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.

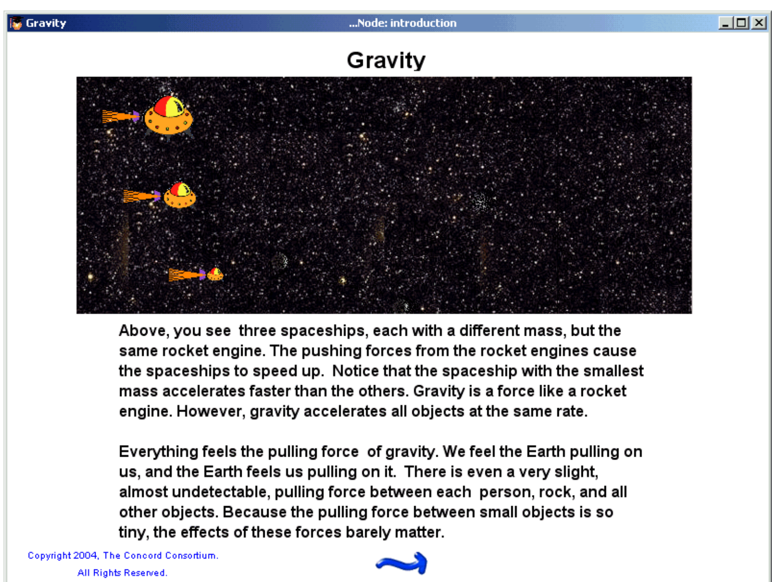
Additional Activities

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.	• 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.	• 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.	• 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.	• Students should recognize and apply mathematics in contexts outside of mathematics. • Objects change their motion only when a net force is applied.

