

# Balancing Forces

## Teacher's Guide

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### 1.0 Summary

“Balancing Forces” is the eighth activity in the Dynamica sequence. This activity should be done after Advanced Collisions and it should take students approximately 45 minutes. This activity has been shortened and revised for the 2004-2005 school year.

### 2.0 Learning Goals

**Driving Question:** What happens when many forces act on the same object?

This activity models several situations where there are multiple forces acting on an object at the same time.

Step One: **Introduction** provides simple situations for students to add force vectors to objects that are supposed to be at rest. For example, a ball that is sitting on a table has the force of gravity acting upon it, but it also has the force of the table pushing up.

Step Two: **Balanced forces** gives students multiple opportunities to apply forces on the same object so that the object will remain still. The magnitude of each force vector is recorded in table format to scaffold the student's understanding.

Step Three: **Unbalanced forces** illustrates what happens when the net force on an object is not zero. Students manipulate forces to achieve different goals.

Step Four: **Tip To Tail** allows students to find the resultant of several forces by using a standard geometric representation of vector addition by drawing vectors tip to tail and observing the total displacement.

Step Five: **Real World Examples** presents opportunities for students to compose free body diagrams of real situations, such as someone on a swing and a boat moving through the water. In each case, the solution can be tested immediately and modified if necessary. In the boat example, students see how forces can be balanced while an object is moving at a constant velocity.

#### Additional Teacher Background

This activity is built around force diagrams. The key concept is **net force**, which is the sum of all the external forces acting on an object. If the net force is zero, the object will stay at a constant velocity (including zero velocity). If the net force is not zero, the object will accelerate in the direction of the force. To predict an object's motion, one doesn't need to know what or how many forces there are; only the net force matters.

In order to find the net force, force vectors are summed just like displacement and velocity vectors. The math is exactly the same, even though the quantities seem quite different.

They can be added geometrically (tip to tail) or by summing the X and Y components separately.

Students often want to include both internal and external forces in their diagrams. For example, a soda bottle may have a large internal pressure resisted by the walls, but neither of these are external forces that would cause the soda bottle to move. Since this model only deals with external forces, it is an opportunity to explore the distinction and ask whether the model is legitimate if it "leaves things out."

Although Newton's Third Law (for each action there is an equal and opposite reaction) isn't explicitly displayed in this model, it is important to bring up a key distinction. "Action = reaction" refers to the forces that two **different objects** exert on each other. If object A and object B interact, the force object A exerts on B is equal and opposite to the force object B exerts on A. These two forces are on two different objects (A and B). The Balancing Forces activity puts external forces on the **same object**, adds them up, and looks at the result of the net force.

For example, if I push on a cart, the cart pushes back on me with exactly the same force (opposing forces on two different objects). If the force I exert on the cart is greater than the resisting friction force, the net force on the cart is not zero (sum of forces on the same object), and the cart will accelerate. If my pushing force exactly equals the force of friction, the net force on the cart is zero, and the cart will move at a constant speed.

### 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.

### 3.0 Standards Alignment

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

Objective	Standards
<b>Students will be able to combine vectors both geometrically and numerically.</b>	<ul style="list-style-type: none"><li>• Students should understand the properties of, and representations for, the addition and multiplication of vectors.</li><li>• Students should understand vectors as systems that have some of the properties of the real-number system.</li><li>• Students should select, apply, and translate among mathematical representations to solve problems.</li><li>• Students should use Cartesian coordinates to analyze geometric situations.</li></ul>
<b>Students will understand the meaning of "balanced" and "net" forces.</b>	<ul style="list-style-type: none"><li>• Students should recognize and apply mathematics in contexts outside of mathematics.</li><li>• Students should understand that objects change their motion only when a net force is applied.</li></ul>
<b>Students will understand why force vectors that make a closed figure add up to zero.</b>	<ul style="list-style-type: none"><li>• Students should judge the meaning, utility, and reasonableness of the results of symbol manipulations, including those carried out by technology.</li><li>• Students should recognize reasoning and proof as fundamental aspects of mathematics.</li><li>• Students should use geometric models to gain insights into, and answer questions in, other areas of mathematics.</li></ul>
<b>Students will determine the net force resulting from several other forces.</b>	<ul style="list-style-type: none"><li>• Students should develop fluency in operations with real numbers and vectors using mental computation or paper-and-pencil calculations for simple cases and technology for more-complicated cases.</li></ul>
<b>Students will understand that objects with balanced forces do not change velocity and objects with unbalanced forces accelerate.</b>	<ul style="list-style-type: none"><li>• Students should understand that objects change their motion only when a net force is applied.</li></ul>

**Students will analyze the forces acting on everyday objects.**

- Students should understand whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.
- Students should judge the meaning, utility, and reasonableness of the results of symbol manipulations, including those carried out by technology.
- Students should recognize and apply mathematics in contexts outside of mathematics.

