
9.8	0.0	9.8	
9.8	0.2	9.41	
9.8	0.4	9.04	
9.8	0.6	8.69	
9.8	0.8	8.35	
9.8	1.0	8.02	
9.8	1.2	7.7	
9.8	1.4	7.4	
9.8	1.6	7.11	
9.8	1.8	6.83	
9.8	2.0	6.56	
9.8	2.2	6.3	

Acceleration (m/sec²) separate combined Acceleration (m/sec²)

Students can view the graphs separately or together.

In the Planet X/Earth screens, the student can change the columns in the data table by selecting different variables in the pull down menus under each model. Clicking the switch button will toggle between merging the two graphs and displaying them separately.

In the next screen, students drop a feather and hammer from a very tall mountain to explore the concept of reaching terminal velocity.

Gravity: Explaining the difference between the hammer and feather.

Environment: Earth (with air) Item: Hammer (1 ... Feather(.01 ...

This cliff is much higher than the previous cliffs from which you dropped items. This will allow dropped items to fall much greater distances and for longer periods of time. Try dropping the hammer now to see if your prediction was correct.

33. Was your prediction correct? If not, why not?

34. Why do you think the feather reaches terminal velocity so much faster than the hammer?

Time (sec)	Hammer (m/sec)	Feather (m/sec)
0.0	0.0	0.0
19.32	2.5	19.32
31.02	5.0	31.02
3.28	7.5	38.11
3.27	10.0	42.4
3.27	12.5	45.0
3.27	15.0	46.58
3.27	17.5	47.53
3.27	20.0	48.11
3.27	22.5	48.46
3.27	25.0	48.67
3.27	27.5	48.8

Velocity (m/sec) separate combined Velocity (m/sec)

The feather reaches terminal velocity faster than a hammer

The next subsection of the activity is "Parachute Jumping."

The screenshot shows a window titled "Gravity: Exploring the effect of parachute size." The text on the left explains that three people will jump from a cliff, and their terminal velocity will be affected by the size of their parachute. A question asks how parachute size affects terminal velocity. Below the text is a green rectangular area and a graph showing velocity (m/sec) on the y-axis (0 to 40) and time (sec) on the x-axis (0 to 15). The graph displays three curves: a blue curve that rises steeply and levels off at approximately 35 m/sec, a pink curve that rises more gradually and levels off at approximately 20 m/sec, and a red curve that rises very gradually and levels off at approximately 10 m/sec. To the right of the graph is a simulation area showing a cliff with three jumpers: a blue smiley with a small parachute, a pink smiley with a medium parachute, and a yellow smiley with a large parachute. The simulation includes a vertical slider on the left to adjust the height of the cliff and a horizontal slider at the bottom to adjust the parachute size. A question mark icon is in the top right corner.

Introduction to the parachute activity

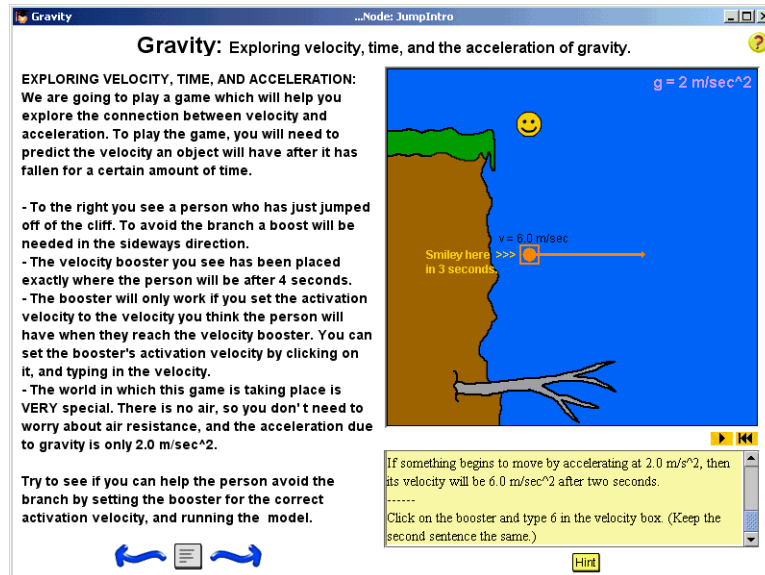
In the parachute game, shown below, the student must land the smiley at the correct velocity and in the acceptable time range. The graph can be used to determine the correct speed and time. The student should use the sliders on the sides of the model to adjust the parachute size and height.