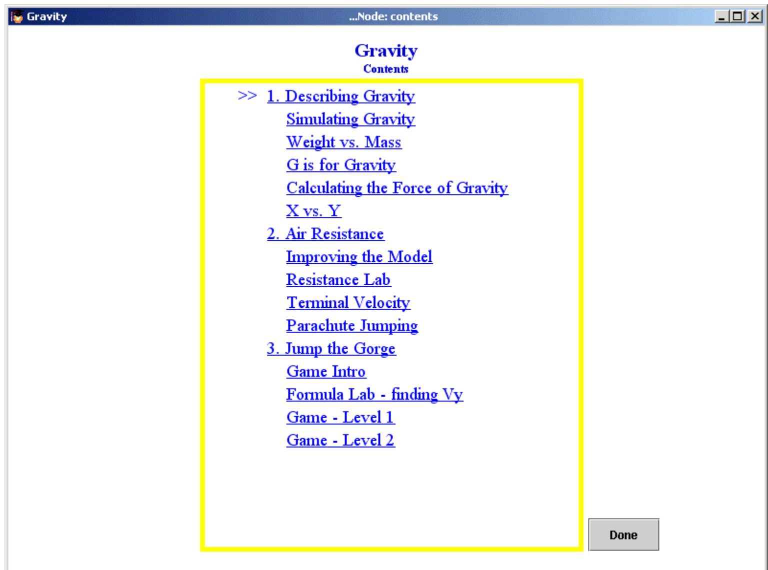


Opening Screen

4.0 Activity Sections

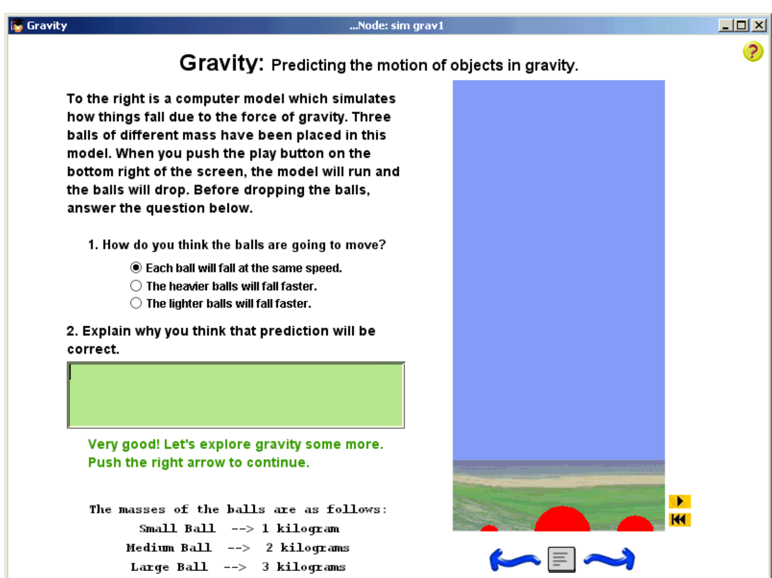
4.1 Table of Contents

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

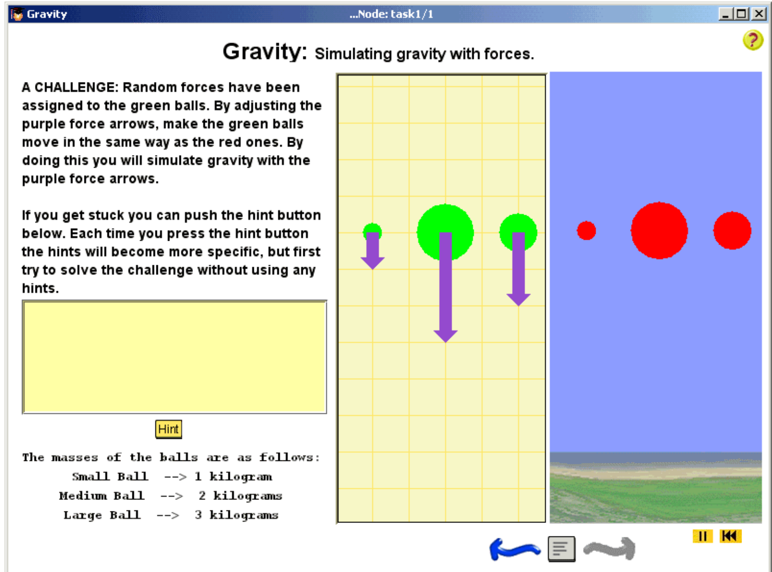


4.2 1) Describing Gravity

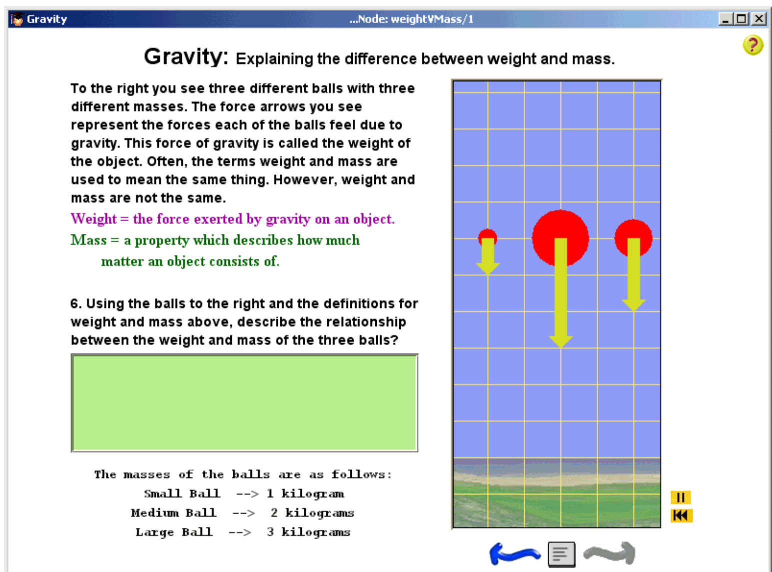
This section introduces students to the force of gravity. The model shows how balls of different mass will drop at the same velocity. Students are then asked to apply forces to the balls and answer questions about the models. In all the screens in this activity, there is a help button available—students can click on the ? icon (located in the upper right-hand corner) for context-specific help.