**Balancing Forces**  
Introduction

**What happens when many forces act on the same object?**

In the real world, there are almost always several forces pushing or pulling on every object. The forces can come from gravity, things touching, ropes, friction, pressure, and so forth.

In these activities you will place several forces on one object and observe what happens. You will learn how to add the forces to determine whether the object will move or stay at rest, go at a constant speed, or accelerate. You will be able to use the models to help you see the result of several forces on the object and apply your understanding to real world situations.

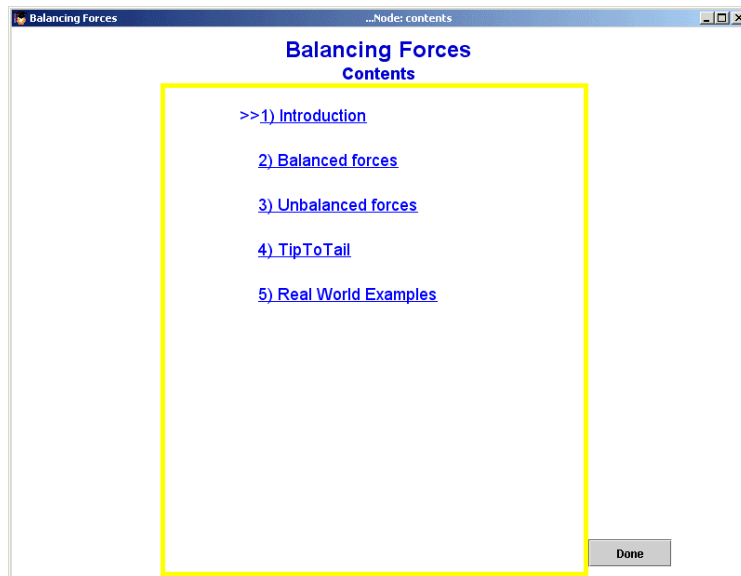
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Introduction Screen

## 4.0 Activity Sections

### 4.1 Table of Contents

This activity has 5 sections.



### 4.2 1) Introduction

Students review vectors and displacement with examples from prior activities.

The screenshot shows a window titled "Balancing Forces" with a subtitle "...Node: intro1". The main content area is titled "Balancing Forces 1) Introduction". The text reads: "You learned about DISPLACEMENT vectors in the Vector Treasure Hunt activity, and VELOCITY vectors in the Vector Motion activity. Now you'll learn how FORCE vectors can be added in the same way as displacement and velocity vectors. Here are pictures of how displacement, velocity, and force are represented in these activities. Answer the questions and go on." Below the text are three numbered questions, each followed by a text input box: 1. How would you describe displacement? 2. How would you describe velocity? 3. How would you describe force? To the right of the questions are three small images: the first shows a map with a path and displacement vectors; the second shows a velocity vector on a grid; the third shows a force vector on a grid. A "Done" button is in the bottom right corner.

Review of vectors

## 4.3 2) Balanced Forces

The introduction to Balancing Forces builds on the student's practical knowledge of the force of gravity. This section introduces the concept of equal and opposite forces such as a ball resting on a table. The ball has multiple forces acting upon it, but it is not moving. That is because the forces are balanced, or the net force is equal to 0 Newtons.

**Balancing Forces**  
2) **Balanced Forces**


In the previous activity, 'Force and Mass', you have looked at the motion of an object when a force acts on it. In our computer model, based on Newton's laws of motion, objects change their velocity when external forces act on them. But what about when something is not moving? Can it have forces on it? What about when it is moving but not changing speed?

