Unit 2 Cycle 2

Beginnings: What if there is more than one force?

LESSON TARGET IDEAS

- When more than one force acts on an object, the combination can be either BALANCED (meaning the forces acting in opposite directions are exactly equal in strength) or UNBALANCED (meaning the forces acting in one direction are stronger than the forces acting in the opposite direction).
- When a balanced combination of forces acts on an object that is at rest (not moving), it will remain at rest.
- When an unbalanced combination of forces acts on an object that is at rest, it will begin to move in the direction in which the stronger total force is acting.
- When a force is applied to an object at rest and it still does not move, there must be an equal strength force being applied to it in the opposite direction (usually by something in the environment).

COMMON MISCONCEPTIONS

- *When a single force acts on an object it can be balanced or unbalanced.* (It cannot be balanced! If only a single force is acting, by definition there are no other forces to "balance" it, so a single force is always unbalanced. However, when more than one force is acting, regardless of how many there are, the forces can be either balanced or unbalanced, depending on the directions in which they are applied and their relative strengths.)
- *The behavior of an object is determined only by the strongest force acting on it. Any weaker forces do not have any effect on its behavior.* (They do! It is the combination of forces that determines the object's behavior.)
- *If a force is applied to an object at rest and it still does not move, then a stronger force must be acting on it in the opposite direction.* (The opposing force must be EQUAL in strength to the applied force, otherwise the forces would be unbalanced and the object would actually start to move "backward"!)

NOTE: Students often have difficulty with the "two-way" nature of the ideas. That is, they may readily understand that if a balanced combination of forces acts on an object at rest it will not move, but they do not necessarily understand that when an object is not moving, the combination of forces acting on it must be balanced.

NOTE: It is important that the subject of this Cycle not be confused with Newton's 3rd law. This Cycle addresses the effects of combinations of forces acting on an object (e.g., the box in the purpose section below experiences a "forward" force from each of the two men pushing, and a "backward" force due to friction). In contrast, Newton's 3rd law states that for every action force there is an equal and opposite reaction force. In the box example below, when one man applies a forward force on the box, the box is applying a force on the man that is equal in strength, but opposite in direction to his push. These forces do not add or cancel out because they are acting on different objects.

WHAT TO FOCUS ON

This Cycle focuses on the effect that combinations of forces have on the motion of an object. During this first lesson, we lay the groundwork for the rest of the cycle by establishing what balanced and unbalanced forces are, and explore how balanced and unbalanced forces affect the motion of an object at rest.

In this activity, students view a video of a low-friction cart on a track that is subjected to various combinations of balanced and unbalanced forces. A plastic cup hanging from a string is attached to each side of the cart and sugar cubes are placed in the cups to apply forces. The number of sugar cubes placed in each cup represents the strength of the force applied (the strength of the force due to the weight of the string and the cup is negligible in comparison). Before viewing the first example in the video, the teacher should draw students' attention to the fact that the two cups apply forces to the cart in opposite directions.

Students should recognize that that forces applied to the cart are balanced when the same number of sugar cubes are in each cup. The first section of the movie 2 shows several combinations of balanced forces and in each example the motion of the cart does not change. These trials provide evidence that when balanced forces are applied to an object at rest, it will stay at rest.

Students should also recognize that unbalanced forces are applied to the cart when one cup has more sugar cubes in it than the other cup. For each example in the second section of movie 2, the cart moves towards the cup with more sugar cubes. This provides evidence that when unbalanced forces act on an object that is at rest, it will begin to move in the direction of the stronger force.

During each video example, students should be focused on the strength of the forces (i.e., are they the same or is one bigger than the other) and on the resulting motion of the cart (i.e., did it move? If so, in which direction?). Evidence that counters the misconception that *the behavior of an object is determined only by the strongest force acting on it* is provided in the videos of this lesson because it is clear that a change in the cart's motion depends on the difference in the number of sugar cubes in the two cups. (The next lesson explicitly addresses that it is this difference that determines the magnitude of motion changes.) At this point it is sufficient for students to focus on whether the cart moves and in which direction.

The misconception that *when a single force acts on an object it can be balanced or unbalanced* may surface in this lesson, but this lesson does not address it. Evidence that counters this misconception is presented in the next lesson.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Student computers with internet access (optional)	1 per student group
Cart-on-track movies	1 per class
The cart-on-track movies can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). Once you reach this page, click on the link provided for Simulations and Videos. The videos for this lesson are in the Unit 2, Cycle 2 Movies section and are designated for the Beginnings lesson.	

Purpose

While most of the cases examined in this Unit will involve only two opposing forces, the example given here uses a combination of three forces. The teacher should emphasize that by a combination of forces we mean any situation in which two or more forces act on an object.

We will start by examining what happens to an object that is not moving when a combination of forces acts on it. The teacher should start by prompting the class to say what would happen to such an object if no forces, or only a single force, were to act on it. At this point we are only looking for the idea that it would either stay at rest, or start moving in the direction of that single force.

What do we think?

Most students should agree that the toy would not start to move in this case. However some may say that it will start to move with one of two lines of reasoning:

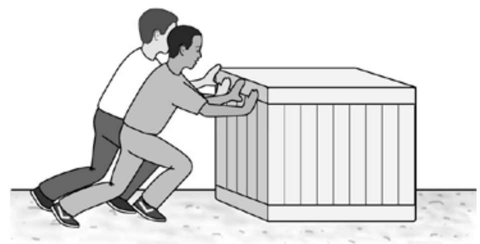
1) The larger brother would exert a stronger force so the toy would move in his direction. In this case, the teacher should point out that while the larger brother might be capable of applying a stronger force, in this situation he does not. His force is exactly the same strength as the smaller brother. Then ask them whether this would change their answer about whether the toy moves or not.
2) Despite the fact that the forces are the same, somehow the fact that one brother is larger than the other will influence the toy to move in his direction. In this case the teacher could ask what would happen if the brothers were equally-sized twins.

Unit 2 Cycle 2

Beginnings: What if there is more than one force?

Purpose

In the previous Cycle of activities you examined what effect a force has on the motion of an object. However, often more than one force acts on a single object at the same time. For example, as two men push a heavy box across the floor, they are each applying a "forward" force to it. At the same time a "backward" frictional force is also being applied to the box by the floor. In this Cycle of activities we will examine what effect such a ***combination of forces*** has on an object?



To start this Cycle we will think about what happens when a combination of forces acts on an object that is not moving.

The big question we will address in this *Beginnings* activity is:

What happens when a combination of forces acts on an object that is not moving?

What do we think?

Two brothers are arguing over a stuffed toy and begin to pull on it in opposite directions. The toy was not moving when they started pulling.

What do you think would happen if the forces applied to the toy by the two brothers have exactly the same strength? Would it start to move or not? If so, in which direction?

Most students should agree that the toy would start to move in this case and that this motion would be in the direction of the stronger force.

The teacher should poll the class on the simple question of whether the toy would start to move in both situations and then ask for reasoning. In the first case (equal forces) students may use reasoning like “The toy would not know which way to move,” whereas in the second case (unequal forces) it would. The teacher should not pass judgment on any of the responses or reasoning, but simply summarize them and say they need to gather some evidence to see which ideas are supported.

Balanced and Unbalanced Combinations of Forces

Before moving on to gather evidence, the teacher should introduce the vocabulary of “**balanced**” and “**unbalanced**” forces. At this stage, it is important to define these in terms of the direction and relative strengths of the forces, rather than the effect they produce (which is what we are trying to determine).

What do you think would happen if the strength of one brother's pull was greater than that of the other brother? Would the toy start to move or not? If so, in which direction?

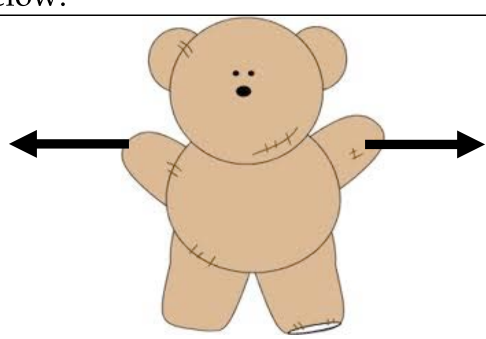
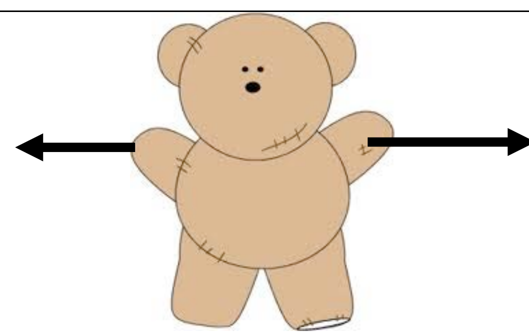
Your teacher will lead a class discussion about everyone's answers to these questions, and the explanations of their thinking.

Balanced and Unbalanced Combinations of Forces

When equal strength forces act on an object in opposite directions we say the forces are ***balanced***. When the two brothers pulled equally hard on the toy, their forces were balanced.

When the strengths of the force acting in opposite directions are not the same, we say the forces are ***unbalanced***. When one brother pulled harder on the toy than the other, the combination of their forces was unbalanced.

We can draw a ***force diagram*** for an object using arrows to show the forces acting on it. The length of the arrows shows the strength of the forces. Force diagrams for the toy when the two brothers were pulling on it, are shown below.

	
Balanced Forces: The two brothers apply equal strength forces in opposite directions. (Both force arrows are the same length.)	**Unbalanced Forces:** One brother applies a stronger force than the other brother. (One force arrow is longer than the other.)

Activity

In this lesson we are simply trying to determine whether the cart starts to move or not, when different combinations of forces act on it. The teacher should show the movies to the whole class so that s/he can pause and continue at key points in the movie.

The cart-on-track movies can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/).
These are QuickTime movies and the QuickTime Player application can be used to view them.

Activity: Step 1

The teacher should show the setup movie to the class and explain how the tests will be carried out. It is important to emphasize that while the cups will be pulling downward on the strings, the strings will be pulling horizontally on the cart, so this will be like the toy bear situation considered earlier.

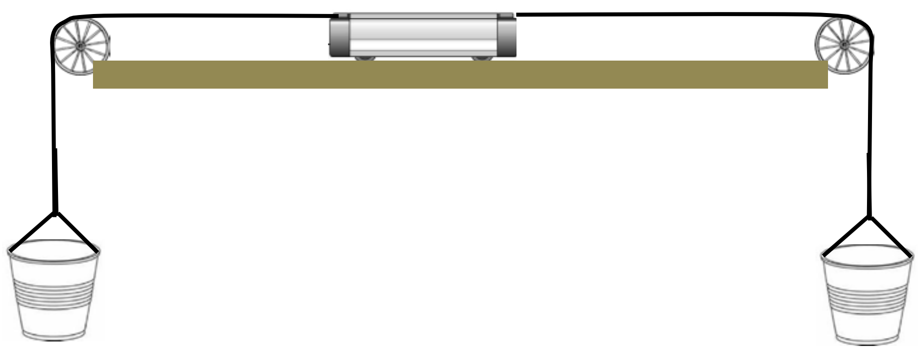
Most students should agree that the cart will not start to move in this case, probably because it would not “know” which way to move.

Activity: Two forces in opposite directions

Your class will work together for this activity. The class will need:

- Computers on which to view movies, or a way for the whole class to view a projected movie.

STEP 1: The object to be used to test the effect of combinations of forces is a low-friction cart on a track. A string is tied to each end of the cart and these strings pass over pulleys at each end of the track. A cup is hanging from the end of each string.



When objects, such as sugar cubes, are added to the cups, they will pull downward on the string. The string, in turn, will apply a force to the cart. When the cart is released it will be free to move and you will be able to see what effect the combination of the two forces acting on the cart has.

Your teacher may direct you to watch a movie showing this setup.

Now, suppose the cart was held still, an equal number of sugar cubes were placed in each of the two cups, and then the cart was released.

Do you think the cart would start to move when released, or not? Why do you think so?

Now suppose more sugar cubes were placed in one cup than in the other while it was being held still.

Most students should agree that the cart will start to move in this case, because there will be a stronger force "telling" it which way to go.

Activity: Step 2

The teacher should be sure to view the movie ahead of time so that s/he can prompt students and pause the movie in the appropriate places (details of when to do so are included below).

It is suggested that the movie be paused while the still frame of the 6 and 6 sugar cube combination is on-screen, and then pose this first set of questions, also asking students what they think will happen when the hand releases the cart. Students may need reminding of the definitions of balanced and unbalanced forces.

It should not be difficult for students to infer that the forces are balanced in this case.

The teacher should remind students that all that is important is whether the cart starts to move or not. It should be evident to students that with the 6 and 6 sugar cube combination, the cart does not start to move.

The teacher should pause the movie and ask students if they think all balanced combinations will produce the same result. The rest of the first section of the movie should then be played.

It should be evident that for all balanced combinations tested the cart does not start moving.

Do you think the cart would start to move now when released, or not? Why do you think so?

Your teacher will lead a class discussion about these questions.

STEP 2: Your teacher will direct you to watch a movie in which various numbers of sugar cubes are added to the two cups in the setup.

The movie will start by testing some combinations for which there are equal numbers of sugar cubes in both cups

In this case are the forces acting on the cart balanced or unbalanced? How do you know?

Describe what happens to the cart after it is released and a balanced combination of forces acts on it. Does it start to move or not?

Do all the balanced combinations of forces tested have the same effect? Why do you think this is?

It is suggested that the movie be paused while the still frame of the first unbalanced combination is on-screen, and then pose this set of questions, also asking students what they think will happen when the hand releases the cart.

It should not be difficult for students to infer that the forces are unbalanced in this case.

It should be evident to students that the cart starts to move. Some may wish to comment on how quickly it moves, but that is not important for the purposes of this lesson.

