

Forces in Two Dimensions

Teacher's Guide

1.0 Summary

"Forces in Two Dimensions" is the sixth activity in the Dynamica sequence. This activity should be done after Balancing Force and it should take students approximately 45 minutes.

2.0 Learning Goals

Driving Question: How do forces in more than one direction affect the motion of objects?

The previous activities looked at the effect of forces along only one dimension, that is, just to the left or right. But forces act in all directions. For example, when you kick a ball through the air, you hit it sideways, gravity pulls it downward, and air resistance pushes against it. This activity will illustrate how the motion and forces along each axis can be studied independently in order to understand a two-dimensional trajectory. For instance, forces in the X direction do not affect motion in the Y direction.

Step One: **Introduction** has a ball that makes distance and velocity graphs in both the X and the Y directions. It demonstrates that forces in the Y direction affect the Y velocity but not the X velocity.

Step Two: **Sideways Forces** is another exercise in observing that motion graphs in the X direction and the Y direction can be studied independently.

Step Three: **Frisbee Practice** is a game section where students figure out the direction of velocities and forces.

Step Four: **Turning Corners** is a challenge where students must apply a force to an object so that it turns 90 degrees.

Step Five: **Basketball** is a game section where students supply the velocity vectors needed to launch a ball into a basket.

Step Six: **Hidden forces** challenge students to infer forces from the appearance of graphs.

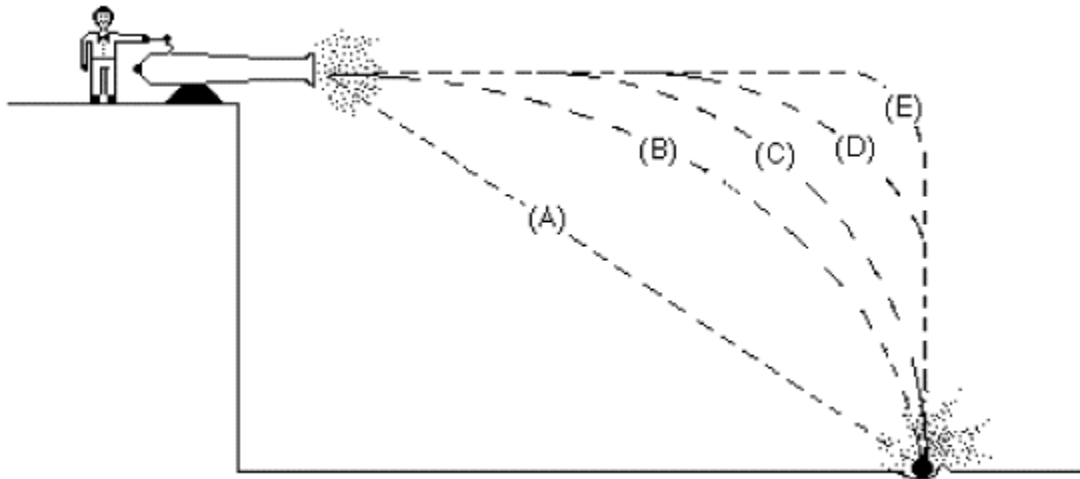
Step Seven: **Lab** provides a "space" where students can experiment on their own or complete exercises provided by the teacher.

Additional Teacher Background

This activity is like the motion graphs activity but in two directions. The independence of X and Y, whether for displacement, velocity, or force, is a powerful tool in physics because it simplifies the analysis. The pair of graphs encourages the

student to distinguish between motion in the Y direction and motion in the X direction.

Many students think that if a rolling ball is hit sideways, it will make a right turn, rather than going at a diagonal; the **same** X velocity and some **new** Y velocity. Another common misconception (which will be addressed again in **Gravity**) is that a ball that is rolled off a table edge will go at a diagonal (A), or straight out, then down (E).



In fact, it goes in an arc (D), which is the combination of its continuing, unchanged horizontal velocity and its gravitational acceleration downward.