4. What are the forces on a person sitting in a chair?

5. If there are forces, why isn't the person moving or changing speed?

6. What are the forces on a train that's moving at a constant speed?

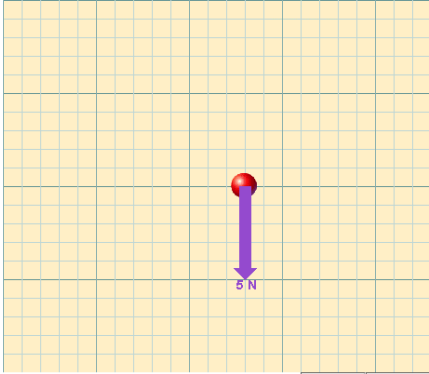
7. If there are forces, why isn't the train changing speed?



Thinking about balancing forces

**Balancing Forces**  
2) **Balanced Forces**

In this model, there is a .5kg ball with the force of gravity pulling it down. Run the model to see the ball fall with the force of gravity (5N).



**Run** **Reset**

Students are asked to predict what the graphs will look like

Balancing Forces  
2) Balanced Forces

Click on the ball to add a force to the ball so that when you run the model, the ball will be suspended in the air. One square on the grid is equal to one Newton.

Clear All Forces Run Reset

Hint

A force arrow of 5N to counteract the force of gravity

Balancing Forces  
2) Balanced Forces

When an object doesn't move, it doesn't mean there are no forces on it. Instead, it means that the sum of the forces, called the **net force**, is zero.

In this model, a ball is sitting on a table. The force of gravity pushes down on the ball. However, the table exerts an equal and opposite force upward on the ball. The net force on the ball is zero and it doesn't move.

8. Now that you've run the model, how would you describe each of the forces?

Run Reset

Equal and opposite forces in the model

In the next set of models, a force table is provided to keep track of the force magnitudes. The student is asked to work with three forces on one object. The goal is to ensure that the sum of the forces is 0. First, the student is to add two additional forces to a ball with one fixed force. Later in this section, the student adds forces by typing in the x and y components for each force.

**Balancing Forces**  
2) **Balanced Forces**

Now we will explore how to balance multiple forces on an object so that the object doesn't move.

In this model, the initial force is fixed. Drag TWO additional forces from the ball and adjust them so that the net force is zero. Use the force table below to help you determine the magnitude and direction of the forces. Run the model to test your design.

Clear All Forces      Run    Reset

Forces	Fx (N)	Fy (N)
Force1	3.0	-4.0
Force2	0.0	0.0
Force3	0.0	0.0
Sum	3.0	-4.0

Hint   

Click and drag on the ball to add a force arrow

**Balancing Forces**  
2) **Balanced Forces**

9. How did you solve this problem?

10. If forces balance, what can you say about their X and Y components?

Clear All Forces      Pause    Reset

Good job! Answer the questions and go on.

Forces	Fx (N)	Fy (N)
Force1	3.0	-4.0
Force2	-3.0	-0.0
Force3	-0.0	4.0
Sum	0.0	0.0

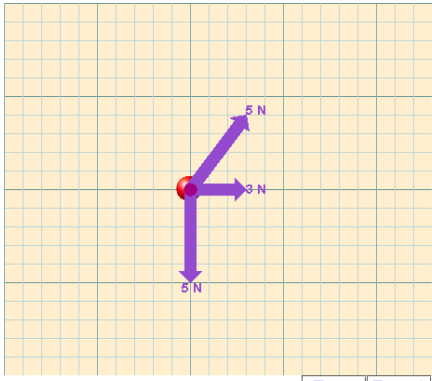
Hint   

Possible solution to the problem



**Balancing Forces**  
**2) Balanced Forces**

Adjust the three forces so that the net force is zero. Then run it to test your design. If you need help, click the Hint button.



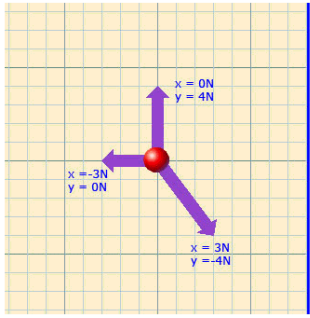
Forces	F <sub>x</sub> (N)	F <sub>y</sub> (N)
Force1	0.0	-5.0
Force2	3.0	4.0
Force3	3.0	0.0
Sum	6.0	-1.0

**Run** **Reset**

**Hint**

Adjust the three forces

**Balancing Forces**  
**How to Balance Forces**



**Balanced Forces**

**Forces in x-direction**

$$\begin{array}{r} 0\text{N} \\ 3\text{N} \\ + \quad -3\text{N} \\ \hline 0\text{N} \end{array}$$

**Forces in y-direction**

$$\begin{array}{r} 4\text{N} \\ -4\text{N} \\ + \quad 0\text{N} \\ \hline 0\text{N} \end{array}$$

Look carefully at the grid above. The ball has three different forces acting upon it, but these forces are balanced.