The teacher may wish to pause the movie immediately after the first unbalanced combination example and ask students what they think will happen if the combination is "reversed." Then show students the next combination, pause the movie, and discuss the result. Next, the teacher can have the class discuss whether they think all unbalanced combinations will start the cart moving, or not. The teacher can then show the rest of the movie.

It should be evident that for all unbalanced combinations tested, the cart starts moving. Students may point out that in some cases the cart moves to the left, and in other cases it moves to the right. Students may also remark on the difference in the apparent speed of motion for different combinations. The teacher should respond that there are good observations that will be investigated further in the next lesson, but for now all we are interested in is whether the cart starts to move or not.

Making Sense Questions

Question 1: Students should agree that in the case of balanced forces the object will not move, and that this is like what happens when no forces act on an object at rest. Students should cite examples from the lesson in which an equal number of sugar cubes were in each cup and compare these cases to the case where no sugar cubes were in either cup. Reasoning is likely to be either of the form that if the forces are balanced, the object doesn't "know" which way to go, or that the balanced forces cancel each other out and so it is like having no force at all.

Question 2: Students should agree that in the case of unbalanced forces the object will start to move in the direction of the stronger force, and that this is like the effect of a single force. Students should cite examples from the lesson in which different numbers of sugar cubes were in each cup and compare these cases to the case where sugar cubes were in only one cup. Reasoning is likely to be either of the form that now the object is pulled more in one direction than the other, or that the forces do not exactly cancel each other out, so there is some force left pushing/pulling one way or the other.

The second part of the movie shows tests in which the numbers of sugar cubes in the two cups are not equal.

In this case are the forces acting on the cart balanced or unbalanced? How do you know?

Describe what happens to the cart after it is released now. Does it start to move or not?

Do all the unbalanced combinations of forces tested have the same effect? Why do you think this is?

Making Sense

Your teacher will lead a class discussion about what happens when a combination of forces acts on an object that is not moving. Write answers to the following questions after each one is discussed by the class.

1. When a **balanced** combination of forces acts on an object that is not moving, what happens? Is this more like the effect of having no forces, or more like the effect of a single force? Why do you think this is?

2. When an **unbalanced** combination of forces acts on an object that is not moving, what happens? Is this more like the effect of having no forces, or more like the effect of a single force? Why do you think this is?

Question 3: Here we try to get students to appreciate that a single force is just the simplest case of unbalanced forces. That is, the force in one direction is stronger than the force in the opposite direction, which is no force in this case!

Some students may have trouble with this idea, but the teacher can now prompt them to reason from the basis of the effect on motion. That is, both a single force and an unbalanced combination of forces will start an object moving, whereas a balanced combination will not.

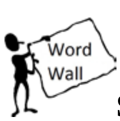
Question 4: Here we try to get students to appreciate that having no force is just the simplest case of balanced forces. That is, the force in one direction is equal in strength to the force in the opposite direction, both of which are "no force" in this case!

Again, some students may have trouble with this idea, but the teacher can prompt them to reason from the basis of the effect on motion. That is, both no force and a balanced combination of forces will not start an object moving, whereas an unbalanced combination will.

Question 5: Now we introduce students to the idea that they can reason "backward" from the motion of an object to the state of the forces acting on it. In this case, because the chair starts to move the forces acting on it must be unbalanced. Most students will not have difficulty with this particular line of logic. Some students may interpret the question to be asking about forces acting on the chair prior to its movement, or forces acting on the chair once it reaches a constant speed. These interpretations would provide opportunities to address the different combinations of forces associated with these different "phases" of the event: chair still at rest, chair starting to move (changing speed), and chair moving at a constant speed.

Question 6: We would like students to say that because the chair does not move, the forces acting on it must be balanced, which means there must be an opposing force that is equal in strength to the push. However, many are likely to say that there must be a force opposing the push that is STRONGER than the push, thus implying that the forces are unbalanced.

Many students will still think that if the opposing force is stronger, the object will not move, without appreciating the logical inconsistency this idea embodies! The teacher can help by leading them step-by-step through the reasoning of what would happen if this were indeed true — the forces would be unbalanced and so the chair would actually move in the opposite direction to the push!



Science Vocabulary

The terms "**balanced forces,**" "**unbalanced forces,**" and "**force diagram**" are introduced in this lesson. If students understand and can explain what these terms mean, then it is appropriate to add them to the word wall.

3. When a single force acts on an object, is it similar to having two forces on an object that are balanced or unbalanced? Explain your thinking.

4. When no forces act on an object is it similar to having two forces on an object that are balanced or unbalanced? Explain your thinking.

5. Imagine you have a chair that is on wheels. If you push gently on it, it will start to move. Does this mean the forces acting on it are balanced or unbalanced?

6. Now imagine you take the wheels off the chair. If you now push gently on it, it will not start to move. Does this mean the forces acting on it are balanced or unbalanced? How can this be?

Unit 2 Cycle 2

Exploration #1: What combinations of forces have the same effect?

LESSON TARGET IDEAS

- When an unbalanced combination of forces acts on an object, the forces can be combined to determine a single equivalent force that would cause exactly the same effect. This single equivalent force is called the net force acting on the object.
- To find the net force acting on an object the forces acting in one direction should be added together, and then the forces acting in the opposite direction should be subtracted from this subtotal.
- When different combinations of forces that produce the same net force act on two identical objects, the objects' motions will be exactly the same.

COMMON MISCONCEPTIONS

- *The behavior of an object is determined only by the strongest force acting on it. Any weaker forces do not have any effect on its behavior.* (They do! It is the net force that determines the object's behavior.)
- *The net force acting on an object is determined by the ratio of force strengths acting in opposite directions.* (It is not, it is determined by the difference of those force strengths.)

WHAT TO FOCUS ON

The focus of this lesson is on investigating the effects of different unbalanced force combinations by examining how far a cart moves in a set amount of time when it experiences different force combinations. Because each cart starts at rest, we can use the distances travelled by each in a particular time to indicate their relative changes in motion (i.e., a greater distance travelled must mean a greater increase in speed).

As with the previous lesson, the number of sugar cubes used in each cup represents the strength of a force the cup applied to the cart. For each video test, students should be focused on 1) the differences in the forces that are applied to each cart and on 2) the distance each cart moves in the set amount of time.

The first two video tests are intended to provide students with evidence that confronts the two common misconceptions described above. In the first test, three identical carts are subjected to different unbalanced force combinations but with the same-sized largest force. Each cart moves a different distance, providing evidence to counter the misconception that only the largest force on an object determines its motion. The second test shows the three carts with the same ratio of forces applied. Again, each cart moves a different distance, providing evidence to counter the misconception that unbalanced forces of the same ratio cause the same change in an object's motion.

In the third test, the carts experience the same difference in forces. Each cart moves the same distance, providing evidence that when an object is subjected to unbalanced force combinations, its change in motion is dependent on the difference between the forces.

In the second activity, students view another video that investigates whether a single force can cause the same motion as an unbalanced combination of forces. Three identical carts are shown, two with a single force applied and one cart subjected to an unbalanced combination of forces. The carts experiencing the same difference in forces both go the same distance over the same time period, providing evidence that there is a single force that will have the same effect on an object as a combination of forces. The strength of this single force is called the net force, found by subtracting the forces acting in one direction from the forces acting in the opposite direction.

Students may be distracted by how the force labels for each cart in the video are not always directly above and/or below each other. In this case, the teacher should focus students on where the carts start with respect to each other (all at the same horizontal location) and not on the placement of the labels themselves.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Student computers with internet access (optional)	1 per student group
Cart-on-track movies	1 per class
The cart-on-track movies can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). Once you reach this page, click on the link provided for Simulations and Videos. The videos for this lesson are in the Unit 2, Cycle 2 Movies section and are designated for the Exploration 1 lesson.	

Purpose

Remind students that in the previous lesson they saw that any unbalanced combination of forces will start an object moving, but now we want to focus on what happens after it starts moving. Will they all move in exactly the same manner, or will there be some differences depending on the particular combinations? Are there any different combinations that will produce exactly the same manner of motion?

What do we think?

Remind students that in the previous lesson they saw that a 4 and 2 unbalanced combination started the cart moving and that it continued to move until the movie stopped.

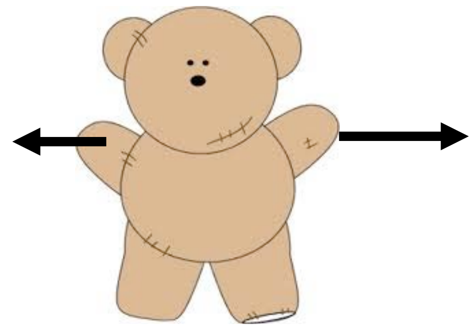
Explain that we now want to see if there are any other combinations of sugar cubes that would make the cart behave in *exactly* the same manner. We will judge this by looking at how far the cart moves when compared to a cart with the 4 and 2 combination.

Unit 2 Cycle 2

Exploration #1: What combinations of forces have the same effect?

Purpose

In the *Beginnings* activity for this Cycle you saw that when an unbalanced combination of forces acts on an object, it will start to move. But, after it has started, would the motion of the cart be **exactly the same** for all unbalanced combinations of forces or would it depend how strong each force was?



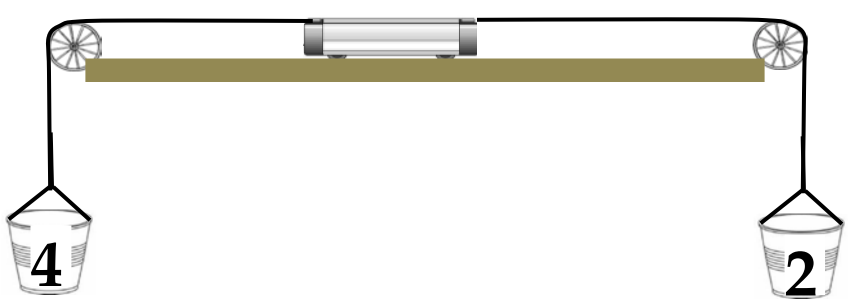
The big question we will address in this *Exploration* activity is:

What unbalanced combinations of forces have exactly the same effect on an object?

What do we think?

In the previous activity you saw a low-friction cart being acted on by various combinations of forces. In that activity, we were interested only in which combinations started the cart moving and which did not. In this lesson we will be interested in which combinations make the cart move in exactly the same manner.

Suppose you had a setup like that shown below, with 4 sugar cubes in one cup and 2 in the other. You know that if this cart was released it would start to move to the left. We will judge the manner in which it moves from the amount of distance it travels in a certain amount of time.



Many students will likely suggest combinations that differ by 2 cubes, reasoning that the 2 on the right will cancel 2 of the 4 on the left, leaving an extra 2 that are not canceled out. So, any other combination that leaves 2 cubes not cancelled out would behave the same way.

Some may have a ratio-based model, reasoning that it is the ratio of the two sides (4:2) that determines its behavior. In this case they are likely to suggest 6:3 or 2:1 combinations.

Some may have the idea that only the strongest force is important, so that as long as they keep 4 cubes in the left side, any combination that has less than 4 in the right side will behave in the same way.

The teacher should record all suggested combinations on a board and verbally summarize the reasoning students give for them. Then tell students they will now check their ideas by watching movies of them being tested.

Activity 1

The teacher should outline the procedure that will be followed. If desired, this would be a good opportunity to introduce the idea of a "control" in an experiment.

Note: When describing the numbers of sugar cubes in cups, these documents use the notation "X and Y" (e.g., "4 and 2"). The notation "X – Y" (e.g., "4 - 2") appears in the movies. There is no difference in the meaning of these two notations.

The cart-on-track movies can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/).
These are QuickTime movies and the QuickTime Player application can be used to view them.

Suggest two or three other arrangements of sugar cubes you could put in the two cups that would make the cart move in exactly the same manner as the 4 and 2 combination. (That is, make the cart travel the same distance as the 4 and 2 combination in the same amount of time.)

Explain why you think your arrangements would work.

Your teacher will lead a class discussion about everyone's answers to this question, and the explanations.

Activity #1: Which combinations behave the same?

Your class will work together for this activity. The class will need:

- Computers on which to view movies, or a way for the whole class to view a projected movie.

Activity 1: Step 1

If this idea did not emerge in the class discussion, the teacher should introduce it as something that was suggested by another class and take time to explain it.

Some students may think these three combinations will have the same effect. Even if the idea did not emerge earlier in the lesson, they will likely support it with some variant of the idea that only the strongest force matters, and so changing the strength of the weaker force will have no effect on the cart's behavior.

The teacher should start the first movie segment. Below are two tips to address questions that students may have. These procedures may need to be repeated for other segments as well.

1. The movie should be paused just as the carts are released, to show that they are all lined up at the start and are released at the same time. Some students may notice that they do not all start from the same point on the track, but the movies have been adjusted so that the carts are lined up on the screen. Following this pause, the movie may be rewound slightly, so students can see the "action" continuously.
2. The movie should be paused on the freeze-frame at the end of the segment so students can visually compare the distance moved by the cart in all three cases. It is worth emphasizing that we are using these distances to judge whether combinations have the same effect or not.

It should be evident to most students that all three combinations have different effects, because the cart moves a different distance in each case.

Some students may say that the effect is the same for all three, based on the previous lesson where all they looked for was whether the cart started moving or not. If so, the teacher should explain that now we are looking at more details of the motion after the cart has started moving and to do that we are comparing distances moved from the starting point.

STEP 1: One suggestion that has been made is that it is only the strongest force that determines how an object behaves, and that the weaker force will not make any difference. If this is true, then any combination that has 4 sugar cubes in one cup and 1, 2, or 3 sugar cubes in the other cup, should behave in exactly the same manner.

Do you think a 4 and 1 or a 4 and 3 combination will behave in exactly the same manner as a 4 and 2 combination, or not? Explain your thinking.