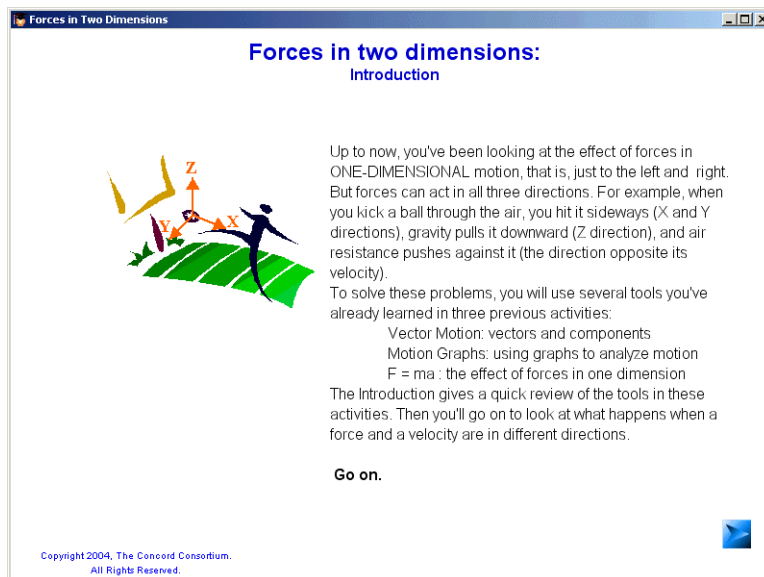
Additional Activities

Force Table - This is a common piece of equipment in physics labs, but it could be improvised. A circular table has pulleys mounted at the edges, with weights on strings. The strings are joined in the middle, and the goal is to have them be balanced so that the central knot stays in the same place. The weights and angles can be adjusted to match the computer activity, or the computer activity can model the physical experiment. Spring scales or force probes can replace weights. The forces become more vivid if students can use force probes to pull on strings connected to a central point.

3.0 Standards Alignment

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

Objective	Standards
Students will analyze two-dimensional forces in terms of independent X and Y components	<ul style="list-style-type: none"> • Students should understand vectors as systems that have some of the properties of the real-number system. • Students should select, apply, and translate among mathematical representations to solve problems;
Students will predict the forces that are needed to make objects follow various trajectories	<ul style="list-style-type: none"> • Students should use the language of mathematics to express mathematical ideas precisely. • Students should use Cartesian coordinates to analyze geometric situations.
Students will understand the correspondence between the motion of objects and velocity-time graphs	<ul style="list-style-type: none"> • Students should recognize and apply mathematics in contexts outside of mathematics.

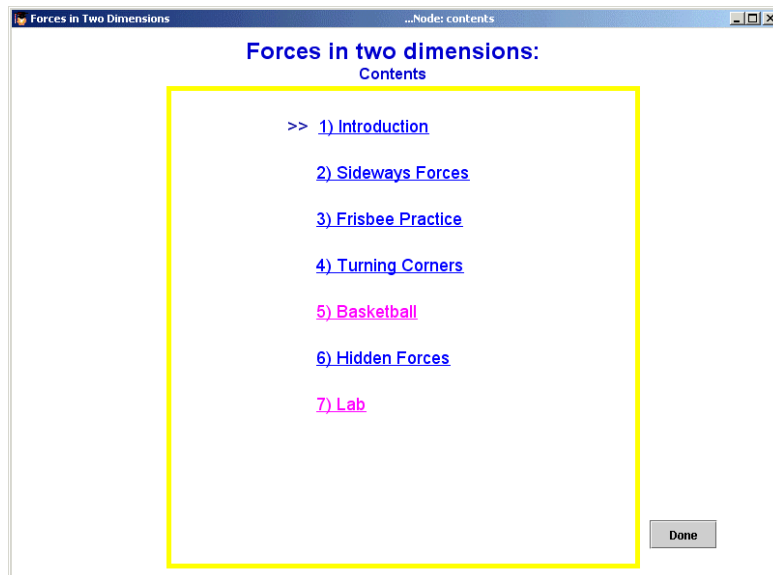


Opening screen

4.0 Activity Sections

4.1 Table of Contents

This activity has 7 sections. The required sections of this activity are sections 1 through 6. The last section is a "Lab" where teachers may assign students custom experiments.



4.2 1) Introduction

The introduction in Force in Two Dimensions is really a review of some of the concepts that students learned in the Vector Motion, Motion Graphs and $F=ma$ activities.