The screenshot shows a window titled "Gravity: Exploring the effect of parachute size." The text on the left describes a challenge: a paratrooper must land in a dangerous area as quickly as possible without moving too fast. A graph shows a limit on velocity (20 m/sec) and time (8 sec). The simulation area shows a smiley with a parachute falling from a cliff. A vertical slider on the left allows adjusting the height of the cliff, and a horizontal slider at the bottom allows adjusting the parachute size. A yellow "Hint" button is visible above the graph. The graph shows a red curve that rises to a peak of 20 m/sec at approximately 4 seconds, then drops to 0 m/sec at 8 seconds. The simulation includes a vertical slider on the left to adjust the height of the cliff and a horizontal slider at the bottom to adjust the parachute size. A question mark icon is in the top right corner.

The smiley should land safely on the ground

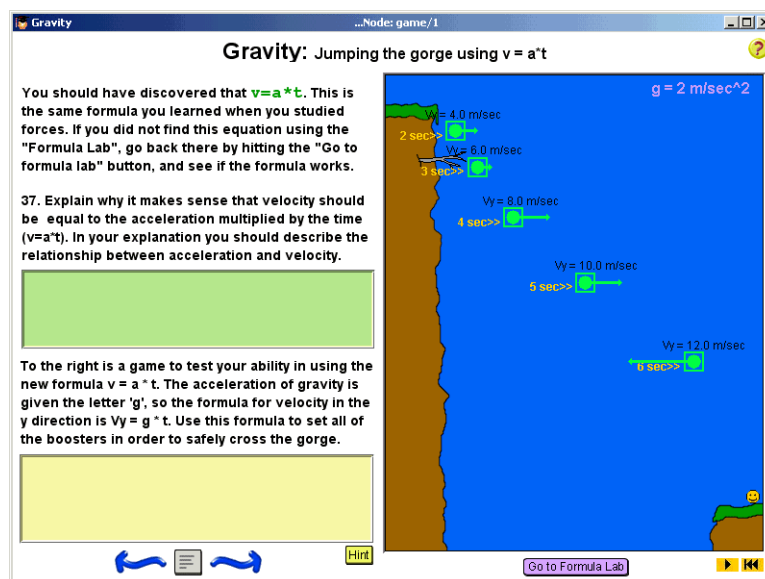
4.4 3) Jump the Gorge

In this section, the student explores the connection between velocity and acceleration. In the first game, the student will need to set the velocity booster so that the falling smiley misses the branch. In the second game, the student must set a series of boosters so that the smiley follows a certain path. To set the value for a booster, the student should click on that booster.



Missing the branch game

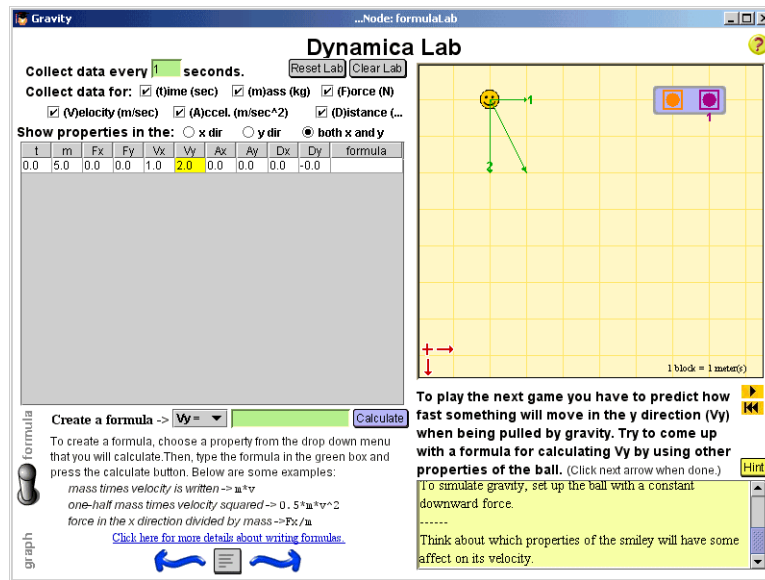
The velocity booster in the screen above will only activate if the smiley hits it with the set velocity. The student must set that velocity. In this case, it is accelerating at 2m/s^2 so it will have a velocity of 6m/s when it hits the booster. Students can click the booster to enter the appropriate activation velocity—a dialog box will pop up. The hints can help students in this case.