You will now see a movie segment in which 4 and 1, 4 and 2, and 4 and 3 combinations are tested at the same time.

What does the movie show? Do all three combinations behave in exactly the same manner or not?

The idea we were trying to test in this STEP was that when the stronger force stays the same in different combinations of forces, the cart moves in exactly the same manner.

Most students will likely agree that this evidence does not support the idea.

Activity: Step 2

If this idea did not emerge in the class discussion, the teacher should introduce it as something that was suggested by another class and take time to explain it.

Some students may think these three combinations will have the same effect. Even if the idea did not emerge earlier in the lesson, they will likely support it with some variant of the idea that it is the ratio of forces that matters.

Play the second movie segment, pausing as necessary.

It should be evident to all students that the three combinations have different effects because the cart moves a different distance in each case.

Most students will likely agree that this evidence does not support the idea.

Does the result of the test you saw in the movie support this idea or not?

STEP 2: Another suggestion that has been made is that it is the ratio of the stronger to the weaker force that determines how an object behaves. For the 4 and 2 combination, the stronger force is twice as big as the weaker force. So, if this idea is correct, then whenever one cup has twice as many sugar cubes as the other cup, such as 6 and 3 or 2 and 1, that combination should have exactly the same effect as the 4 and 2 combination.

Do you think either a 6 and 3 or a 2 and 1 combination would behave in exactly the same manner as a 4 and 2 combination, or not? Explain your thinking.

You will now see a movie segment in which 6 and 3, 4 and 2, and 2 and 1 combinations are tested at the same time.

What does the movie show? Do all three combinations behave in exactly the same manner or not?

The idea we were trying to test was that whenever the stronger force is twice as large as the weaker force the cart moves in exactly the same manner.

Does the result of the test you saw in the movie support this idea or not?

Activity 1: Step 3

If this idea did not emerge in the class discussion, the teacher should introduce it as something that was suggested by another class and take time to explain it.

Many students will likely think that these three combinations will have the same effect, based on the idea that in all cases one "force" is 2 units stronger than the other.

Play the third movie segment, pausing as necessary.

It should be evident to all students that the three combinations have the same effect because the carts seem to move side-by-side and move the same distance. A few students may wish to focus on very small differences. If so, point out that the behavior of the carts in this case is very close to being identical and much more similar than in the previous tests.

Most students will likely agree that this evidence supports the idea.

STEP 3: A third suggestion that has been made is that it is how much bigger the stronger force is than the weaker force that determines how an object behaves. For the 4- and 2 combination, the stronger side has two more sugar cubes than the weaker side. This idea suggests that whenever one cup has two more sugar cubes than the other, the combination should have exactly the same effect as the 4 and 2 combination. Examples of such combinations would be 5 and 3 and 3 and 1.

Do you think either a 5 and 3 or a 3 and 1 combination would behave in exactly the same manner as a 4 and 2 combination, or not? Explain your thinking.

Your will now see a movie segment in which 5 and 3, 4 and 2, and 3 and 1 combinations are tested at the same time.

What does the movie show? Do all three combinations behave in exactly the same manner or not?

The idea we were trying to test was that whenever the stronger force is bigger than the weaker force by the same amount, the combinations of forces causes the cart to move in exactly the same manner.

Does the result of the test you saw in the movie support this idea or not?

Activity 1: Step 4

During the discussion the teacher may wish to have a class display of the results of how the different combinations tested compared to the 4 and 2 combination.

It should be evident to students that the arrangements with a difference of two cubes behaved the same as the 4 and 2 arrangement, whereas those with a different difference did not. These data suggest that the third idea tested is the correct one. (While we can never "prove" an idea to be correct in science, the fact that this is the idea that the evidence supports is enough to make it the idea we want to carry forward from this point.)

If the correct idea is not evident, the teacher could review all the ideas tested and check off whether they worked or not, perhaps even writing strongest force, ratios, and differences next to each one.

Activity 1: Step 5

Having established which idea seems to work using a 4 and 2 combination, the class will now check its thinking using a 4 and 3 combination.

The teacher should explain the scenario and ask students to work together to suggest combinations that would behave in exactly the same way as a 4 and 3 combination.

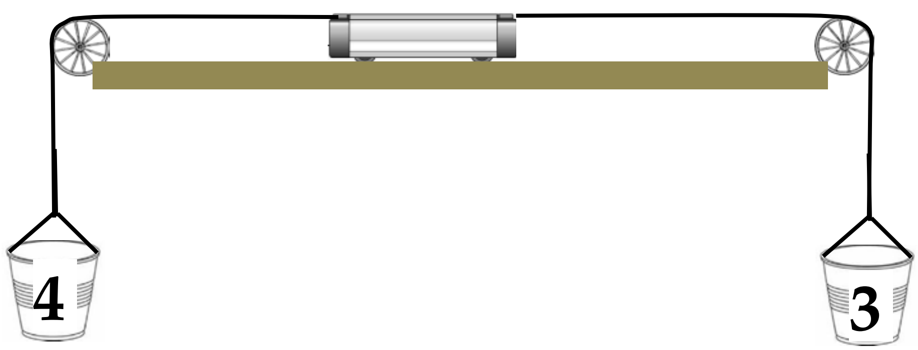
Record all combinations suggested on a display, grouping them by the reasoning used to arrive at them. Then play the next section of the movie, pausing as necessary.
Actually, the only combinations tested in the movie are ones that work! They are 2 and 1, 3 and 2, 5 and 4 and 6 and 5. These are shown in two segments.

STEP 4: You have now seen tests of three possible ideas about what unbalanced combinations of forces have the same effect on the cart.

Your teacher will lead a class discussion about these tests

Which of the three ideas you have seen tested seems to be correct?

STEP 5: In STEP 1 you saw that a 4 and 2 combination did not have exactly the same effect on the cart as a 4 and 3 combination.



Use the idea you identified as correct in STEP 4 to suggest two or three different combinations that you think would have exactly the same effect on the cart as a 4 and 3 combination. Explain your thinking.

Your teacher will lead a class discussion about everyone's ideas and then you will see two movie segments that show various combinations tested at the same time as a 4 and 3 combination.

Check off those that are seen to work on the previously constructed list.

Given all that has happened in the lesson so far, students should now be comfortable with the idea that all these combinations have a left side that has one more cube than the right side.

Someone may have suggested a 1 and 0 combination. If so, the teacher can assure them they will move on to examine such combinations next.

Activity 2

In this part of the lesson, we address the idea of net force. We start with the question of whether we can produce the same behavior as an unbalanced 2 and 1 combination without putting any cubes in the cup on the right side.

Activity 2: Step 1

Based on the idea developed in Activity #1 most students are likely to opt for the 1 and 0 combination. Some may opt for both combinations, based on the lingering idea that it is only the stronger force that matters. Some others may say that neither will work, probably because in their eyes they are no longer combinations but single forces, and thus will have a different effect.

If the 1 and 0 combination was already suggested as being equivalent to the 4 and 3 combination in Activity #1, the teacher can remind the class about this. Because we already know that the 2 and 1 combination behaves in the same manner as the 4 and 3 combination, this will be an indirect test of that earlier suggestion.

Make a note of the combinations tested in the movie that behave in exactly the same manner as the 4 and 3 combination?

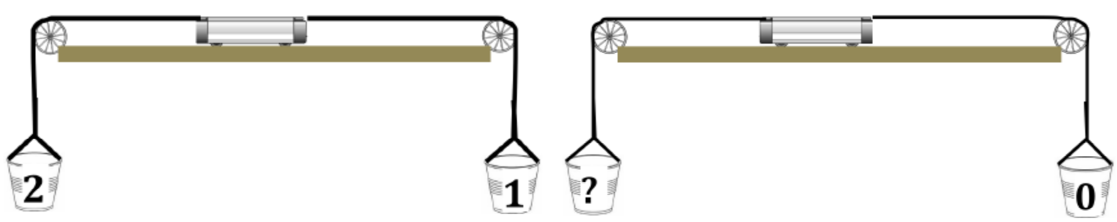
Why do you think all these combinations behaved in the same manner? What did these arrangements have in common?

Activity #2: Combinations for which one force is zero?

Your class will work together for this activity. The class will need:

- Computers on which to view movies, or a way for the whole class to view a projected movie.

STEP 1: Now suppose you wanted to find a combination that behaved in exactly the same way as a 2 and 1 combination, ***but were not allowed to put any sugar cubes in one of the cups***.



Suppose you tested both a 1 and 0 and a 2 and 0 combination alongside a 2 and 1 combination.

Do you think the 1 and 0 combination, the 2 and 0 combination, both, or neither would behave in the same manner as the 2 and 1 combination? Explain your thinking.

Play the first segment of the second movie for this lesson, pausing as necessary.

It should be evident to students that the 1 and 0 combination behaves in the same manner as the 2 and 1 combination.

Given all that has happened in the lesson so far, students should now be comfortable with the idea that both of these combinations have a left side that has one more cube than the right side.

Net Force

The teacher should now explain the idea of net force, in terms of arrangements of sugar cubes. All arrangements that have a net force of 1 cube behave in the same way.

Note: If students point to the string and empty cup as producing a force on the cart, teachers should acknowledge their accurate observation, but inform the class that the masses of the string and cup on both sides are so small that they can be ignored here.

You will now see a movie segment in which 2 and 1, 1 and 0, and 2 and 0 combinations are tested at the same time.

What does the movie show? Which combination behaves in exactly the same manner as the 2 and 1 combination, the 1 and 0 or the 2 and 0?

Why do you think this particular combination behaves in the same manner as the 2 and 1 combination?

Net Force

As you have seen, there were many combinations of sugar cubes that would have the same effect on the cart as the 2 and 1 combination (for example, 3 and 2, 4 and 3, etc.). You have also seen that there was one combination in which you needed to put a single sugar cube in only one cup to have the same effect. Because there was a sugar cube in only one cup, and none in the other, there was only a single force acting on the cart in this case. When a combination of forces acts on an object, you can always find a single force that will have exactly the same effect. We call the strength of the single force that will have same effect as a combination of forces the **net force** acting on the object.

For example, if we had 2 sugar cubes in one cup and 1 in the other we could also make the cart behave in exactly the same way by putting only 1 sugar cube in one cup and leaving the other empty. So we can say that the net force acting on the cart was that of only 1 sugar cube.

Activity 2: Step 2

The teacher should make sure students know we are looking for two answers here that do not have to be the same.

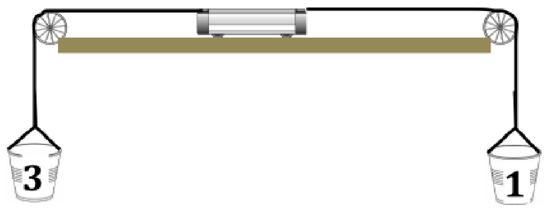
Given the previous explanation of net force, students should realize that the net force is 2 cubes to the left for the 3 and 1 combination and 3 cubes to the left for the 4 and 1 combination.

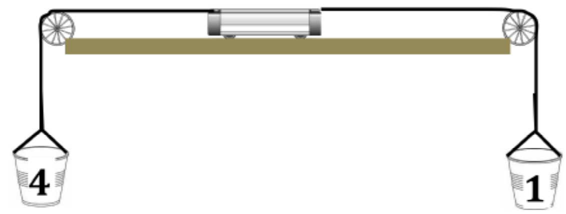
The teacher should make sure students understand what is being asked here. Given that, even if they are not yet comfortable with idea of net force, most students should realize that 2 and 0 and 3 and 0 combinations would be appropriate.

After the class discussion, play the last two movie segments, pausing as necessary to let students record the results.

It should be evident that it is the 2 and 0 combination that behaves in the same manner as the 3 and 1 combination.

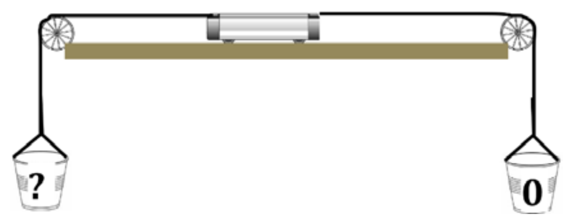
STEP 2: Now suppose you had a 3 and 1 combination and a 4 and 1 combination.





What is the net force for each of these combinations?

How could you make the cart move in the same manner as each of these, by placing sugar cubes in only one cup?



Your teacher will lead a class discussion about everyone's ideas and then you will see two movie segments in which you will see various combinations tested.

Which combination behaves in exactly the same manner as the 3 and 1 combination, the 2 and 0 or the 3 and 0?

It should be evident that it is the 3 and 0 combination that behaves in the same manner as the 4 and 1 combination.

Some students will cite the 2 and 3 cube differences in the appropriate combinations. Other may say the net force is the same. Either answer is acceptable.

Making Sense Questions

Question 1a: Most students should be comfortable with the idea that any combination with a difference of 3 (higher number at the left) will work. Encourage students to refer to specific cases observed in the videos (i.e., 4 and 2, 5 and 3, and 3 and 1 arrangements) to support the claim that the same difference in the two forces will have the same effect on motion.

Question 1b: Many students should be able to state the net force as “3 sugar cubes” on the left. Some may have to be prompted to imagine a 3 and 0 arrangement as an intermediate step.

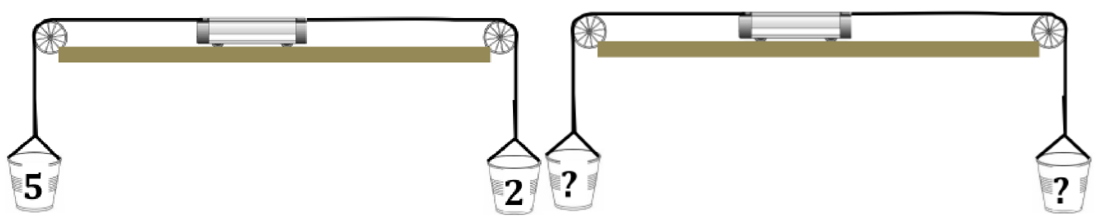
Which combination behaves in exactly the same manner as the 4 ***and*** 1 combination, the 2 ***and*** 0 or the 3 ***and*** 0?