The screenshot shows a window titled "Forces in Two Dimensions" with a subtitle "...Node: introduction1". The main heading is "Forces in two dimensions: 1) Introduction: Vector Motion".

On the left, there is a grid with a blue vector arrow pointing into the first quadrant. The horizontal component is labeled '3' and the vertical component is labeled '2'. A small orange box with the number '1' is in the top right of the grid.

Below the grid is another grid showing a red vector arrow from the origin to the point (3,2). Dashed lines indicate the components: a horizontal line of length 3 and a vertical line of length 2. The coordinates (3,2) are written in red next to the tip of the arrow.

Text on the right:

In the Vector Motion activity, it was demonstrated that velocity can be divided into X and Y components. Velocity in any direction (in two dimensions) is a vector combination of these two.

The picture is an example from Vector Motion.

1. In this example, what is V_x ?

2. In this example, what is V_y ?

That's correct. The velocity vector is the sum of the two components.

Go on.

A small icon of a computer monitor is in the bottom right corner.

Review of Vector Motion

Forces in Two Dimensions ...Node: introduction2

Forces in two dimensions:

1) Introduction: Motion Graphs

3. At a constant velocity,
 The position graph is flat.
 The position graph is sloped.

4. At a constant velocity,
 The velocity graph is flat.
 The velocity graph is sloped.

5. What's the velocity of the ball? (m/s)

Submit Answer

Velocity-time graph

Pause Reset

Review of Motion Graphs

Forces in Two Dimensions ...Node: introduction3

Forces in two dimensions:

1) Introduction: Force and Mass

Force strength (N): Force duration (s):

Ball's mass (kg): Starting velocity (m/s): Final velocity (m/s):

Pause Reset

In the $F=ma$ activity, the model showed that change in velocity is caused by external forces. The relationship between force, mass and acceleration is called Newton's Second Law.

$$\text{Acceleration} = \text{Force} / \text{mass}$$

$$a = F/m \text{ or } F = ma$$
 Another way to write this is:

$$\text{Change in velocity} = (\text{strength of force}) (\text{duration of force}) / \text{amount of mass}$$
 In this example, the force, its duration, and the mass of the ball are fixed. **Adjust the value of the FINAL VELOCITY so that it matches the velocity the ball will have after it hits the force booster.**

Hint

To move past this screen, students must set the slider to 5

4.3 2) Sideways Forces

In this section, students are introduced to objects moving in one direction that encounter a force that moves them in a different direction. There are two additional examples in this section that emphasize the independence of the velocity in each direction. For example, in the peashooter game, a shot pea and a dropped pea have the same y velocity but a different x velocity.

Forces in two dimensions:
2) Sideways forces

In the model below, The ball's initial velocity is set at $V_x = 0\text{m/s}$ and $V_y = 4\text{m/s}$. The ball will hit a force booster, which will apply a force in the X direction. After you answer the question below, you will be able to run the model.

6. Predict what each velocity graph will do when the ball hits the force booster.

Move to the right in an arc

Submit Answer

2
Seconds

2 m/s
4 m/s

Pause Reset

Velocity-time graph

Run the model and examine the graphs

Forces in two dimensions:
2) Sideways forces

Here is one way to summarize what you have observed. The following statements are correct.

- With constant velocity, the velocity graph is a horizontal straight line.
- With constant force, the velocity graph is a sloped straight line.
- With constant velocity, the position graph is a sloped straight line.
- With constant force, the position graph is a curved line.
- **What happens in the X direction doesn't affect what happens in the Y direction.**

Use these features, especially the last one, as you do the next section.

Students should think about the independence of forces and velocities in each direction for the remainder of this section

Forces in two dimensions:
2) Sideways forces

Now the sideways force is continuous, in the positive X direction.
The ball has an initial velocity, in the positive Y direction.