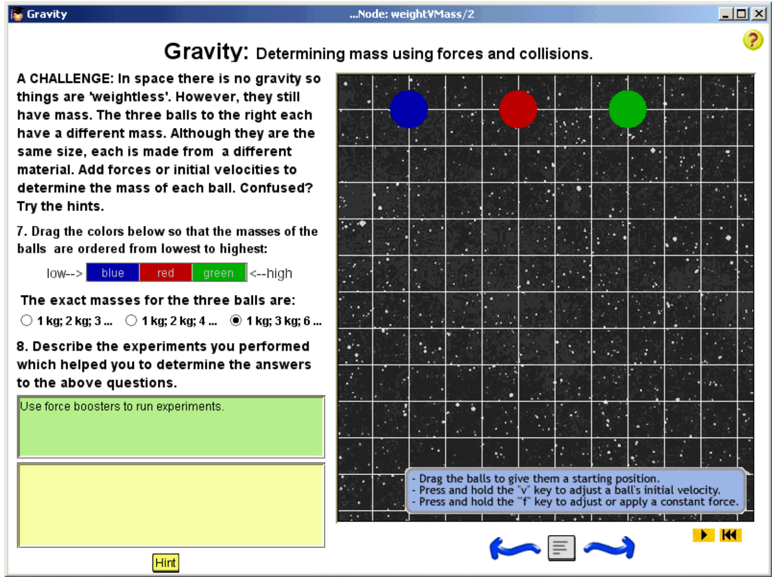
First subsection



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



Definitions of weight and mass



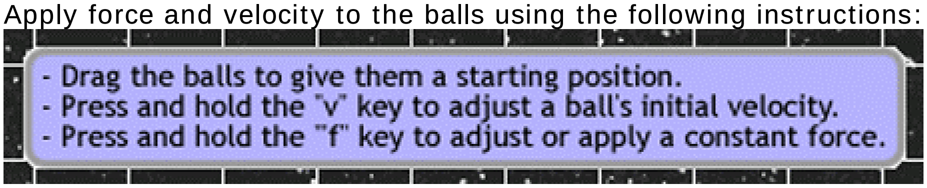
Gravity in space

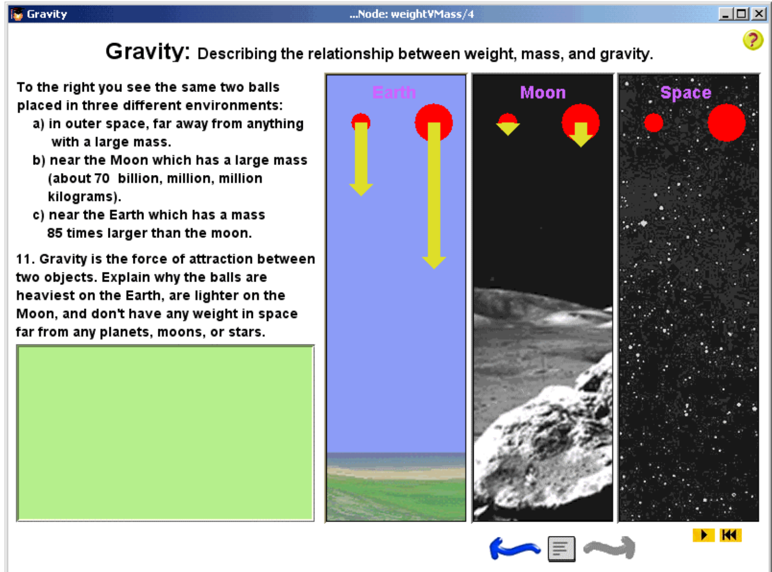
Students can experiment by setting the initial velocity of each ball and/or applying a force to each ball. The student must decide which ball has the greatest mass, which has the least and which is in between. Then the student should select the correct mass for each ball. Strategies for doing this include:

- 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.

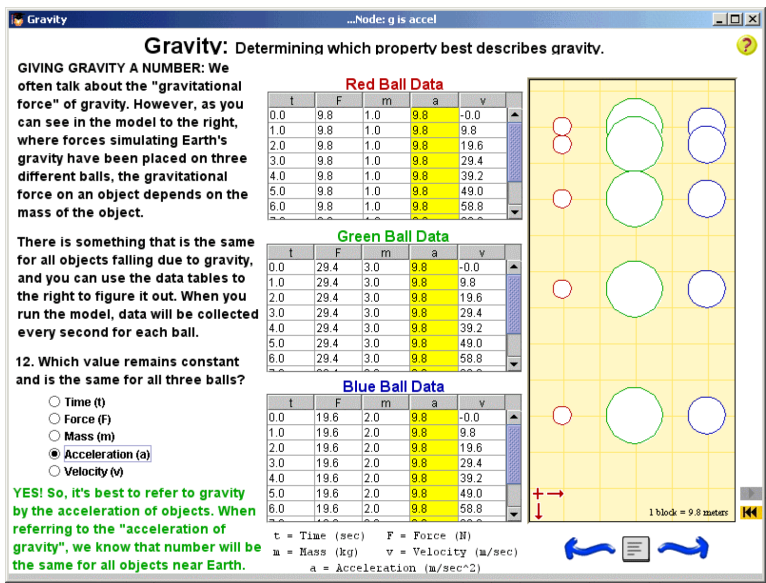
To calculate the specific masses, apply a force to each ball such that the balls accelerate at the same rate. The length of the force arrows will tell you the relative masses. If students have trouble passing the screen above, the correct answers are in the screen shot below. The blue ball has the lightest 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:



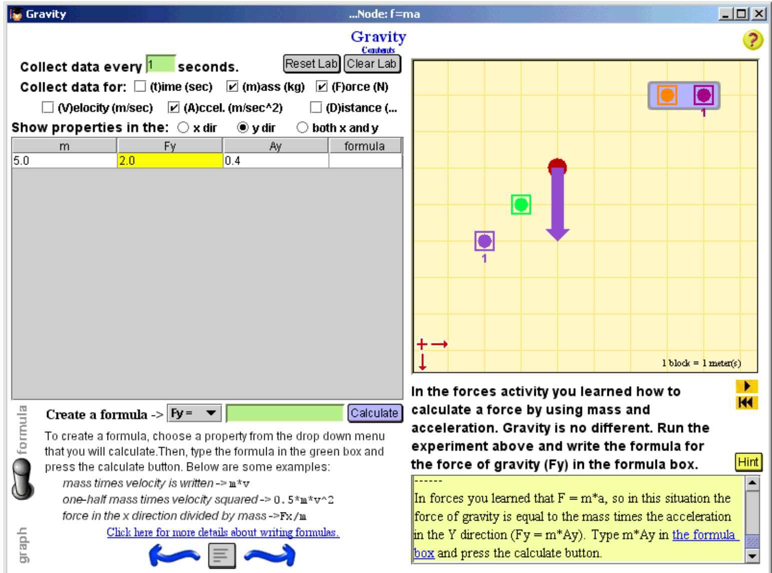


Weight changes depending on gravity but mass remains the same.