To determine the total force on the ball, add the forces in each direction as above. The ball will not move because the total force on the ball is 0N in the x-direction and zero Newtons in the y-direction.

Add the x-components and the y-components to find the net force

Balancing Forces  
2) Balanced Forces

In this model, two forces are fixed. Add a third force to the ball so that the net force is zero. Run the model to test your design.

Remember, the force in the x-direction and the force in the y-direction must both add up to zero.

Clear All Forces Run Reset

Hint

Add a balancing force

Balancing Forces  
2) Balanced Forces

12. The existing force is fixed. Create TWO forces that balance it by entering their X components and Y components in the boxes below. Use hints if you need them.

New Forces	Fx (N)	Fy (N)
Force1	<input type="text" value="-3"/>	<input type="text" value="0"/>
Force2	<input type="text" value="0"/>	<input type="text" value="4"/>

Submit Answer Run Reset

Now run the model to test the forces.

Hint

Add a force by typing the appropriate x and y components

Balancing Forces ...Node: staticSum

### Balancing Forces


#### 2) Balanced Forces

Think back to Vector Treasure Hunt. In that activity, you added up DISPLACEMENT vectors to get a total displacement.

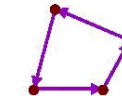
13. When the displacement vectors add up to zero, how far will the person move if they do one displacement vector after another?

14. Does the ORDER in which they do the displacements change where they end up?


Yes  No



A closed figure of displacement vectors



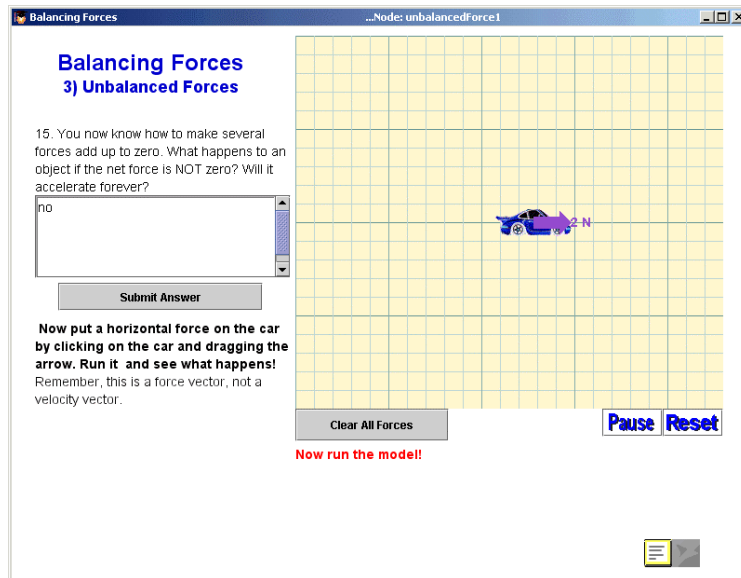
A closed figure of force vectors



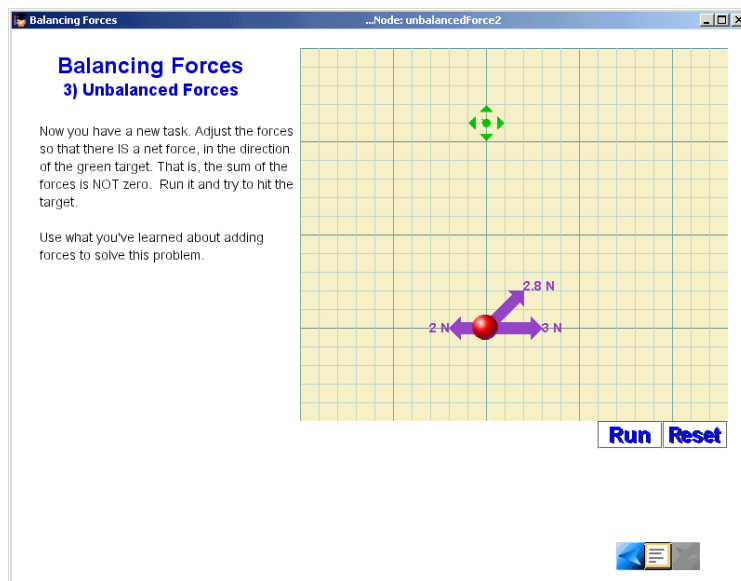
Comparison of 0 displacement with 0 net force