Why do you think it is that these particular combinations behave in the same manner as the 3 ***and*** 1 and 4 ***and*** 1 combinations?

Making Sense

Your teacher will lead a class discussion about combinations of forces and net force. Write answers to the questions below after each one is discussed.

1. Suppose the combination was changed to have 5 sugar cubes in one cup and 2 in the other.



a) Suggest two different arrangements of sugar cubes that would make the cart behave in the same manner as the 5 and 2 combination.

b) What is the net force for the 5 ***and*** 2 arrangement? How do you know?

Question 2: Students must first realize that the arrangement on the right side is equivalent to 6 cubes in one cup. Then they can imagine a 6 and 4 arrangement and so get a net force of 2 cubes on the right. The teacher may need to prompt this reasoning in steps.

The teacher should point out that this is a situation where there are actually 3 forces, but that we can still determine a net force. It may help to ask students to first consider the total force pulling to the right and then to think about the net force acting on the cart.

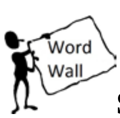
Students might bring up the "pull" contributed by the additional cup. If this happens, assure students that the pull from the additional cups is very small compared to the pull from the sugar cubes.

Question 3: We now ask students to describe a general procedure for determining a net force (subtracting the sum of the forces acting in one direction from the sum of the forces acting in the opposite direction). At this stage most students will be able to find a net force but may find it hard to verbalize how they are doing it. The teacher can help by leading the class through some different examples and writing down what they did at each step.

Finally the teacher should pose a more complex situation (two or three cups on each side!) and have each student determine the net force individually, then discuss with their neighbors, and finally check that everyone gets the same result.

Question 4: Although it may be obvious to some students that balanced forces represent a net force of zero, some may be uncomfortable with how to determine this. If so, the teacher can lead them through the procedure developed in the previous question.

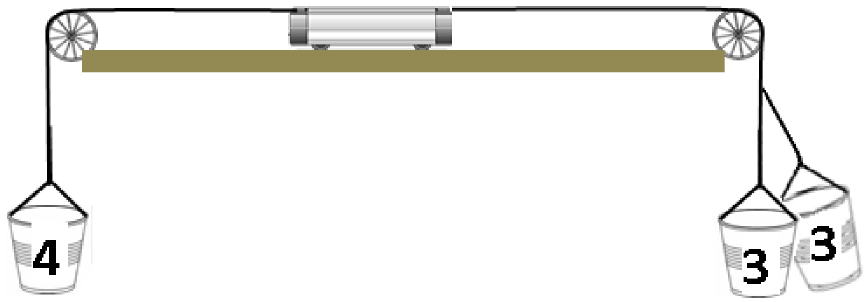
Several examples should be done with the class, including the one with no forces on either side! Once the idea of zero net force is established, the teacher should make the connection between "balanced forces" and "no force" through the idea that the net force is zero in both cases, thus the behavior is the same.



Science Vocabulary

Although the term "**net force**" is introduced in this lesson, it will be revisited in future lessons. Consequently, the teacher should not add this term to the word wall yet.

2 Suppose you had three cups and placed sugar cubes in them as shown below.



What is the net force of this arrangement of sugar cubes? How do you know?

3. Describe how you can find the net force acting for any combination of forces acting on an object.

4. If a balanced combination of forces acts on an object, what is the net force acting on it?

Unit 2 Cycle 2

Exploration #2: What effect do combinations of forces have on motion?

LESSON TARGET IDEAS

- When an unbalanced combination of forces acts on a moving object, the object's motion will change.
- When a non-zero net force acts on a moving object in the same direction as its motion, its speed will increase.
- When a non-zero net force acts on a moving object in the opposite direction to its motion, its speed will decrease (and it may eventually stop momentarily and then reverse direction).
- When a balanced combination of forces (net force of zero) acts on a moving object, the object's speed will remain constant.

COMMON MISCONCEPTIONS

- *When a non-zero net force acts on an object in the same direction as its motion, the object's speed will remain constant.* (It will not! Such a net force would cause an increase in speed.) This misconception is often stated as: constant speed requires a constant non-zero net force in the direction of motion.
- *When any force acts on a moving object in the opposite direction to its motion its speed will decrease.* (Not necessarily, it depends on the strength of any forces acting in the same direction as motion and in which direction the net force is acting.)
- *When the net force acting on a moving object is in the opposite direction to its motion it will immediately reverse direction.* (It will not, it must slow to a stop before the direction can reverse, though this may happen very quickly if the net force is very strong.)
- *When a balanced combination of forces acts on a moving object it will either stop immediately or slow and stop more gradually.* (It will not, a net "backward" force is required to slow and then stop an object.)

WHAT TO FOCUS ON

In this lesson we focus on the idea that unbalanced combinations of forces will make an object's speed change, while a balanced combination will result in no change in speed. Using the idea of net force, these experiences can be directly related to the behavior of an object when a single force or no forces act on it.

Throughout the lesson, students engage with experiments involving a moving cart subjected to various combinations of unbalanced and balanced forces. To make it easier for students to observe changes in the motion of the cart, dots on the video mark the position of the cart at equal time intervals. Students should be focused on the direction of the net force acting on the cart at a given time and on what the dot patterns represent in terms of changes in motion.

The first experiment shows a cart subjected to a constant non-zero net force in the direction of its motion. The white dots get farther apart providing evidence that a non-zero net force acting on a moving object in the direction of its motion causes it to move faster and faster.

In the second experiment, the constant non-zero net force acts in the direction opposite to the cart's motion. The white dots get closer together as it moves, indicating decreasing speed. After the cart stops and begins moving in the direction of the non-zero constant net force, the red dots get farther apart, indicating increasing speed. The pattern of white dots provide evidence that when a non-zero net force acts on a moving object in the opposite direction to its motion, its speed will decrease and may slow to the point of eventually stopping.

The third experiment shows a cart first subjected to a constant single force, which causes it to move with increasing speed in one direction (white dots are displayed). After a short while, a non-zero net force is applied in the opposite direction. Green dots mark the position of the cart as it moves after this second force is applied. The patterns of white dots and green dots provide evidence that reinforces the ideas that were targeted in experiments one and two. The video provides evidence that counters the misconception that *when the net force acting on a moving object is in the opposite direction to its motion it will immediately reverse direction* because the cart gradually slows before reversing direction.

In the fourth experiment, a cart is first subjected to a constant single force, which causes it to move with increasing speed in one direction. After a short while a force of the same strength is applied in the opposite direction, resulting in a net force of zero. The green dots (appearing once the net force on the cart is zero) are equally spaced apart, providing evidence that when a balanced combination of forces (net force of zero) acts on a moving object, the object's speed remains constant. The constant speed of the cart counters the misconception that *when any force acts on a moving object in the opposite direction to its motion (including a balanced set of forces), its speed will decrease.*

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Student computers with internet access (optional)	1 per student group
Cart-on-track movies	1 per class

The cart-on-track movies can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/). Once you reach this page, click on the link provided for Simulations and Videos. The videos for this lesson are in the Unit 2, Cycle 2 Movies section and are designated for the Exploration 2 lesson.

Purpose

The teacher should explain the purpose of the lesson and stress the idea that it does not matter how the objects get moving to start with. We simply want to investigate what happens to their motion when a particular combination of forces acts on them.

What do we think?

The teacher should explain the scenario and stress that how the skateboarder got started in the first place is not important. Given that the skateboarder is already moving, what we are interested in is what happens to his motion when the combination of your push and the second friend's push is acting on him.

Unit 2 Cycle 2

Exploration #2: What effect do combinations of forces have on motion?

Purpose

You now know what happens when a combination of forces (either balanced or unbalanced) acts on an object that is not moving. We will now examine what happens to an object that is already moving when a combination of forces acts on it.

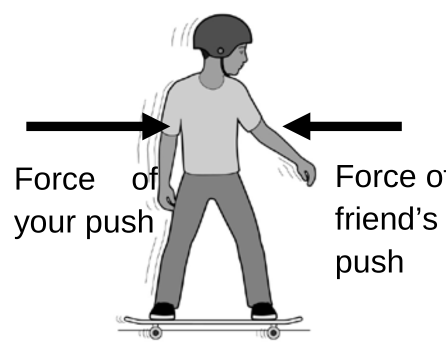
For example, suppose a boy pulls on his toy wagon to start it moving across the floor in the direction of his pull. Because her teddy bear is in the wagon, his sister starts to pull on the wagon in the opposite direction to her brother. How would the speed of the wagon behave now, with this combination of forces acting on it? Would it matter whether the combination of forces was balanced or unbalanced?

The big question we will address in this *Exploration* activity is:

> ***What effect does a combination of forces have on a moving object?***

What do we think?

Imagine your friend is already moving along on his skateboard. As he is moving you push on him in the same direction as he is moving, while another friend pushes on him in the opposite direction. What will his motion be like while you are both pushing? Would your answer be different depending on which force was strongest?



Students are likely to express one of four ideas:

1) Some may say that his speed will increase, based on the idea that the net force is in the direction of motion.
2) Some may say that his speed will remain constant, still holding to the idea that a constant force results in a constant speed.
3) Some may say that his speed will decrease because there is a force acting on him in the opposite direction to his motion. These students likely think that any backward force will have this effect, regardless of the strength of any forward forces.
4) Some may say that he will reverse direction immediately, because they think that any backward force will cause this to happen.

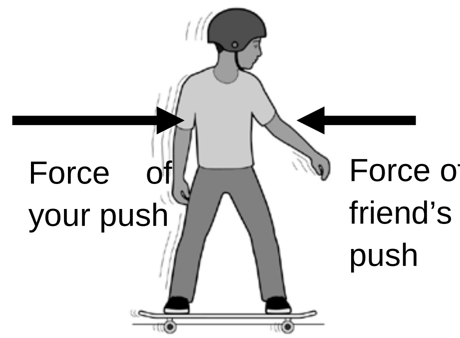
Students are likely to express one of two ideas:

1) Some may say that his speed will decrease, based on the idea that the net force is in the opposite direction to motion.
2) Some may say that he will reverse direction immediately, because they think that any backward force will cause this to happen.

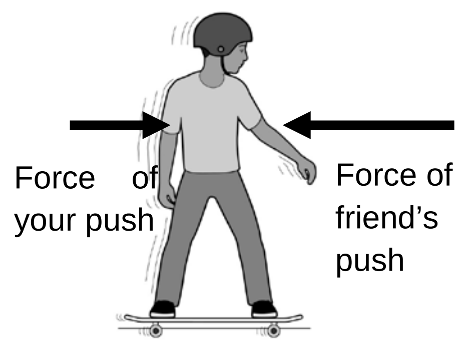
Students are likely to express one of five ideas:

1) Many will likely say that his speed will decrease and he will stop, based on the idea that balanced forces mean no motion.
2) Some may say that he will stop immediately, again based on the idea that balanced forces mean no motion.
3) A few may reason that his speed will remain constant because the net force is zero and so it is like having no forces acting.
4) Some may realize that the net force is zero, but still hold that it is a natural property of moving objects to slow and stop in the absence of a forward force to maintain motion.
5) Some may say that his speed will decrease because any backward force will have this effect, regardless of the strength of any forward forces.

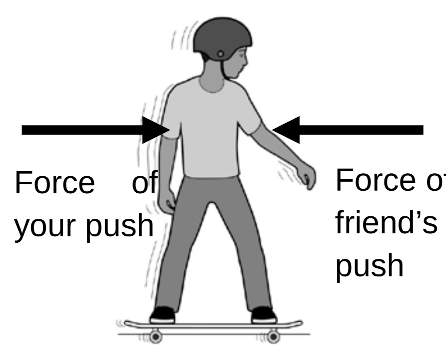
If your forward push was **stronger** than your friend's backward push, do you think the skateboarder's speed would increase, decrease, or stay constant? Why do you think so?



If your forward push was **weaker** than your friend's backward push, do you think the skateboarder's speed would increase, decrease, or stay constant? Why do you think so?



If your forward push was **equal in strength** to your friend's backward push, do you think the skateboarder's speed would increase, decrease, or stay constant? Why do you think so?



The teacher should make sure all ideas present in the class are made public, together with the reasoning behind them, then proceed to explain that they will now be checked by using data from the video (the cart/track/cups/sugar cubes setup).

Activity 1

The teacher should project the movie so that s/he can pause and continue at key points in the movie.

Note: When describing the numbers of sugar cubes in cups, these documents use the notation "X and Y" (e.g., "4 and 2"). The notation "X – Y" (e.g., "4 - 2") appears in the movies. There is no difference in the meaning of these two notations.

The cart-on-track movies can be accessed through the AIM Force and Motion Teacher Resources page (http://www.horizon-research.com/aim/fmworkshop/).
These are QuickTime movies and the QuickTime Player application can be used to view them.

Activity 1: Step 1

It should be evident to students that this combination is unbalanced. The teacher may want to ask them what the net force is and, again, students should be comfortable with the idea that this combination is equivalent to a net force of 2 sugar cubes to the left.