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

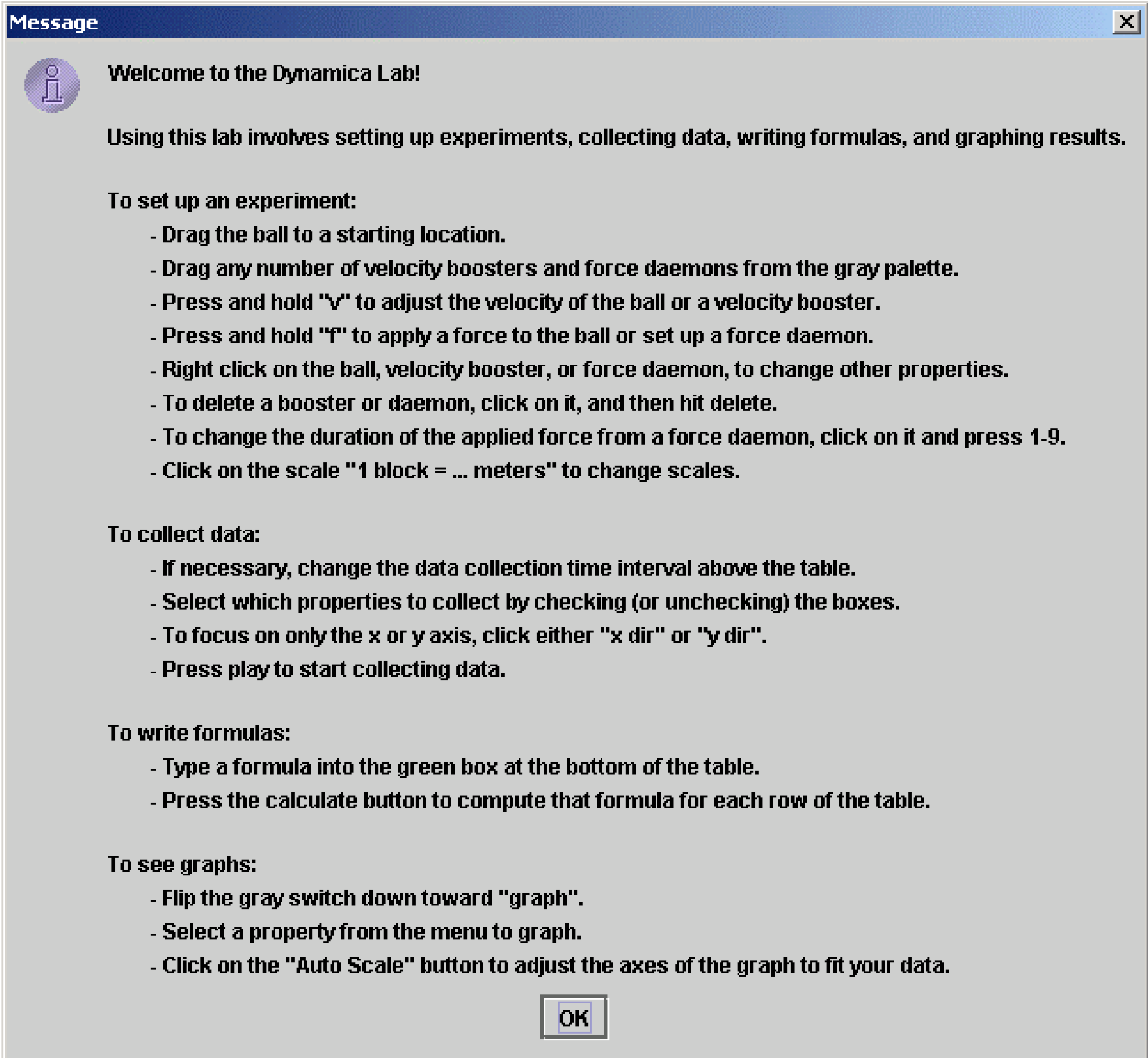
In the screen above, students should examine the data charts to answer the question; the correct answer is “Acceleration.” If the student answers incorrectly, he or she should reset the model and try another answer.

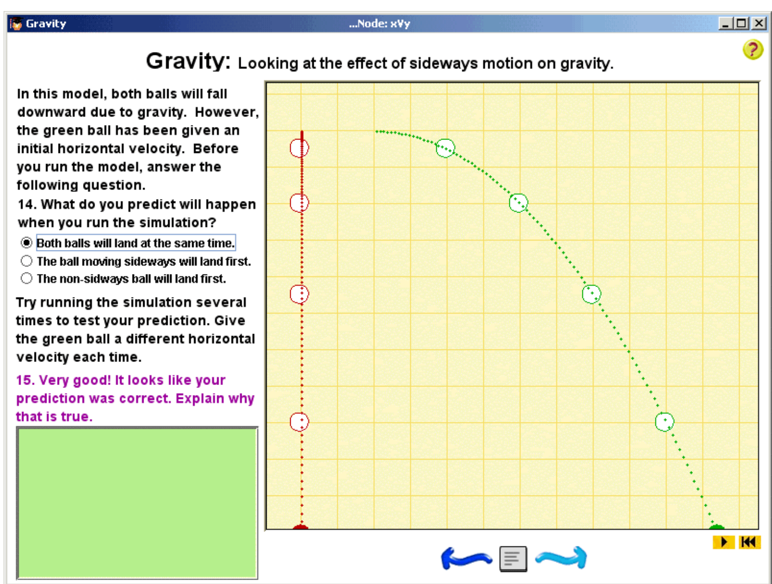


Calculating the Force of Gravity Lab

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:

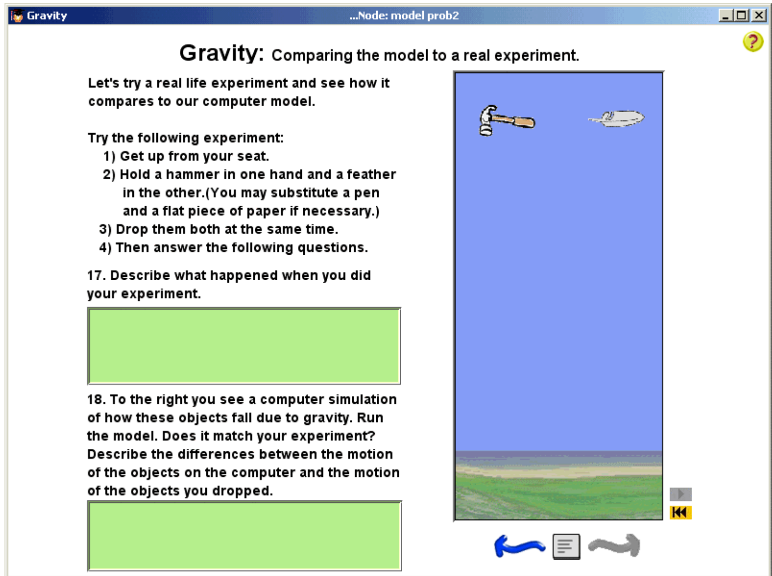




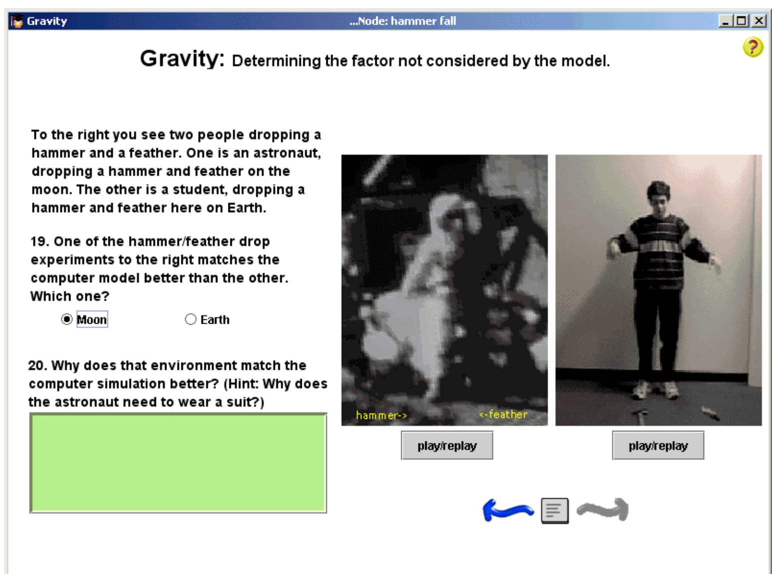
Final subsection X vs. Y is a review of Force in 2D.

4.3 2) Air Resistance

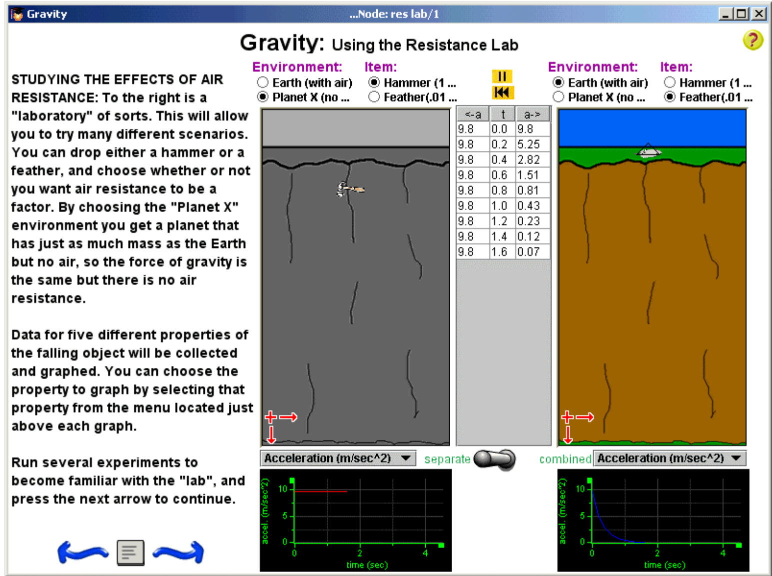
This section asks students to think about how computer models of gravity are different than the real world. For example, so far in the activity, students have been investigating the force of gravity while ignoring other forces such as air resistance.