10. The V_x graph will
 be flat slope upward curve upward

11. The V_y graph will
 be flat slope upward curve upward

0
Seconds

2 m/s

Velocity-time graph

Run Reset

Students are asked to predict what the graphs will look like

Forces in two dimensions:
2) Sideways forces

12. The V_x graph sloped upward. Why?

13. The V_y graph was flat. Why?

14. Does a force in the X direction affect the velocity in the Y direction?
 Yes No

15. How can you tell from the graphs?

2
Seconds

2 m/s

1 kg

Velocity-time graph

Pause Reset

Students are asked to explain the relationship between the model and the resulting graphs

In the next two games, students are asked to predict the action of two objects. In the first game, students are asked to predict if both balls, each with the same V_x but a different horizontal force will reach the top at the same time. In the second game, the peashooter, students drop a pea and shoot a pea from the same height. They are asked to predict which pea will hit the ground first.

Forces in Two Dimensions ...Node: SidewaysTarget

Forces in two dimensions: 2) Sideways forces: Reaching the target

Now there are two balls. One has a constant force on it to the right, and one has no force. They both have the same initial velocity and mass. **Answer the question and run the model.**

18. Which ball will get to the top of the screen first?

Red ball Green ball Both the same

Velocity-time graph

Pause Reset

The student can adjust the force of the green ball

Forces in Two Dimensions ...Node: SidewaysTarget3

Forces in two dimensions: 2) Sideways forces: Reaching the target

Now run the model and test your prediction.

20. which pea will reach the ground first?

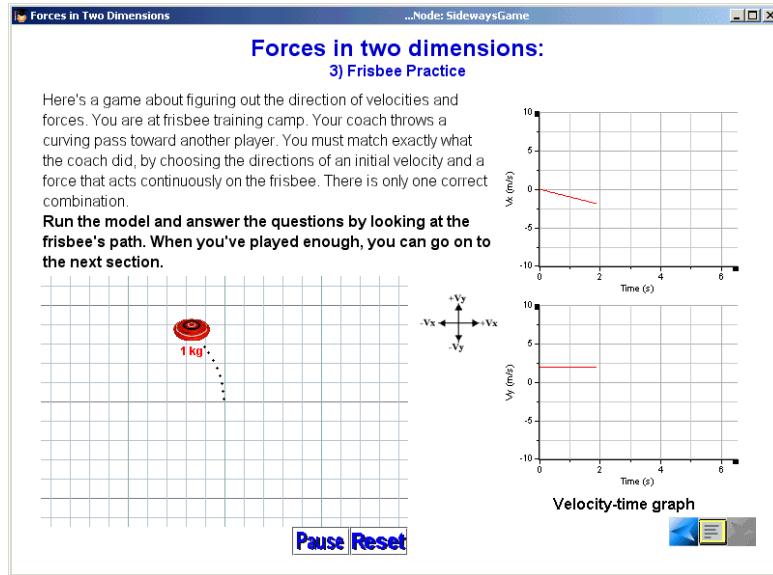
dropped pea shot pea Both the same

Submit Answer

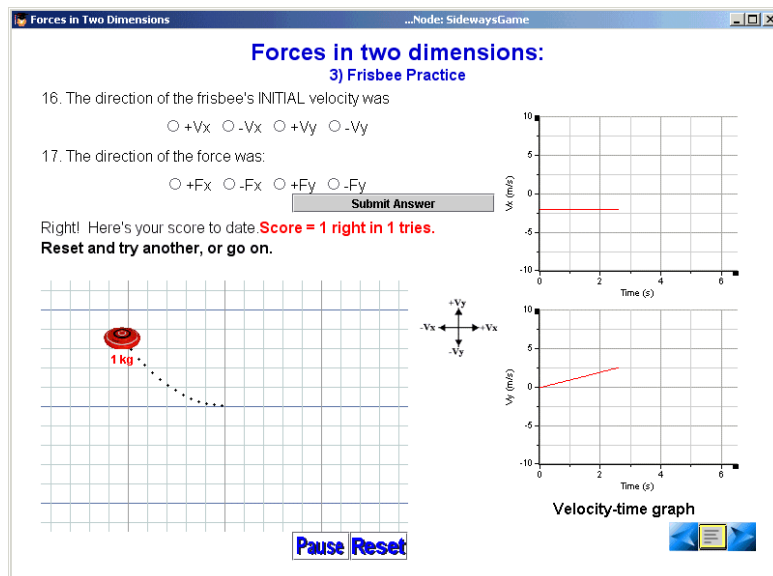
Both peas will hit the ground at the same time

4.4 3) Frisbee Practice

This section helps students better understand the relationship between the initial velocity of an object and a force acting in a different direction. Students indicate the direction of a frisbee's initial velocity and the direction of the force. The direction and velocity of the frisbee is chosen randomly so each student will have a slightly different model.