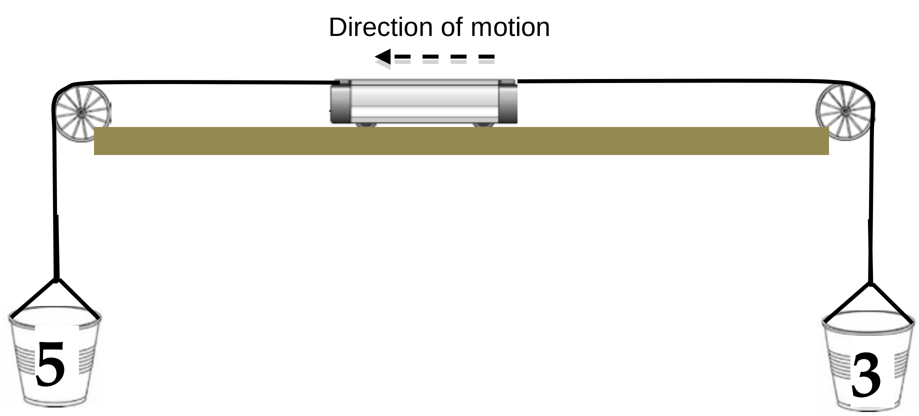
Your teacher will lead a class discussion about everyone's answers to these questions.

Activity #1: How does the speed behave when unbalanced forces act on a moving object?

Your class will work together for this activity. The class will need:

- Computers on which to view movies, or a way for the whole class to view a projected movie.

STEP 1: We will again test our ideas using the setup of a cart on a track and loading sugar cubes into the cups attached to each end. Suppose you had a setup like that shown below, with a 5 and 3 combination of sugar cubes. You know that when this cart is released it will start to move to the left but now we are interested in what happens to its speed **after it starts moving**, while this unbalanced combination of forces is still being applied to it.



The teacher should acknowledge that we already know this cart will start moving when we release it, because of the unbalanced forces being applied to it. However, after it starts moving we will then have a situation like the first one involving the skateboarder in the "What do we think?" section. That is, we will have a moving object with an unbalanced combination of forces being applied to it, and with the strongest force in the same direction as its motion.

Our concern now is what effect this particular combination of forces will have on the cart while it moves. Students' predictions are likely to be similar to those already outlined for the equivalent situation with the skateboarder, and no judgment should be made on them at this point.

The teacher should start the first movie segment. It should be paused on the freeze-frame at the end of the segment so students can examine the pattern of dots. (Some student may interpret this freeze frame as indicating the cart stopped at this point. They should be assured that it did not stop, this is just when the camera stopped "filming" it.)

If the class has already been through the lessons in Cycle 3 of Unit 1 on motion diagrams then students should be able to interpret the pattern of dots as indicating increasing speed.

If not, then the teacher may have to discuss with the class what the pattern is showing and how to interpret it (i.e., the greater the space between dots, the more distance traveled in one second and thus the greater the speed of the cart).

In the end there should be consensus that the speed of the cart increased while this particular combination of forces was being applied to it.

After it starts moving, do you think the cart's speed will increase, decrease, or stay constant? Why do you think so?

Your teacher will show you a movie of this setup. In order to judge what is happening to the cart's speed, its position will be marked with a white dot at one-second time intervals.

After it starts moving does the cart's speed increase, decrease, or stay constant? How does the pattern of dots tell you this?

Activity 1: Step 2

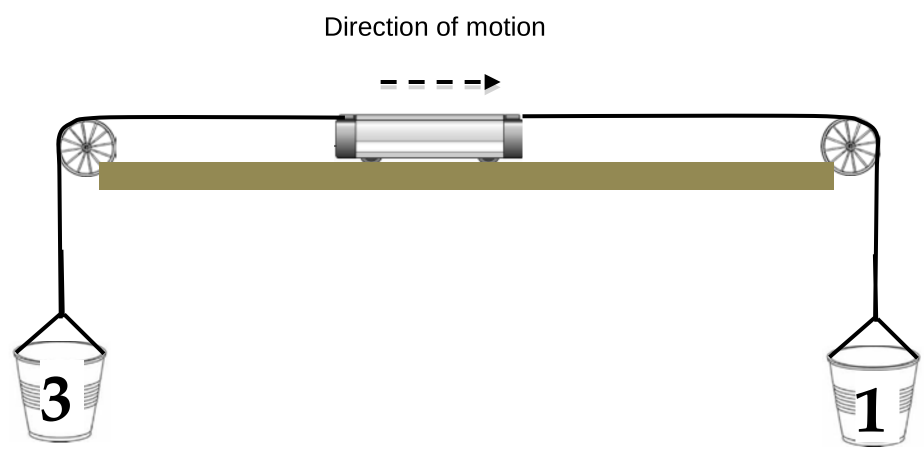
In the second situation to be examined we need to arrange for the cart to be moving in the opposite direction to the stronger force. In order to have this happen we will give the cart a quick push to start it moving to the right. However, after the push we will then have a situation like the second one involving the skateboarder in the "What do we think?" section. That is, we will have a moving object with an unbalanced combination of forces being applied to it, and with the stronger force in the opposite direction to its motion.

Our concern now is what effect this particular combination of forces will have on the cart while it moves. Again, students' predictions are likely to be similar to those already outlined for the equivalent situation with the skateboarder.

The teacher should start the second movie segment. It should be paused on the freeze-frame at the end of the segment so students can examine the pattern of dots.

The teacher should emphasize that for now we are only looking at the white dots. Students should be able to interpret the pattern as indicating decreasing speed but it also fairly easy to infer this just from the visual perception of the cart's behavior.

STEP 2: Now we want to check what happens if the stronger force is pulling in the opposite direction to the cart's motion. To see this we will take the 3 and 1 combination setup shown below, but start it moving to the right with a quick push. After the push is over the stronger force will be pulling on the cart in the opposite direction to its motion.



After the push, while the cart is moving to the right, do you think its speed will increase, decrease, or stay constant? Why do you think so?

Your teacher will show you a movie of this setup. In order to judge what is happening to the cart's speed its position will be marked with a dot at one-second time intervals.

After the quick push is over what happens to the cart's speed at first? Does it increase, decrease, or stay constant? How does the pattern of WHITE dots tell you this?

If students are having difficulty with this question the teacher should help them realize that because the cart slowed to a stop, now they have an object at rest (even if only for a moment) with an unbalanced combination of forces acting on it, which is a situation they already examined in the previous lesson.

The teacher should emphasize that now we are only looking at the red dots. Students should be able to interpret the pattern as indicating increasing speed.

If students are having difficulty with this question the teacher should help them realize that this situation is the same as that they already examined in STEP 1.

Activity 1: Step 3

The teacher should emphasize that we are talking about the net force after the cart has started moving. The only two forces are those of the sugar cubes in the cups.

The teacher may wish to project, or draw, the appropriate diagram of the setup from STEP 1. From this it should be evident to students that the net force was in the direction of motion. If not, the teacher could prompt them to think about how to produce the same net force by placing sugar cubes in only one cup. Would that cup be pulling on the cart in the same direction as, or in the direction opposite to, the motion?

Why do you think the cart starts moving back in the opposite direction after it has come to a stop?

While the cart is moving back to its starting point does its speed increase, decrease, or stay constant? How does the pattern of RED dots tell you this?

Why do you think the cart's speed behaves like this on the way back to the starting point? What is it about the forces acting on it that makes this happen?

STEP 3: In the previous lesson you saw that when an unbalanced combination of forces acts on an object you can always combine those forces into a single force, called the net force, that would have the same effect.

In the setup you saw in STEP 1, was the net force acting on the cart in the same direction as its motion, or in the opposite direction to its motion?

At least some students should make the connection with the effect of a single force increasing speed if continuously applied in the same direction as motion. If no one does, the teacher may need to prompt them in this regard. For example, the teacher might revisit the idea of net force and use numerical examples to help students realize that applying a net force in the direction of motion is the same as applying a single force (of the same magnitude as the net force) in the direction of motion.

The teacher may wish to project, or draw, the appropriate diagram of the setup from STEP 2. From this it should be evident to students that the net force was in the opposite direction to motion. If not, the teacher could prompt them to think about how to produce the same net force by placing sugar cubes in only one cup. Would that cup be pulling on the cart in the same direction as, or opposite direction to, the motion?

At least some students should make the connection with the effect of a single force decreasing speed if continuously applied in the opposite direction to motion. If no one does, the teacher may again need to prompt them in this regard. For example, the teacher might help students realize how this question, like the question at the top of this page, is also asking about net force versus a single force, only now the force is applied in the direction opposite to the object's motion.

Why might it make sense that when the stronger force is acting in the same direction as the cart's motion, its speed increases?

In the setup you saw in STEP 2, was the net force acting on the cart in the same direction as its motion, or in the opposite direction to its motion?

Why might it make sense that when the stronger force is acting in the opposite direction to the cart's motion, its speed decreases (and it then reverses direction)?

Your teacher will lead a class discussion about these questions.

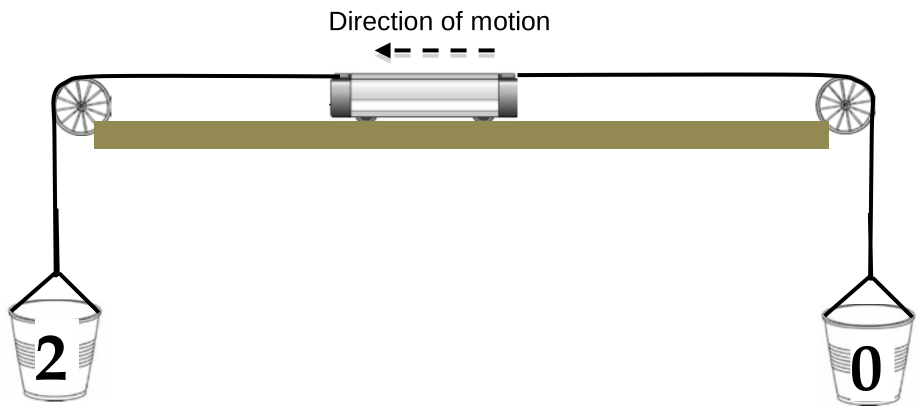
Activity 1: Step 4

This scenario involves both situations considered so far in one “run.” The cart starts from rest with unbalanced forces acting on it. After a short time, the strength of the “backward” force is adjusted to make it stronger than the forward force.

Hopefully, students should now be comfortable with the idea that the speed of the cart will increase because after it has started moving the net force is in the same direction as its motion.

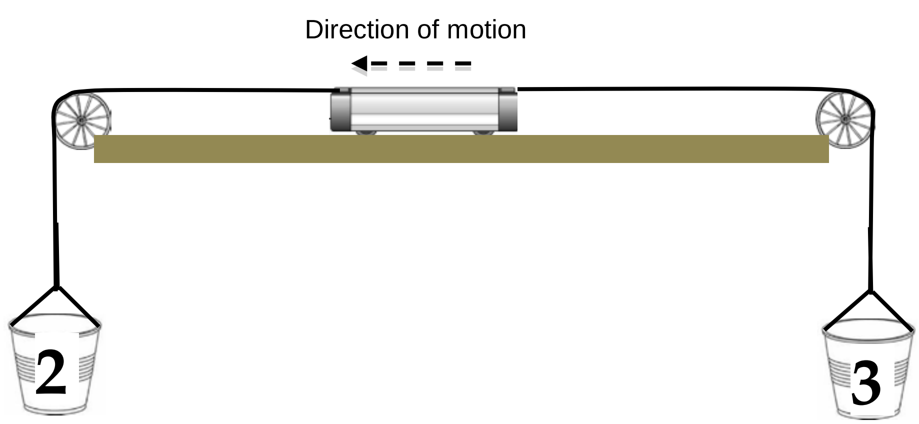
The teacher should carefully describe what will happen and help them to see that now the net force will be in the opposite direction to the cart’s motion.

STEP 4: Now let's check our thinking with a slightly more complicated situation. Suppose we release the cart while a 2 and 0 combination is applied to it.



After it starts moving (with the 2 and 0 combination still being applied), do you think the cart's speed will increase, decrease, or stay constant?

After the cart has been moving for a short time, 3 sugar cubes will be dropped into the right cup, so making the force in the opposite direction stronger than the force in the direction of motion.



Many students should now agree that the speed will decrease (just as they saw happen in STEP 2) because the net force is in the opposite direction to the cart's motion. Some may also say that the cart will reverse direction and then increase speed going back toward its starting point. While this is not the main point of what they will see, they should be asked why they think this will happen.

The teacher should start the third movie segment. It should be paused on the freeze-frame at the end of the segment so students can examine the pattern of dots.

Students should be able to interpret the pattern of white dots as indicating increasing speed.

Again, students should now be comfortable with the idea that the speed of the cart increases because after it has started moving, the net force is in the same direction as its motion.

Students should be able to interpret the pattern of green dots as indicating decreasing speed. Some may wish to say something about it also reversing direction, which is OK too.

After the 3 sugar cubes are dropped into the right cup do you think the speed of the cart will increase, decrease, or stay constant? Why do you think so?

Your teacher will lead a class discussion about this question.

You teacher will show you a movie of this setup. As, usual, in order to judge what is happening to the cart's speed its position will be marked with a dot at one-second time intervals.

After it starts moving, while the 2 and 0 combination is applied to it, does its speed increase, decrease, or stay constant? How does the pattern of WHITE dots tell you this?

Why does its speed behave in this manner at first?

After the 3 sugar cubes are dropped in the right cup, does the cart's speed then increase, decrease, or stay constant? How does the pattern of GREEN dots tell you this?

At this point students should be able to reason based on the direction of the net force relative to the cart's direction of motion. When the net force is in the same direction as motion, speed increases. When the net force is in the opposite direction to motion, speed decreases.

Activity 2

Now we will examine what happens to motion when balanced forces act on a moving object. Some students may ask how it could be moving to start with, as balanced forces cannot make an object start to move. It is OK for the teacher to explain that we will indeed need to use unbalanced forces to start it moving, but once it is moving we will arrange for the forces to become balanced. It is what happens when the forces are balanced and the cart is already moving that we are interested in.