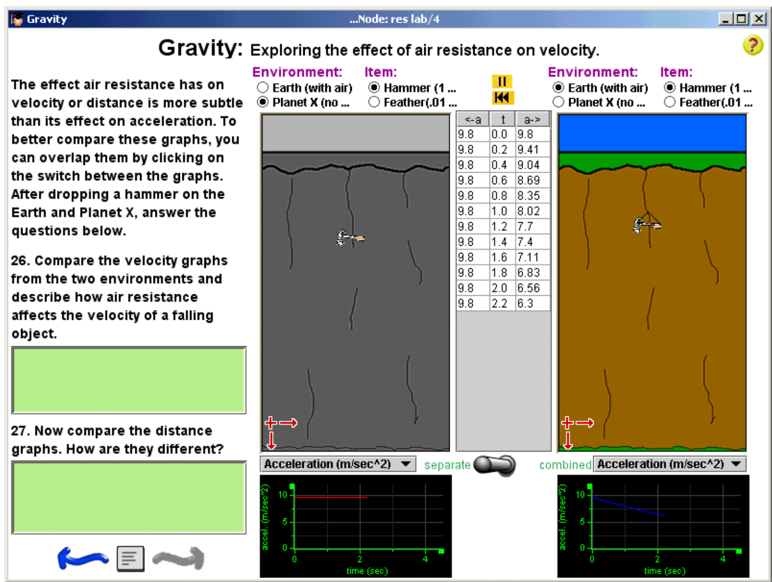
The hammer and feather example



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



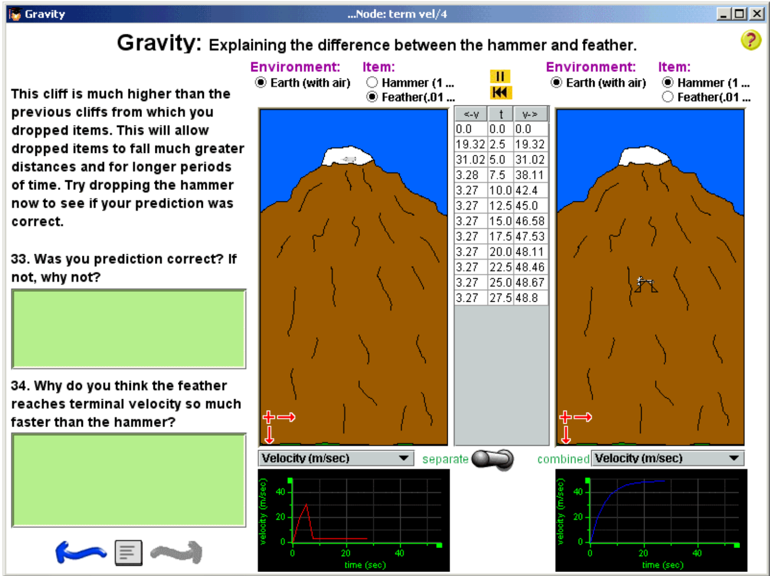
Students choose Earth or Planet X, feather or hammer, for each model.



Students can view the graphs separately or together.

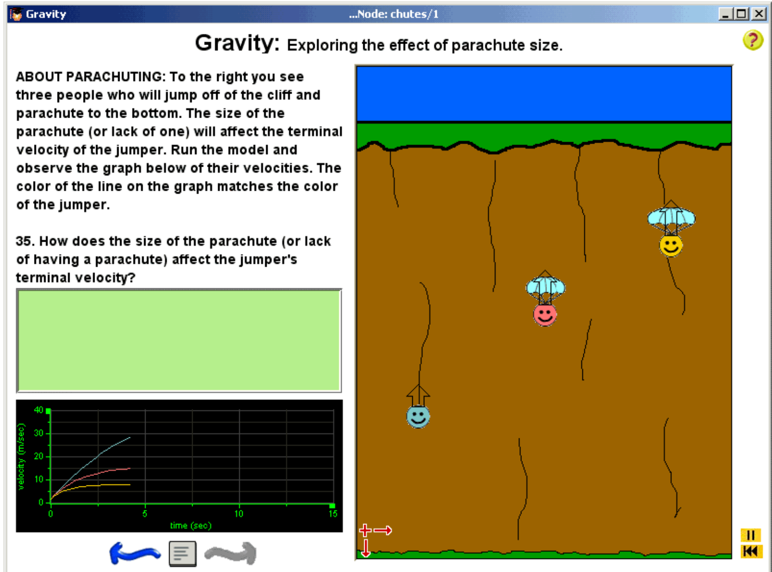
In the Planet X/Earth screens, the student can change the columns in the data table by selecting different variables in the pull down menus under each model. Clicking the switch button will toggle between merging the two graphs and displaying them separately.