Multiple booster game

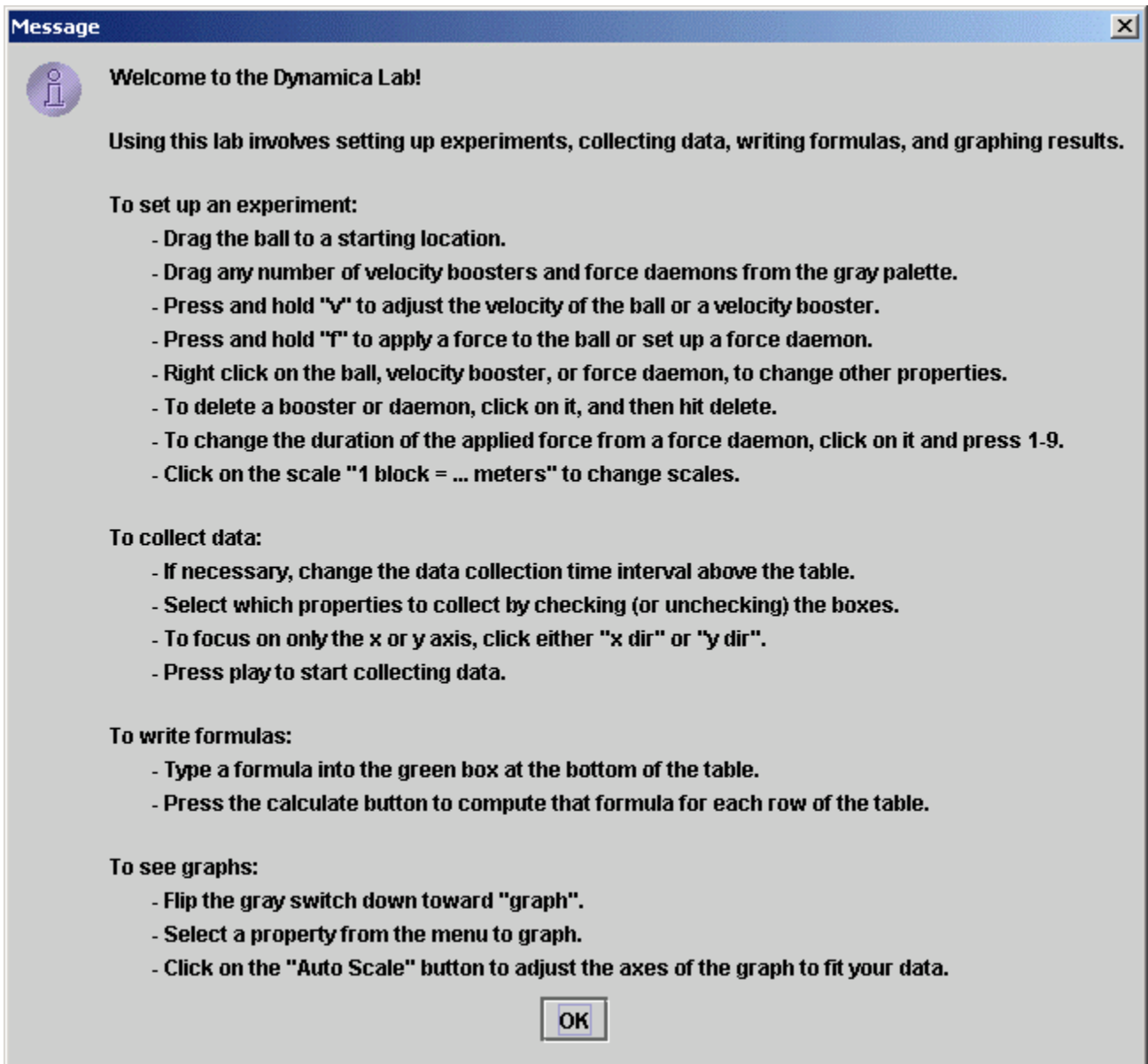
In the game above, the student must set the velocity at which the smiley will be moving in the y-direction when it reaches each of the boosters. To set the

velocity, students should click on each booster and type in the correct value. Students should use the $v = a * t$ formula. The hints will be very helpful for students in this game.



Lab screen

In order to use the lab screen above, students will need the instructions. The instructions will open when the student clicks on the  button in the corner of the screen. TO start the smiley face moving, make sure to apply an initial velocity to it. Here are the instructions for applying velocity and force:



5.0 Student Reports

Your students' work in "Gravity" is logged and viewable on the MAC Project Web Portal at <http://mac.concord.org>. You will see all your students' responses for each screen in the activity.

This is the final Dynamica activity. At this point, students should take the post-test. Please make sure that students have an entire class period to take the post-test.