Activity 2: Step 1

The teacher should explain how we are going to arrange for this to happen. We will start with an unbalanced combination that will start the cart moving, then we will add sugar cubes to make the forces balanced.

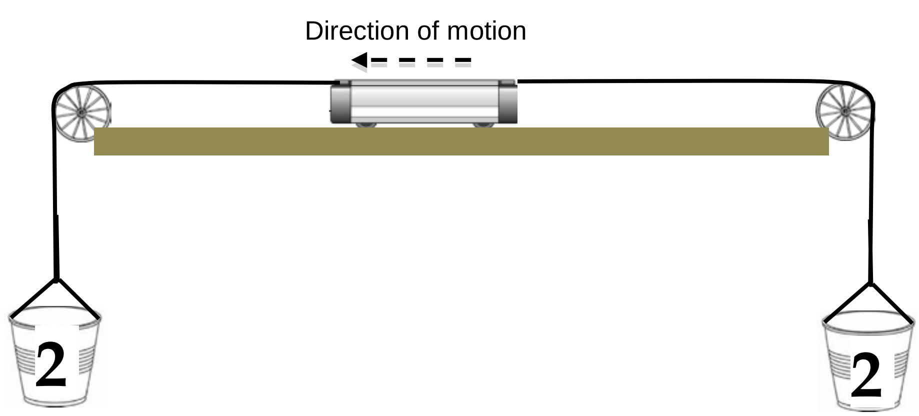
Why do you think the cart the cart's speed behaves differently after the 2 and 0 combination is changed to a 2 and 3 combination?

Activity #2: How does the speed behave when balanced forces act on a moving object?

STEP 1: In the first part of this lesson we investigated how an unbalanced combination of forces affects an object that is already moving. Now we will think about what would happen if balanced forces are applied to an object that is already moving.

We will again test our thinking by releasing the cart while a 2 and 0 combination is applied to it.

However, after the cart has been moving for a short time 2 sugar cubes will be dropped into the right cup, making the forces **exactly balanced**.



Students are likely to express the same four ideas as in the “What do we think?” section:

1) Many will likely say that the cart’s speed will decrease and it will stop, based on the idea that balanced forces mean no motion.
2) Some may say that it will stop immediately, again based on the idea that balanced forces mean no motion.
3) A few may reason (correctly) that its speed will remain constant because the net force is zero and so it is like having no forces acting.
4) Some may realize that the net force is zero, but still hold that it is a natural property of moving objects to slow and stop in the absence of a forward force to maintain motion.

It is important that all ideas suggested by the class be discussed at this point.

The teacher should start the last movie segment. It should be paused on the freeze-frame at the end of the segment so students can examine the pattern of dots.

Hopefully there will be consensus that the green dots seem to be equally spaced, thus indicating constant speed. However, some students may perceive some very slight irregularities. If so, the teacher can appeal to the general sense that the pattern does not seem to indicate regularly increasing or decreasing speed and is more consistent with the speed not really changing. (Any slight irregularities are probably more due to the limitations of how the movie was made and dots placed!)

Students may need help with this question, so strong are some of the misconceptions associated with balanced forces. We would hope that the idea emerges that balanced forces means zero net force, which in turn is like having no force at all. In Cycle 1 of Unit 2 students should have decided that when no forces act on a moving object its speed will not change. Resolution of this issue will continue in the Making Sense questions so no definite consensus is needed at this point.

After the 2 sugar cubes are dropped into the right cup do you think its speed will increase, decrease, or stay constant, or will something else happen? Why do you think so?

Your teacher will lead a class discussion about this question.

Your teacher will show you a movie of this setup. The white dots will show that its speed was increasing while the 2 and 0 combination was applied.

After the 2 sugar cubes are dropped in the right cup, does the cart's speed then increase, decrease, or stay constant? How does the pattern of GREEN dots tell you this?

Why do you think the cart's speed behaves in this way after the 2 and 0 combination is changed to a 2 and 2 combination?

Making Sense Questions

Question 1a: Students should now be comfortable with the idea that unbalanced forces make the speed change. They have seen evidence in the videos to support this in terms of both increasing and decreasing speed, depending on the direction of the net force relative to the direction of motion.

Question 1b: Because unbalanced forces are equivalent to a net force (that is not zero), the effect of such an unbalanced combination should be the same as that of a single force—that is, to change an object's speed. The teacher may need to be somewhat proactive in promoting this reasoning, but students should be comfortable with it. For example, the teacher might first prompt students to think about what "net force" means, and then ask how net force compares to a single force acting on an object.

Question 2a: This idea is more difficult for students but they do have evidence from the videos to support the idea that the speed stays constant. At a very minimum, the class should agree that the behavior was certainly more like that of "no forces" than like that of a single force. A transition to an intellectual argument connected with part b) of this question may be needed to help students reason this out. For example, the teacher might ask: "What is the net force if there is a balanced combination of forces acting on an object?"

Question 2b: Students may need help with this reasoning. The teacher can prompt them along the following line of thinking:

By now students should be comfortable with the idea that when the forces are balanced, the net force is zero, and that a net force of zero is like having "no force" acting on an object. They have seen in the previous Cycle that when no forces act on the CD puck it seems to just keep going and going, with a speed that remains essentially constant. So whenever the net force is zero, does it not make sense that the motion would be the same as this (i.e., no change)?

In addition an appeal can be made to the idea that we need a non-zero net force to change the speed, so if the net force is indeed zero, then there is nothing to cause the speed to change.

Making Sense

Your teacher will lead a class discussion about the effect that combinations of forces have on the motion of an object. Write answers to the questions below after each one is discussed.

1. a) When an unbalanced combination of forces acts on a moving object what happens to its speed? Does it change, or does it remain constant?

   b) Why does this make sense in terms of the net force acting on the object?

2. a) When a balanced combination of forces acts on a moving object what happens to its speed? Does it change, or does it remain constant?

   b) Why does this make sense in terms of the net force acting on the object?

Question 3: Now we ask students to argue in reverse. That is, based on a description of an object's motion, to decide if the forces are balanced or unbalanced. Students may have difficulty doing this at first, so the teacher may have to model it for them.

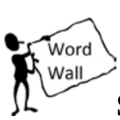
Question 3a: This first situation should not be difficult for students. Because the car is not moving, this is indicative of the forces being balanced. However, a few students may still hold the "stronger resisting force" idea mentioned earlier in this Cycle. To address this idea, the teacher can lead students through the following line of reasoning: if there was a stronger resisting force on the car then the forces would be unbalanced. If the forces were unbalanced then the car would move in the direction of the stronger force (i.e., backwards). However, the car is stopped so the forces must be balanced!

Question 3b: Most students should be able to associate increasing speed with unbalanced forces. The teacher can ask students to describe the forces and changes in motion from one of the video segments that represents this situation. The teacher may wish to ask them to identify the direction of the stronger force. Most students should be able to explain that it must be in the same direction as the motion.

Question 3c: This question is likely to be more difficult for students. While some will be ready to associate constant speed with balanced forces, the deeply held idea that forward motion requires a forward force will likely lead to some saying the forward force has to be stronger to maintain motion. If so, at this point the teacher will likely need to review what they have learned about connecting force and motion up to this point and emphasize that as far as we know these rules always work for all situations. It may be helpful to recall, from the last activity, that the cart's speed remained constant when two sugar cubes were added to the right cup to balance the two sugar cubes in the left cup.

Question 3d: By this point most students will likely be comfortable with the idea that changing speed requires unbalanced forces. The teacher can then prompt them as to the direction of the stronger force.

A very few students may still hold the idea that even if the forces are balanced the car will still slow down. If so, the teacher should again lead them through the intellectual argument about what seems to be needed to change speed. It may be helpful to refer again to the cart experiments: the constant motion of the 2 and 2 balanced forces and the decreasing speed when a net force (2 and 3) was applied in the direction opposite motion.



Science Vocabulary

There are no new vocabulary terms introduced in this lesson. However, by now, students should be comfortable with the term "**net force**." If students understand and can use this term correctly, it would be appropriate to add "**net force**" to the word wall at this point.

3. A car is waiting at a stop light. When the light turns green the car starts moving, getting faster and faster. After a few seconds it reaches 30 mph and then continues at a constant speed down a long straight road for a while. It then slows and stops at the next stop light. For each of these parts of its motion, decide whether the forces acting on the car are balanced or unbalanced. Also explain how you know.

   a) While the car is waiting at the red light, not moving.

   b) While the car is getting faster and faster as it moves away from the light.

   c) While the car is moving at a constant speed of 30 mph down a long straight road.

   d) While the car is getting slower and slower as it approaches the next stop light.

Unit 2 Cycle 2

Application: Balanced or Unbalanced?

LESSON TARGET IDEAS

- When the speed of an object is increasing, the forces acting on it must be unbalanced, with the net force acting in the same direction as its motion.
- When the speed of an object is decreasing, the forces acting on it must be unbalanced, with the net force acting in the direction opposite to its motion.
- When the speed of an object is constant, the forces acting on it must be balanced. This idea includes an object at rest that remains at rest.

COMMON MISCONCEPTIONS

- *If an object is in motion in any manner whatsoever, then there must be a net force in the direction of motion.* (There is a net force in the direction of motion only if the speed is increasing.)
- *If an object is slowing gradually then the forces acting on it may be balanced rather than unbalanced.* (Balanced forces will not cause a change in speed.)

WHAT TO FOCUS ON

From the first few lessons of this Cycle we have used evidence to establish a set of ideas telling us how an object will move depending on whether the forces acting on it are balanced or unbalanced. Students have observed that when unbalanced forces act on an object its motion changes, and when balanced forces act on an object its motion stays constant. We now move on to applying these ideas in "reverse." That is, given information about the motion of an object, what can we infer about whether the combination of forces acting on it is balanced or unbalanced?

In this lesson, students observe a wooden block on a flat surface subjected to various combinations of forces. For each activity, students should be focused on whether the motion of the block changes. The change, or lack of change, in motion serves as an indicator that the forces on the block are either unbalanced or balanced, respectively.

In Step 1, when students initially push the block they should observe that its motion changes (it goes from not moving to moving), an indication that the forces acting on the block must be unbalanced, with the net force acting in the direction of motion (i.e., the push force is stronger than the force of friction). As students push the block at a constant speed, they should observe that its motion does not change, an indication that the forces acting on the block must be balanced, with the net force being zero (i.e., the push force is equal to the force of friction).

In Step 2, students should observe that when they stop pushing the wooden block its motion changes (its speed decreases), an indication that an unbalanced force must be acting on the block, with the net force in the direction opposite to motion. In this case, the force of friction is the only force acting on the block.

In Step 3, students should observe that the block at rest does not have a change in motion, an indication that the forces acting on the block must be balanced, with the net force being zero. In this case, there are no forward or backward forces acting on the block).

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Wooden block (approximately 2” X 4” X 2”)	1 per student group

Purpose

The teacher should explain that now students will observe the motion of an object, and from that they will be asked to determine whether the forces acting on it are balanced or unbalanced.

What do we think?

This "What do we think?" section is intended to serve a slightly different purpose than most. While it does give an opportunity for students to express their ideas, it is also intended that the class discussion at the end of the section culminate in a review of the ideas that connect force combinations and motion. This review should end with the teacher writing some summary statements that can be displayed and/or distributed as a permanent reminder to students.

Students should have no difficulty stating that the forces must be balanced in this case and so John's and Sam's forces must be equal in strength.

While students should again have no difficulty stating that the forces must now be unbalanced, they may have difficulty drawing appropriate force arrows. The teacher should resist the temptation to review, and allow them to discuss and work on it with their neighbors for now. However the teacher can assure them that John and Sam continue pushing in the same directions as shown, but may have changed the strength of their pushes.

Unit 2 Cycle 2

Application: Balanced or Unbalanced?

Purpose

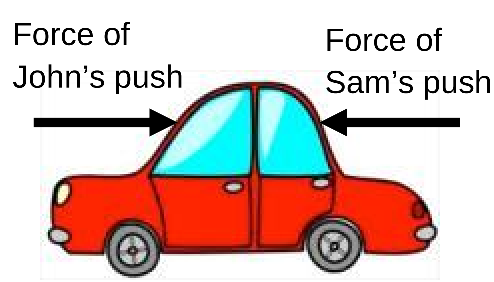
You now know how balanced and unbalanced combinations of forces affect the motion of an object. In this *Application* activity you will practice using these ideas to think about the forces acting on various objects. The big question we will address in this activity is:

How can we tell if the forces acting on an object are balanced or unbalanced?

What do we think?

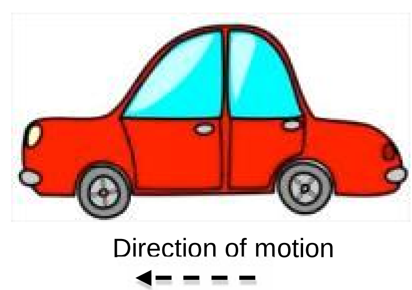
Suppose John and Sam push in opposite directions on a toy car that is standing still.

If the car still does not move while they are pushing on it what can you say about the forces acting on the car? Who is applying the stronger force, John or Sam, or are they the same strength?



Now suppose that after a few seconds, the car starts to move in the direction shown.

As the car is starting to move are the forces acting on it balanced or unbalanced? Who is applying the stronger force now, John or Sam? Draw force arrows on the picture of the car to show your thinking.



Most students will again be comfortable with the idea that increasing speed implies unbalanced forces. (They may want to draw the force arrows differently than the previous case but this is not strictly necessary because the same unbalanced combination could be responsible for both.)

This step will likely produce a difference of opinion. Some will make the appropriate connection and say a constant speed can result only if the forces are balanced. However, others may still have the idea that if the car is in motion, the force pushing it forward must be stronger than any force opposing it, concluding the forces must be unbalanced.