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



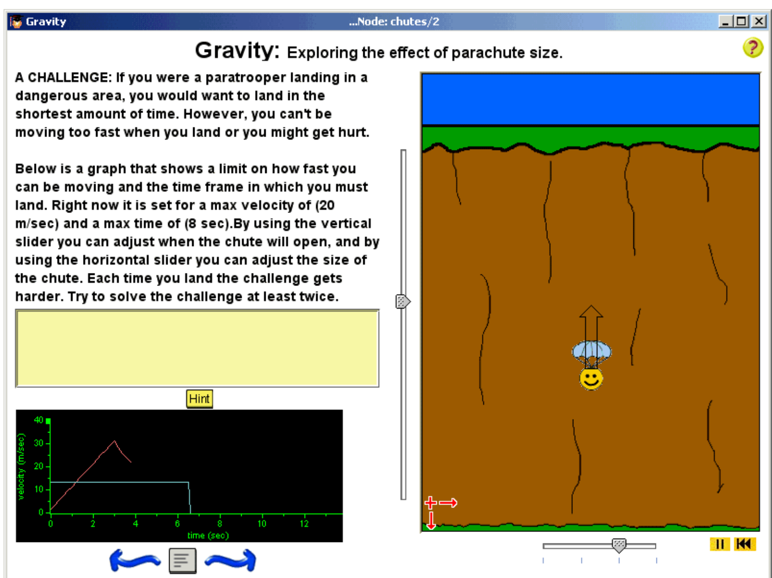
The feather reaches terminal velocity faster than a hammer

The next subsection of the activity is “Parachute Jumping.”



Introduction to the parachute activity

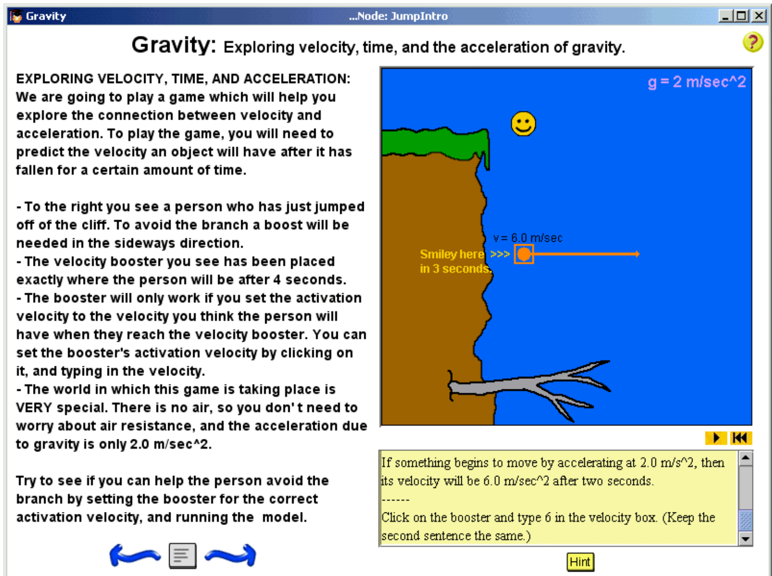
In the parachute game, shown below, the student must land the smiley at the correct velocity and in the acceptable time range. The graph can be used to determine the correct speed and time. The student should use the sliders on the sides of the model to adjust the parachute size and height.



The smiley should land safely on the ground

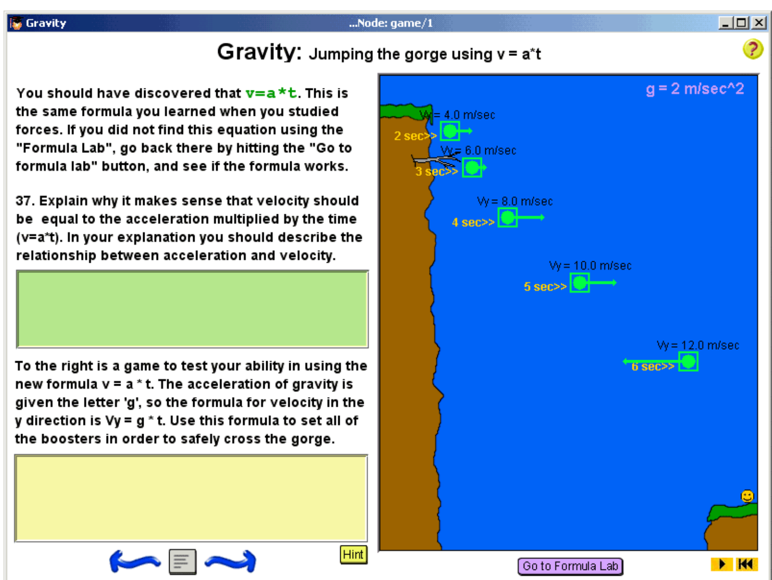
4.4 3) Jump the Gorge

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.