Students run graph of a frisbee being thrown



Student selects the direction of the frisbee's initial velocity and the applied force

4.5 4) Turning Corners

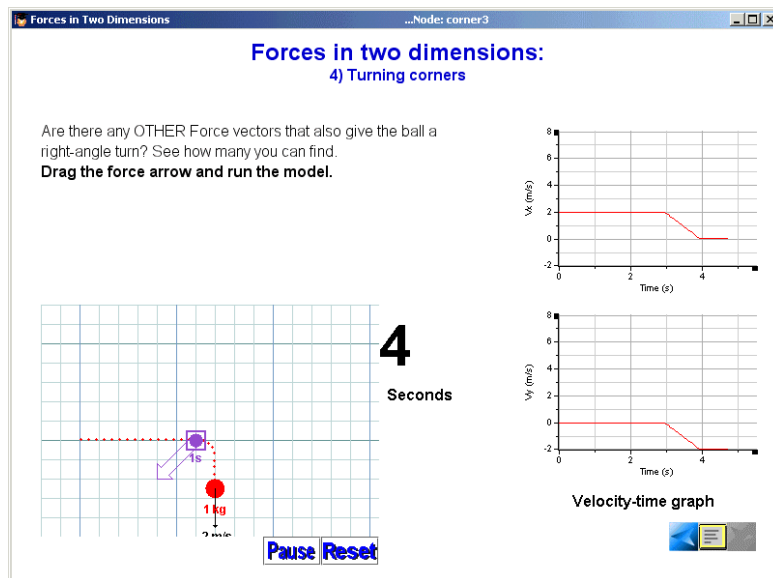
Turning Corners asks students to apply a force such that a ball turns and moves 90 degrees from the original path. The student must find two different forces that allow this to occur.

The screenshot shows the simulation window titled "Forces in Two Dimensions" with the sub-heading "4) Turning corners". The text on the left reads: "Here's a ball with a velocity of 2 m/s in the positive X direction. The ball's mass is 1 kg. It will run into a force booster. You can change the force arrow by clicking and dragging on the booster. Each square represents 1 N of force. The force will last for 1 second. **Set the direction and length of the arrow on the force booster so that the ball turns to the left and goes STRAIGHT UP in the Y direction - a right-angle turn.**" The central grid shows a red ball labeled "1 kg" moving right at "2 m/s" towards a purple square labeled "1s" with an upward-pointing arrow. A digital clock on the right shows "0 Seconds". At the bottom right are "Run" and "Reset" buttons.

Students are asked to adjust the force arrow such that the ball makes a 90 degree turn

The screenshot shows the simulation window at "5 Seconds". The text on the left now reads: "That's right. You made a right-angle turn." The central grid shows the red ball moving upwards at "2 m/s" after passing the purple "1s" booster. A dashed red line indicates the ball's original path. A digital clock on the right shows "5 Seconds". At the bottom right are "Pause" and "Reset" buttons. Below the grid is a text input field with the question: "21. Explain how the force must be set to make a right-angle turn." and a "Submit Answer" button.

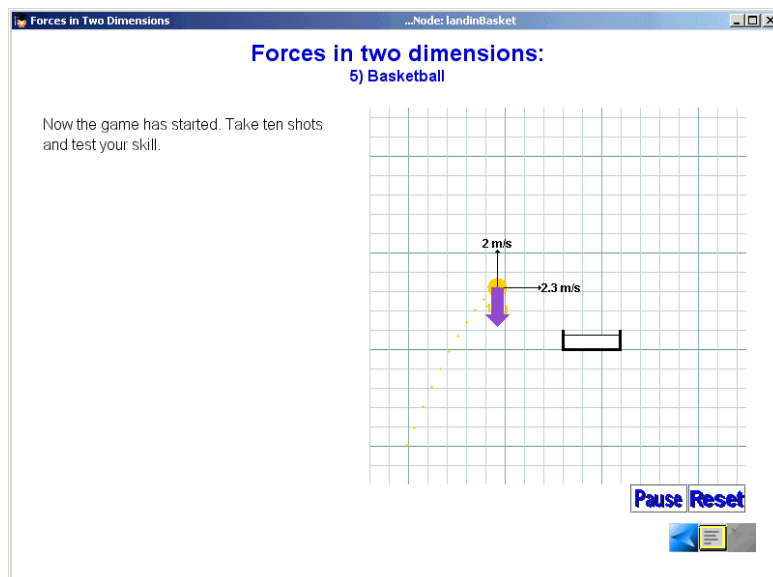
Free response question to assess understanding