### 4.4 3) Unbalanced forces

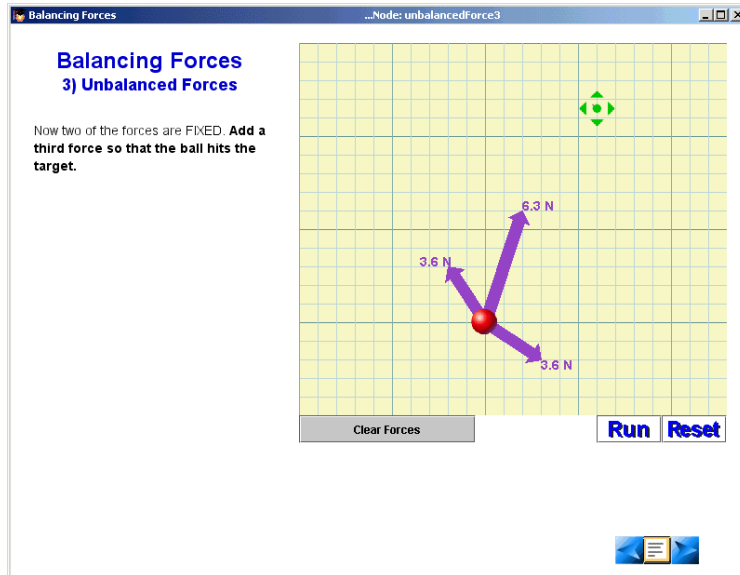
In this section, students experiment with the effects of unbalanced forces. In the first model, students see what happens when a single force is applied to a car—it accelerates forever. In other models, students manipulate multiple forces in order to hit a target.



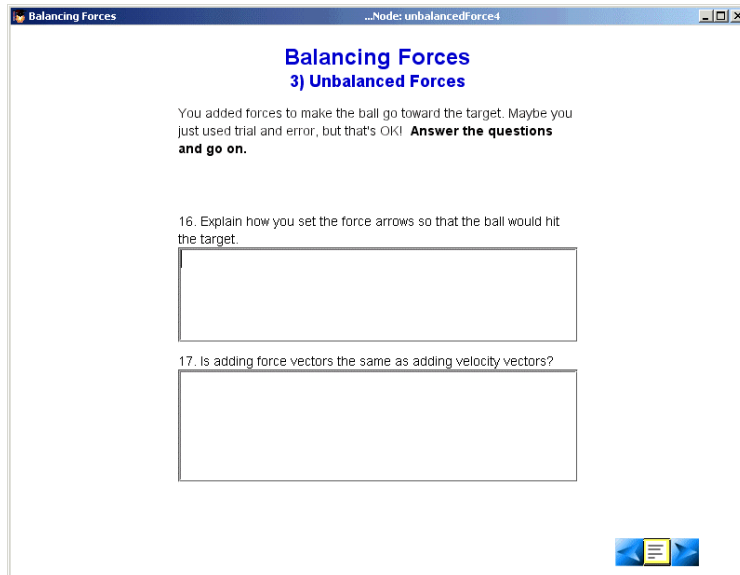
The car will accelerate forever!



Hit the target



Once the student hits the target, Reset will provide additional problems



Questions for understanding


Balancing Forces ...Node: unbalancedForce5

### Balancing Forces

#### 3) Unbalanced Forces

Now you'll explore a standard method for adding force vectors. (It's the same as for displacement and velocity vectors.)

You may recall the definition of a RESULTANT vector. It's the result, or sum, when you add vectors together.