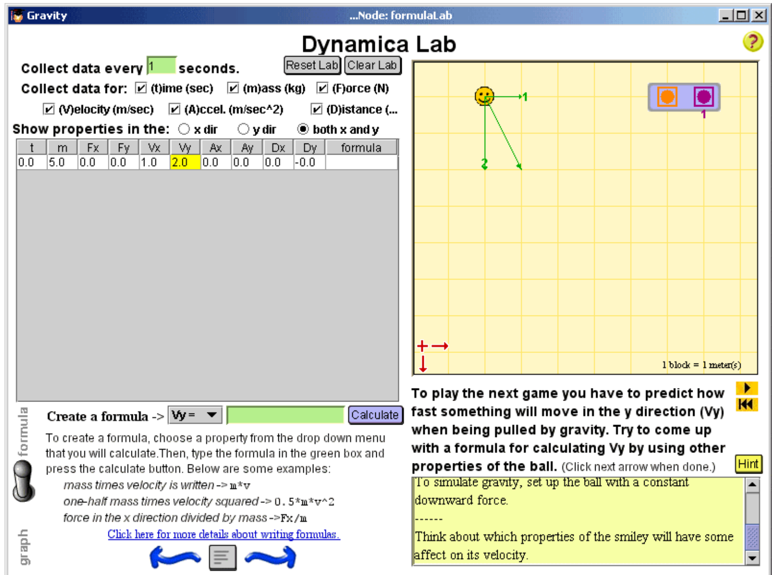
Missing the branch game

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.



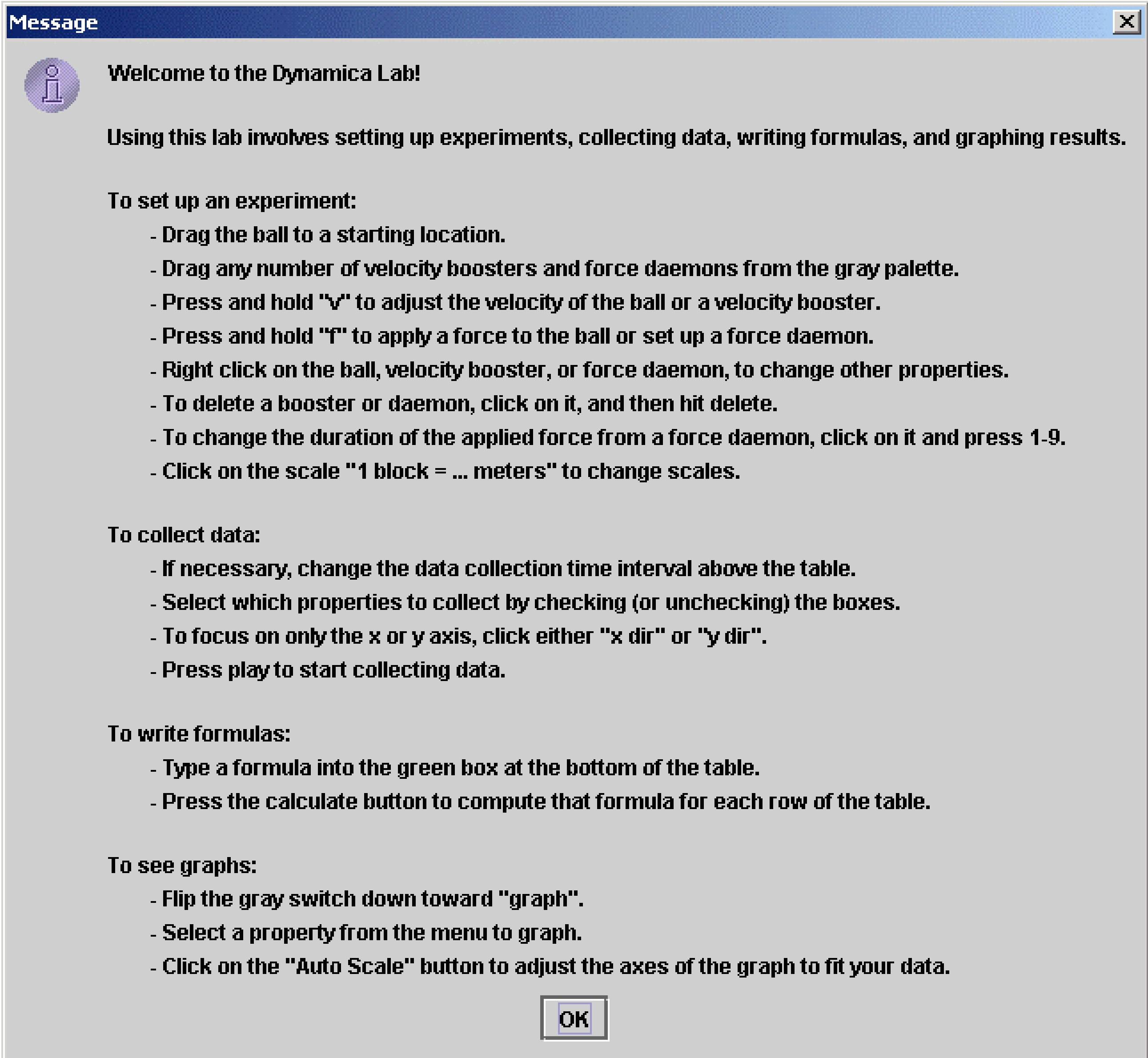
Multiple booster game

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.