Those students who have made the appropriate connections will realize that in this case the forces must be unbalanced, with the stronger force opposing the motion. However, others may still be holding some deep-rooted misconceptions and so may opt for a gradually weakening forward force as being responsible for the car slowing and eventually stopping when this forward force becomes equal in strength to the backward force. Yet others may still hold the idea that if the forces are balanced the car would slow and stop, because balanced forces means no motion, which is the state the car is headed for. At this part in the lesson, all teachers should do is help students communicate their ideas and be prepared to summarize the ideas expressed.

It is suggested that each group put their force diagrams on a display board and then the whole class review them. If necessary, the teacher could now take the opportunity to review the drawing of force diagrams. If there are any differences of opinion for any of the situations, the teacher should lead a discussion of all the ideas developed so far about how combinations of forces affect motion and try to come to consensus on all the situations.

It is strongly suggested that the teacher write some agreed upon general statements that can be permanently displayed or distributed for the whole class to use.

After the car starts to move, its speed keeps increasing for a few seconds.

As the car is moving faster and faster are the forces acting on it balanced or unbalanced? Who is applying the stronger force, John or Sam? Again, draw force arrows on the picture of the car to show your thinking.

Direction of motion, increasing speed

After a few seconds the car's speed stops increasing and it then moves at a constant speed for a few more seconds.

While the car is moving at a constant speed are the forces acting on it balanced or unbalanced? Who is applying the stronger force, John or Sam? Again, draw force arrows on the picture of the car to show your thinking.

Direction of motion, constant speed

Finally the car slows and stops.

While the car is moving at a slower and slower speed are the forces acting on it balanced or unbalanced? Who is applying the stronger force this time, John or Sam? As usual, draw force arrows on the picture of the car to show your thinking.

Direction of motion, decreasing speed

Your teacher will lead a class discussion about everyone's answers to these questions.

Activity 1

In the previous scenario, both forces were provided by people pushing on the toy. However, in many situations when an object moves, one of the forces involved is friction. In this scenario we will try to determine how strong the friction force is compared to the pushing force.

The teacher should remind the class that the same ideas connecting force and motion will still apply.

Any non-wheeled object will work, such as a book. The wooden blocks used earlier are suggested because students have already used them in an earlier lesson on friction.

Activity 1: Step 1

Given the previous discussion and consensus, students should have no difficulty inferring that the pushing force must be stronger than the friction force. Detailed reasoning may be more difficult for some students but should include the following elements: "To start an object moving, the forces acting on it must be unbalanced, with the force in the direction of motion stronger than the opposing force. Thus the pushing force must be stronger than the friction force."

The teacher should monitor the groups to make sure they are drawing the force diagram appropriately.

While this question may be more difficult, at least some students will likely be able to infer that the pushing force must be equal in strength to the friction force. Their reasoning should include the following elements: "When the speed of an object is constant, the forces acting on it must be balanced, meaning that the pushing force must be equal to the friction force." However, even now, some may still hold the idea that for motion to continue there must be a net force in the direction of motion, and based on this idea they will likely conclude that the push is still stronger than the friction force.

Activity 1: How does friction compare to your force?

You will work with a partner for this activity. You will need:

- A wooden block

STEP 1: Place the wooden block on the table in front of you. Push it so that it starts to move and keep pushing so it slides across the table at a constant speed. Because it is sliding you know that a friction force must be acting on it, but so is the force of your push.

As the block starts to move which force is strongest, the force of your push or the force of friction? Explain how you know and draw a diagram showing the forces acting on the block to show your thinking.

As the block is sliding across the table at a constant speed which force is strongest, the force of your push or the force of friction? Explain how you know and draw a diagram showing the forces acting on the block to show your thinking.

Activity: Step 2

Most students should be comfortable with the idea that the pushing force is now gone and so the only force acting on it is the friction force. Because this force is in the opposite direction to the block's motion, it will make it slow and stop.

Activity: Step 3

This question is likely to be more difficult for students. The teacher may need to model a more intellectual type of reasoning to help students see that in these circumstances there is no friction force. The reasoning should be as follows:

"There is no pushing force, so if there were a friction force it would be the only horizontal force acting on the block. However, when a single force acts on an object at rest it begins to move, so if there were a friction force in this case the block would start to move "on its own." Because this clearly does not happen, there cannot be a friction force in this situation."

STEP 2: When you stop pushing on the block it will quickly slow and stop.

While the block is slowing what is the only forward or backward force acting on it? Explain why this force makes it move slower and slower and draw a force diagram to show your thinking.

STEP 3: Now think about the block while it is resting on the table, not moving, and you are not pushing it.

Is there a friction force acting on the block while it is not moving, and you are not pushing it? Carefully explain your reasoning.

Making Sense

Your teacher will lead a class discussion about the forces acting on the block under different conditions. Write answers to the following questions after each one is discussed.

Making Sense Questions

Question 1: Encourage students to relate the scenarios in questions 1 a-c to the observations they made and the conclusions they reached in this lesson's activity with the sliding block.

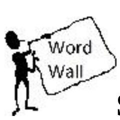
Question 1a: Decreasing speed means unbalanced forces are acting on the race car, with the stronger force acting in the opposite direction to the motion.

Question 1b: Starting to move means unbalanced forces are acting on the snail, with the stronger force acting in the direction of motion.

Question 1c: Constant speed means balanced forces are acting on the sports car.

Question 2: This situation was first addressed at the end of the previous lesson when discussing a chair that is not on wheels. Because the couch does not move the forces must be balanced, so the static friction force must be exactly equal to the pushing force.

However, even now, many students may still hold the idea that if an object that is being pushed does not move, the opposing force must be stronger than the pushing force. If so, the teacher should review the intellectual argument as to why this cannot be. (If the static friction force were stronger, the forces would be unbalanced and so the couch would actually start to move in the opposite direction to the push!)



Science Vocabulary

Although the terms "kinetic friction" and "static friction" are introduced in the second Making Sense question in this lesson, it is not critical that students develop a full understanding of these terms at this time.

1. For each of the following objects, state whether the forces acting on it are balanced or unbalanced, and how you know.

   a) A race car as it slows after finishing a race.

   b) A snail as it starts to move.

   c) A sports car as it drives down a long straight road at 70 mph.

2. You are used to thinking about a frictional force acting on a moving object. Scientists call this ***kinetic friction***. However, when you attempt to start an object moving, before it starts to move another form of friction (known as ***static friction***) opposes your attempt. Suppose you try to move a heavy couch across the floor, but despite pushing as hard as you can, it does not start to move. Is the static friction force acting in the opposite direction weaker than, equal to, or stronger than your force? Carefully explain how you know.

Unit 2 Cycle 2

Application #2: Are the up and down forces balanced or unbalanced?

LESSON TARGET IDEAS

- The same ideas that connect force and motion in the horizontal direction also apply to vertical motion.
- When an object is sitting on a solid surface, that surface exerts an upward supporting force on the object. If the object is at rest on a level surface, the supporting force must be equal in strength to the force of gravity pulling the object downward (also called 'the object's weight').
- Liquids and gases exert an upward force (called a buoyant force) on objects that are immersed in them.

COMMON MISCONCEPTIONS

- *Vertical forces and motion do not follow the same laws as horizontal motion*. (They do!)
- *If an object is moving upward in any manner whatsoever, then the upward force must be stronger than the downward force*. (This is only true if the upward speed is increasing! This misconception may arise, but is not explicitly addressed in this lesson.)
- *Surfaces do not exert an upward force, but stop objects from falling by simply "getting in the way."* (Surfaces do exert an upward force on the object, at the point of contact between the surface and the object.)
- *The supporting force exerted by a surface is always equal to an object's weight*. (This is true only if the object is on a level surface at rest, or moving upward or downward at a constant speed.)
- *Only liquids exert a buoyant force on objects immersed in them*. (Gases, such as the air, also exert buoyant forces, but they are much weaker and so only noticeable under very special circumstances.)

WHAT TO FOCUS ON

In this final lesson we attempt to have students apply the ideas they have already developed (in the context of horizontal motion) to vertical motion. This transition is difficult for many people because they implicitly believe that the laws of physics work differently for vertical motion. This incorrect thinking is probably because in the horizontal dimension we have some control over the forces we apply to objects, but in the vertical dimension the gravitational force is ever-present and cannot be controlled. For this reason people tend to think of gravitational force in a different way to pushes and pulls they can see being applied.

In the first part of this activity, students consider the vertical forces acting on a wooden block in varying scenarios. Similar to the previous activity, students should be focused on whether the motion of the block changes, which is an indicator of whether the force of the hand/table on the block is balanced (motion of the block is constant) or unbalanced (motion of the block changes) by the force of gravity.

When objects are at rest (i.e., forces are balanced) on a solid horizontal surface (such as the block on a table), we know that the force of gravity must be equal to another force that acts in the upward direction. Scientists call this the "normal force" but the term "supporting force" is more appropriate for students in this grade level.

The second part of the activity focuses on the buoyant forces exerted by liquids and gases. Again, students should be focused on whether the motion of the ball and helium-filled balloon change in order to infer whether the forces in each case are balanced or unbalanced. The initial examples involve the ball and balloon being held at rest by the teacher. These examples are particularly important because they provide students the opportunity to use their knowledge of forces and motion to infer that there must be an upward force acting on the ball and balloon to balance the downward forces applied by gravity and the teacher's hand. Scientists call the upward force applied by a liquid or gas the "buoyant force."

Students may struggle with inanimate objects, such as solid surfaces, liquids, and particularly gases, exerting forces on objects they are in contact with. The teacher should help students reason through the scenarios by first having them consider what they know must be true about the forces on non-moving objects (i.e., the forces must be balanced). Then, the teacher can help them identify what forces are acting on the ball/balloon. The students should be able to identify gravity and the teacher's hand. If they do not mention the surrounding air or water, the teacher can remind students that a force happens whenever two things interact and ask if there is anything else touching the ball/balloon. This question should help students identify the air/water as something else interacting with the ball/balloon.

MATERIALS NEEDED FOR THIS LESSON

Material	Quantity
Wooden block (approximately 2" X 4" X 2")	1 per student group
A large pail or bowl of water (clear container is best)	1 per class
A floating ball to fit in container (ping-pong ball, tennis ball etc.)	1 per class
A helium-filled balloon	1 per class

Purpose

The teacher should introduce the lesson by reviewing the ideas developed in this Cycle and reminding students that these ideas will work for <u>any</u> situation.

What do we think?

The teacher should explain the scenario and remind students that from the descriptions given, they need to decide whether the forces are balanced or unbalanced, and describe how they know. If unbalanced, is the stronger force upward or downward?

All students will likely agree that the upward force of the engines is stronger than the downward gravitational force. However, they are likely to reason this based on the upward motion of the rocket rather than its increasing upward speed.

The teacher should monitor groups to make sure they are drawing force arrows that are consistent with their thinking.

Application #2: Are the up and down forces balanced or unbalanced?

Purpose

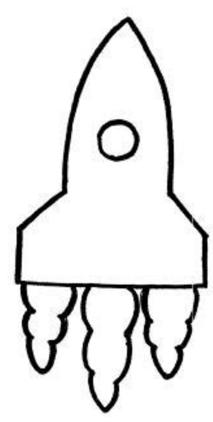
So far all of the examples of combinations of forces you have examined were pushing or pulling objects horizontally. In this *Application* activity you will use the same ideas to think about situations in which the forces act vertically, that is they point upward and downward. The big question we will address in this activity is:

How can we tell if the forces acting upward and downward on an object are balanced or unbalanced?

What do we think?

Think about a toy rocket sitting on the launch pad. It has three engines attached to it. When all three engines fire the rocket starts to move upward, getting faster and faster as it climbs.

Which force acting on it do you think is stronger, the gravitational force pulling downward on it, or the total force of all three engines pushing upward on it, or are they the same strength? How do you know? Draw force arrows on the picture to show your thinking.



After a few seconds one of the engines stops working, but it continues to climb higher at a constant speed.

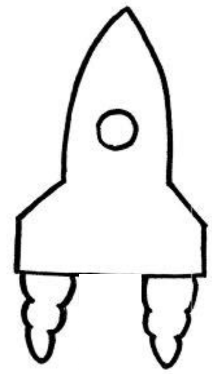
While some students may reason correctly that the forces must be balanced based on the idea that the upward speed is constant, many will likely still think the upward force is stronger based simply on the fact that the rocket is still moving upward.

Again, some students may reason correctly, based on decreasing upward speed, that the upward force is now weaker than the downward force. However, others will likely still think the upward force is stronger based simply on the fact that the rocket is still moving upward. There may be some students who think the forces are now balanced, reasoning that balanced forces will bring a moving object to rest.

The teacher may again need to remind students that the same ideas they have developed before for horizontal motion also apply to vertical motion. After this reminder, the various responses proposed by the class for the three situations involving the rocket should be reviewed for consistency with those ideas.

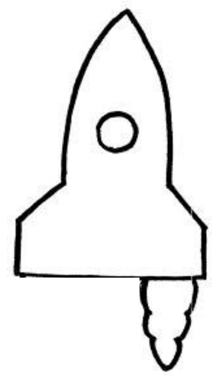
It may be necessary to temporarily transpose the situation to a horizontal case, perhaps something like a rocket car that has a frictional force opposing its motion. (In this case we substitute the friction force for gravity.) Then a discussion of the forces involved when the rocket car's speed is increasing, staying constant, or decreasing, can serve as a stepping stone before returning to the vertical case.

Which force acting on the rocket do you think is stronger now, the gravitational force pulling downward on it, or the force of the two engines still upward on it, or are they both the same strength? How do you know? Draw force arrows on the picture to show your thinking.



After yet another few seconds a second engines stop working. The rocket still continues climbing higher, but now gets slower and slower as it climbs

Which force acting on it do you think is stronger now, the gravitational force pulling downward on it, or the force of the one working engine still pushing upward on it, or are they both the same strength? How do you know? Draw force arrows on the picture to show your thinking.