18. For example, in the diagram, which vector is the resultant? That is, which one is the sum of the other two?

A  B  C  None

19. How can you tell that B is the resultant?

It is

That's right, vector B is the sum (resultant) of the other two. That is,  $B = A + C$ . If you walked along C, then along A, your combined displacement would be B. **Go on.**

Select the resultant force (B)

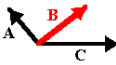
Balancing Forces ...Node: unbalancedForce6

### Balancing Forces

#### 3) Unbalanced Forces

Now you'll explore a standard method for adding force vectors. (It's the same as for displacement and velocity vectors.)

You may recall the definition of a RESULTANT vector. It's the result, or sum, when you add vectors together.



20. Here are the same three vectors, differently arranged. Now which vector is the resultant?

A  B  C  None

21. How can you tell that B is the resultant?

again

That's right, vector B is still the sum (resultant) of the other two. If you applied a force A and a force C to an object, it would head off in the direction of B. The two diagrams are two ways of showing the same thing. **Go on.**

Select the resultant force (B)

**Balancing Forces**  
3) Unbalanced Forces

In this section you will learn three methods of adding vectors.

1. Add up the X and Y components of the vectors
2. Line the vectors up tip to tail
3. Make a parallelogram

Forces	Fx (N)	Fy (N)
Force0	5.0	2.0
Force1	3.0	-5.0
Force2	-6.0	3.0
Sum	2.0	0.0

These methods may look different at first, but they give the same result. Each one can be useful. They work for any kind of vector  $\vec{D}$  displacement, velocity, or force. **Go on.**

Vector addition methods

**Balancing Forces**  
3) Unbalanced Forces

Here are two forces on the same object.  
What will the resultant force be?

Fill in the X and Y components of the resultant force and click submit answer.  
Your force will be added to the model.  
When you have the correct force, the arrow will be green.

New Forces	X-component	Y-component
Force1	5	0
Force2	0	3
Resultant force	<input type="text" value="5"/>	<input type="text" value="3"/>

That's right! Your arrow is the resultant of the two forces. Click "New Problem".

Add the force vectors to find resultant

**Balancing Forces**  
3) Unbalanced Forces

Now the ball has one fixed force. Your goal is to hit the purple target. The resultant you want is the vector that points to the target. **Add a force to the ball to get the right resultant.** To add a force, enter the components.

**Run the model to test your answer.**  
Look at the hints if you need them.

New Forces	X-component	Y-component
Fixed force:	3	0
Force to add:	<input type="text" value="0"/>	<input type="text" value="4"/>
Resultant force	3	4

Yes! Your resultant pointed to the target. Click "New Problem" and try another one.

Add a force vector to hit the target

#### 4.5 4) Tip To Tail

This is a short section that gives students another method for balancing forces, the Tip-to-tail method. Here, students drag the forces arrows from a closed figure onto the ball by dragging the non-arrow end of the arrow (a pink dot).

**Balancing Forces**  
4) Tip To Tail

You have discovered how to add up several forces on an object and calculate the resultant. Here's another way of looking at the same thing. The force arrows have been removed from the ball and arranged so that they make a triangle when placed "tip to tail".

24. If they are all put on the ball, do you think it will move?  
 Yes  No

25. Why?

Is the net force of these three forces 0? Yes.



Balancing Forces

...Node: tptotail02

### Balancing Forces

#### 4) Tip To Tail

Move the force boosters onto the ball. Click on the round end to drag a force arrow. **Put all the round ends on the ball. Then run it. Move the forces by dragging on the round end of the force arrows.**

Run Reset

Move the force arrows by clicking and dragging with the mouse

Balancing Forces

...Node: tptotail04

### Balancing Forces

#### 4) Tip To Tail

Here's the rule we're exploring:  
*"If the force arrows form a closed figure (like a triangle), then they add up to zero."*

Is it true for a figure with more than three sides? Here are FOUR force booster arranged so that they make a closed figure when placed tip to tail.

Run Reset

26. If they are all put on the ball, do you think it will move?

Yes  No

Submit Answer

Will all closed figures have a net force of 0? Yes.

Balancing Forces  
4) Tip To Tail

Answer: When you follow the arrows in a closed figure, you come back to where you started. The sum of the arrows is zero! The resultant is zero! The sum of each of the components is zero! So there's no net force. **Go on.**

Run Reset

To change force, hold 'Shift' key and drag from force booster.