Student must then solve the problem in a different way

4.6 5) Basketball

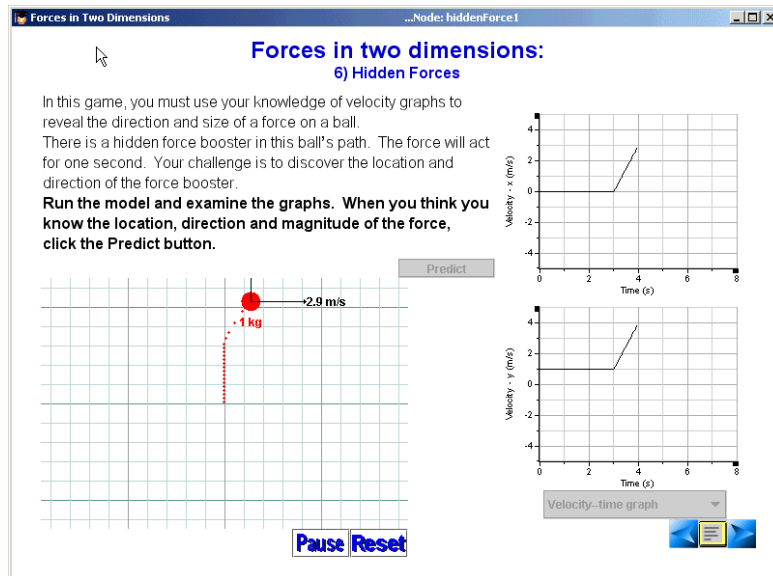
The Basketball game gives students 10 tries to shoot a basket. Students apply an initial velocity in the x and y directions to the ball. The ball also has the force of gravity acting upon it (there is a force arrow already on the ball). The basket location is generated randomly, so each student will have a different solution to this game. In fact, multiple solutions will work with each basket location.



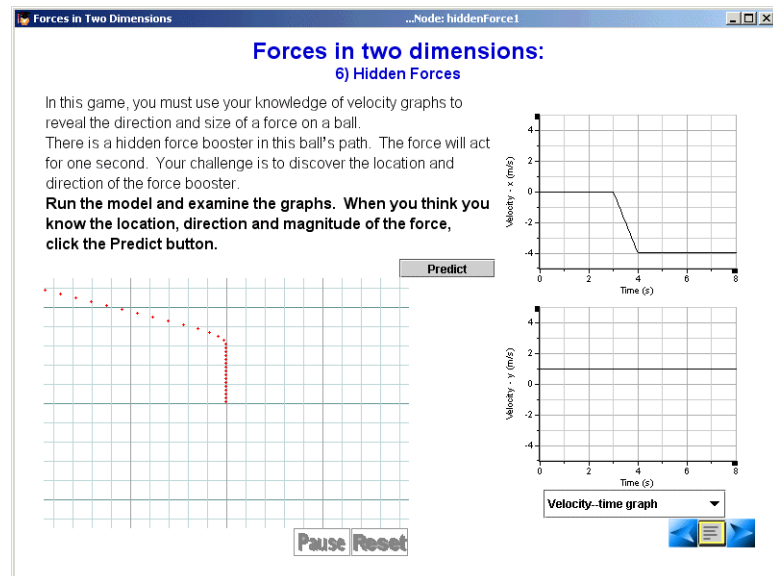
The student has 10 chances to make a basket

4.7 6) Hidden Forces

Students run a model where a ball encounters a hidden force and is moved from its original path. Using the model and the graphs as a guide, students must determine the location, magnitude and direction of the force. This model is generated randomly, so each student will have a different force location and magnitude. The force booster is hidden but the student can gather information from the graphs