Forces	Fx (N)	Fy (N)
Force0	3.0	0.0
Force1	2.0	2.0
Force2	-4.0	3.0
Force3	-1.0	-5.0
Sum	0.0	0.0

Hold the shift key down to change the magnitude and direction of the forces

## 4.6 5) Real World Examples

In this section, students experiment with two real world models. The first is a cat hanging on a swing. First, the cat is suspended by one rope, then by two. In the second example, a boat is traveling on the water. Students will observe that multiple forces on the boat (gravity, buoyancy, motor and water resistance) have a net force of zero; however, while the forces are balanced, the boat is moving at a constant velocity.

Balancing Forces  
5) Real World Examples

At this point in this activity, you know how to add forces to make the net force equal to zero. You've practiced this by drawing force arrows, but so far the examples have been abstract and theoretical. In this section you will apply what you've learned to solve more practical problems.

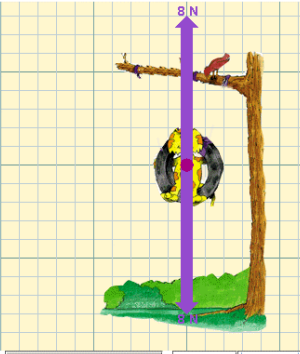
The first problem is weighing something...

A tire swing

Introduction to real world examples section

**Balancing Forces**  
5) Real World Examples

This cat is hanging on a rope swing. Gravity is acting on the cat and the swing such that they weigh a total of 8N. Notice the force arrow in the model; this arrow represents the weight of the cat. The rope is also exerting a force on the cat. Draw a force arrow (by dragging it out from the purple dot on the cat) to represent the tension in the rope. Then click "Run" to see whether the force is balanced. An unbalanced force will cause the cat to move.



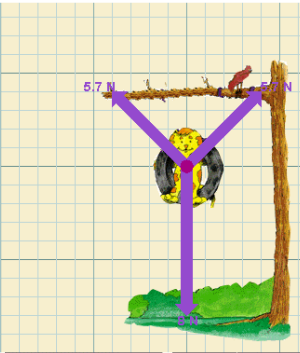
Clear All Forces Run Reset

Hint

Apply an upward force, equal and opposite to the rope

**Balancing Forces**  
5) Real World Examples

Now there are two ropes holding up the cat. Force is exerted on both ropes. In order for the cat to not move, the force on the two ropes must equal the force of gravity that is on the cat. Add force arrows to the model to represent the force of each rope on the cat. Press "Run" to test your design.



Clear All Forces Run Reset

Add force arrows along both ropes

Balancing Forces  
5) Real World Examples

Run Reset

Now we're going to apply balancing forces to a new situation. Here is a motorboat floating in the water. At the moment, its motor is not turned on, so it is not moving. The boat weighs 5 Newtons. Draw all the forces that you think are acting on the boat when it is at rest. Then, click Play to see whether you got it right.

Apply forces to a boat at rest

Balancing Forces  
5) Real World Examples

Pause Reset

Note that the boat is going faster and faster. That's not what was supposed to happen - we said that it was going at a constant speed. What's wrong? Hit Reset and try again.

Now the motor has been turned on, and the boat is moving to the right at a constant speed of 5m/s in a straight line. The force of the motor is shown in the diagram, and so are the force of gravity and the buoyant (floating) force that you figured out in the previous step. Are those three forces all that are acting on the boat, or are there more? If you think there are more, draw whatever you think is missing and then hit Play. If you think these forces are all there are, just hit "Run".

Hint

Without the friction force of the water, the boat will accelerate forever

Balancing Forces

...Node: freeBody5

### Balancing Forces

#### 5) Real World Examples

Run Reset

Now the motor has been turned on, and the boat is moving to the right at a constant speed of 5m/s in a straight line. The force of the motor is shown in the diagram, and so are the force of gravity and the buoyant (floating) force that you figured out in the previous step. Are those three forces all that are acting on the boat, or are there more? If you think there are more, draw whatever you think is missing and then hit Play. If you think these forces are all there are, just hit "Run".

Hint

With an additional force, the boat moves at a constant speed

## 5.0 Student Reports

Your students' work with the Balancing Forces 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, and final, activity in the Dynamica sequence is Gravity.