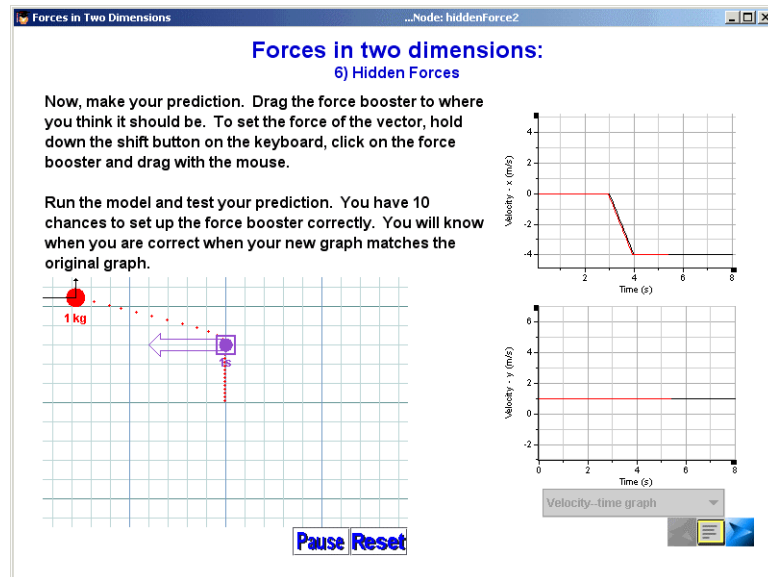
The ball moves as though it encountered a booster



A different booster configuration

The student should click the Predict button to move to the next screen. Once the student is in the prediction screen, s/he should adjust the booster to replicate the action of the hidden force. The student can click and drag on

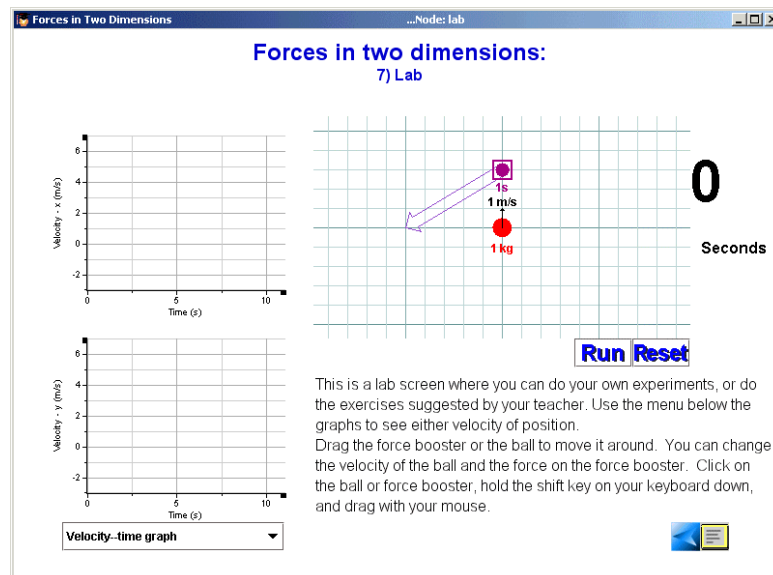
the graphs to move them around and see how the velocity of the ball changes over time. To add force to the booster, shift-click and drag on it. The following is a successful run as illustrated by the red line on the graph following the original black line.



Successful attempt at matching the hidden force

4.8 7) Lab

The Lab section of the Force in Two Dimensions activity allows students to set up their own experiments using one ball and one force booster. The student can move and adjust the objects on the screen. Clicking and dragging on the force booster will change the force arrow. Velocity vectors can be added to the ball by holding the shift key down while clicking and dragging on the ball.



Move the force vector and drag the force arrow, shift-click on the ball to add a velocity vector

5.0 Student Reports

Your students' work with the Forces in Two Dimensions activity is logged and viewable on the MAC Project Web Portal at <http://mac.concord.org>. For each student, you can view a report containing questions and student answers.

The next activity in the sequence should be Collisions and Momentum in 1D.