Your teacher will lead a class discussion about everyone's answers to these questions.

Activity 1

In this activity, we address the issue of why objects resting on a surface do not fall and use this to infer the existence of upward supporting forces exerted by surfaces. We start by using the hand to support an object because it may be easier for some students to appreciate the supporting force in this context, when they can actually feel themselves exerting it.

Activity 1: Step 1

Students should be able to reason that because the block is not moving up or down, there must be an upward force acting on it that is exactly balancing the downward gravitational force.

Again, students should have no difficulty realizing this force must be acting upward. Some may draw the arrow as an upward push, others as an upward pull. This distinction is not too important as long as they realize it is indeed upward.

Most students should recognize that it is the hand that is applying this force to the block.

Students should realize that without this upward force the block would fall, because the only force acting on the block would be the downward gravitational force.

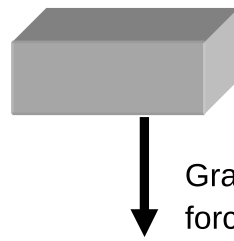
Activity 1: Resting on a surface?

You will work with a partner for this activity. You will need:

- A wooden block

STEP 1: Hold your hand so the palm is a flat surface. Place the block on your hand but do not move it up or down.

- You know a gravitational force is pulling the block downward, but there must also be another force acting on the block as it sits at rest on your hand. Explain how you know this.



- Draw an arrow on the drawing of the block to show which direction you think this other force is acting.

- Which other object do you think is applying this force to the block?

- What would happen to the block if this other force were taken away? Explain why this would happen.

Activity 1: Step 2

The teacher may have to explain that we are talking about the block as it starts to move upward. As with the earlier rocket example, most students will readily state that the forces are unbalanced, with the upward force being stronger. However, some may still reason this incorrectly from the upward direction of motion, rather than from the change in motion (in this case the speed) associated with starting to move upward.

Activity 1: Step 3

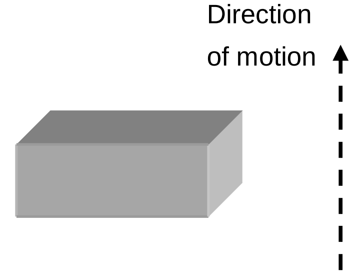
Some students will readily state that the table must be applying an upward force to the block, based on the fact that it is not falling. However, others may simply think the table "gets in the way" without applying a force to the block. This is a manifestation of the idea that inanimate objects cannot exert forces.

Again, some students will be able to reason from the lack of motion that the upward supporting force must be equal in strength to the downward gravitational force. However, at least some are likely to say that the upward force must be stronger to counteract the effect of the downward force. (This is the vertical analog of thinking that a pushed couch does not move because the opposing frictional force is stronger than the push.) If this idea does emerge in the class the teacher can model the same reasoning as to what would happen to the block if the upward force were really stronger.

The class discussion should again review the general ideas that link combinations of forces and motion, emphasizing their application in vertical contexts.

STEP 2: Now move your hand up, so that the block starts to move upward.

As the block is starting to move upward, are the two forces acting on it balanced or unbalanced? Which of these forces is the strongest, the upward or downward force? Explain how you know.



STEP 3: Finally, put the block on the table in front of you.

Is the table applying a force to the block? If so, in what direction? How do you know?

How do you think the strength of the force applied by the table to the block compares to the strength of the gravitational force acting on it? Are they equal, or is one stronger than the other? Explain how you know.

Your teacher will lead a class discussion about everyone's answers to these questions.

Supporting Forces

The teacher should review the reasoning that leads us to infer the existence of supporting forces that stop objects falling.

Activity 2

We now move on to examine buoyant forces, again inferring their existence from the behavior of objects immersed in fluids (water and air). Note: fluids are materials that can flow; all liquids and gases are fluids.

Make sure the ball used will float in water. (A tennis or racquet ball works well.) Also make sure the helium-filled balloon is ‘”fresh” and does indeed float upward when released. (Helium tends to escape from some balloons over the course of only a few hours!)

Activity 2: Step 1

The teacher should not submerge the ball as it is placed in the water.

By now it should be evident to students that the water must be exerting an upward force on the ball because the ball is not falling.

By now, most students should be able to reason from the lack of motion that the upward force acting on the ball must be equal in strength to the downward gravitational force. However, a few may still say that the upward force must be stronger to counteract the effect of the downward force. As described previously, the teacher can model the reasoning as to what would happen to the ball if the upward force were really stronger.

Supporting forces

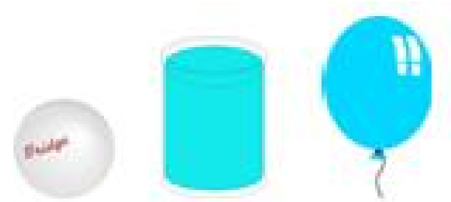
We know that a gravitational force pulls all objects downward, but most objects do not seem to be falling. For instance, as you sit in your chair, a gravitational force is pulling you downward, but you do not fall. However, if someone were to pull your chair away from under you, then you would fall.

If an object is not moving upward or downward, then the downward gravitational force must be exactly balanced by an upward force applied to it by whatever it is resting on. This could be a chair, a table, your hand, or even the floor (or the ground). We will call these ***supporting forces***. We know these forces must be there because if the table or chair were to be suddenly removed then the object would start to fall, telling us the forces acting on it have become unbalanced.

Activity 2: Why do some objects float upward?

The class will work together on this activity. The class will need:

- A small ball
- A pail or bowl of water
- A helium-filled balloon



STEP 1: Your teacher will place the ball in the water so that it is floating on the surface.

Is the water applying a force to the ball? If so, in what direction? How do you know?

How do you think the strength of the force exerted by the water on the ball compares to the strength of the gravitational force pulling downward on it? Are they equal, or is one stronger than the other? Explain how you know.

Activity 2: Step 2

The teacher should hold the ball as far under the water as possible and count down to the release, so that students can focus their attention on what happens.

It should be evident to students that the ball rises quickly to the surface. While it will not be obvious that the speed is increasing, the teacher should at least promote the idea that the ball starts to move upward when released and does not just simply stay where it was.

With the emphasis on the idea that the ball started to move upward, students should have no difficulty identifying that the forces were unbalanced.

With the evidence being the start of upward motion, all students should be able to identify the upward force as being stronger than the downward force.

Activity 2: Step 3

We now move on to examine the behavior of the helium-filled balloon. While the reasoning is essentially the same, it is likely to be more difficult for students because in this case they are asked to consider the three forces that are involved in keeping the balloon at rest. Some students may also have difficulty associating an upward force with the air, because they cannot see it.

The teacher should position the hand in such a way that it is ON TOP of the balloon, stopping it from floating upward.

Hopefully, by now students should be able to associate the evidence of no upward or downward motion with a state of balanced forces.

Students should be able to identify thee teacher's force as pushing downward on the balloon. If not, the teacher can demonstrate what happens then their hand is removed and then lead students to reason what effect the force of the hand was having. (Because it was stopping the balloon from moving upward, the force of the hand must have been pushing downward.)

STEP 2: Your teacher will now hold the ball under the surface of the water and then release it.

Describe what happens to the ball after it is released.

Just after the ball is released are the forces acting on it balanced or unbalanced? Explain how you know.

Just after the ball was released, before it reaches the surface, how do you think the strength of the force applied by the water to the ball compares to the strength of the gravitational force acting on it? Are they equal, or is one stronger than the other? Explain how you know.

STEP 3: Your teacher will now hold the helium-filled balloon so that it is not moving up or down.

Are the forces acting on the balloon balanced or unbalanced? How do you know?

Your teacher is applying a force to the balloon to stop it moving, but in which direction is your teacher's force acting, upward or downward? How can you tell? (Hint: what would happen to the balloon if your teacher's hand was not there?)

Because the forces are balanced, and we know the gravitational force and the force of the hand both act downward, there must be an upward force to balance these out. Some students may have difficulty imagining that it is the air itself that is applying this force. If students doubt that air can exert a force, have them imagine holding their hand out of a car window as it drives along—they will certainly feel the force of the air then!

Some students may say that it is the helium inside the balloon that is exerting the upward force. If so the teacher should ask them whether an object can lift itself upward. Have them try sitting in a chair (feet off the ground) and lifting themselves up to see if this is possible.

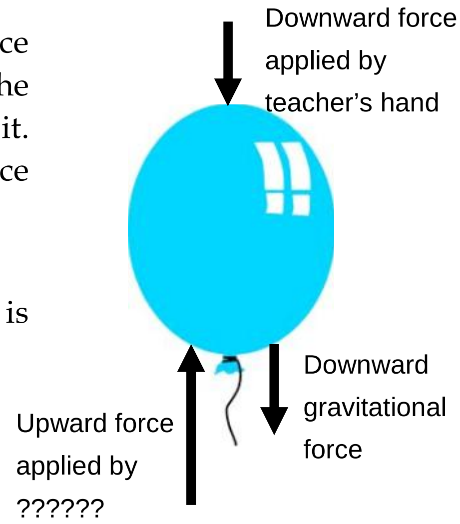
Some students may not believe there is a gravitational force in this case, but the reasoning will still be the same as far as an upward force and what is causing it.

Students should be able to reason that if the forces were balanced, and then one of them is removed, then the forces must become unbalanced.

Students will know that the balloon would begin to rise upward. However, explaining why this happens in terms of forces may be more difficult and the teacher may have to lead the class through it.

We are looking for students to say that if the forces were balanced and a downward force removed, the upward force would be stronger than any remaining downward force. The result of this unbalanced combination of forces would be for the balloon to start moving upward.

The balloon is not moving, yet both the force applied by your teacher's hand, and the gravitational force, are acting downward on it. This means there must be some other force pushing it upward.



What object, or substance, do you think is applying this upward force to the balloon?

If the force your teacher is applying to the balloon were to be removed, would the forces acting on it be balanced or unbalanced?

What would happen to the balloon if the force your teacher is applying to the balloon were removed? Explain why this would happen in terms of the forces that would still be acting on it.

Buoyant Forces

⚠ The teacher should describe the idea of a buoyant force and then carefully explain the given examples of objects in water, in terms of whether the combination of buoyant force and gravitational force is balanced or unbalanced.

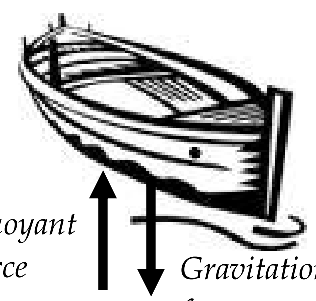
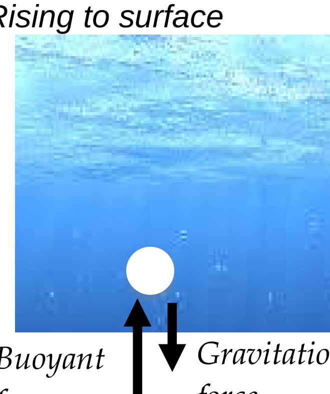
The teacher should state that the air also exerts a buoyant force on all objects within the atmosphere, but usually it is so weak compared to the gravitational force that it can be ignored. However, when the gravitational force is very weak (such as for the helium-filled balloon), the buoyant force can actually be stronger.

⚠ The teacher may wish to prepare an air-filled balloon of about the same size as the helium-filled balloon. When released, this balloon will actually fall downward, rather than rising upward as the helium-filled balloon does. This is not because the buoyant force is any weaker, but because the gravitational force on the air balloon is stronger than the buoyant force acting on it, whereas the gravitational force on the helium-filled balloon is weaker than the buoyant force acting on it. (Drawing force diagrams for the two balloons may help explain this.)

Buoyant forces

All liquids and gases, such as water and the air, exert force that pushes upward on objects that are placed in them. We call this a ***buoyant force***. If the buoyant force pushing upward on an object in water exactly balances the gravitational force pulling downward on it, then the object will float. An example of this would be a boat floating on a lake. However, if the buoyant force is not strong enough to do this, then the object will sink downward, because the forces acting on it are unbalanced, like a stone tossed into a lake. (It is important to realize that such an object's speed will increase as it continues to sink, because the forces acting on it are unbalanced.)

Finally, it is also possible that the buoyant force may be stronger than the gravitational force, in which case the object will actually start to move upward and rise to the surface. (As it does so, its upward speed will increase because the forces acting on it are unbalanced.) An example of this is a ping-pong ball that is released under water and quickly rises to the surface.

Floating	*Sinking*	*Rising to surface*
 *Buoyant force* / *Gravitational force*	 *Buoyant force* / *Gravitational force*	 *Buoyant force* / *Gravitational force*
Buoyant force strength is equal to gravitational force strength.	*Buoyant force is weaker than gravitational force.*	*Buoyant force is stronger than gravitational force.*

The buoyant force exerted on objects by the air is very weak and can usually be ignored because the gravitational force is much, much stronger. However, in some cases, such as the helium-filled balloon, the gravitational force is actually weaker than the buoyant force and so, if no other forces are present, these objects will actually move upward (with increasing speed), rather than fall downward.

Making Sense Questions

Before discussing the questions, the teacher should emphasize that the class has found out a lot of things in this lesson by simply applying the ideas they developed previously to new situations.

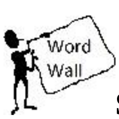
Question 1a: We are looking for students to recognize that the forces must be unbalanced because upward motion is starting (its motion is changing). It may be helpful to ask students to relate this example to a previous example of horizontal forces and motion (e.g., unbalanced forces producing changes in motion seen in the cart videos in lesson U2C2 Exploration 1).

Question 1b: In this case the students will likely recognize that the forces are balanced because there is no upward or downward motion. Again, it may be helpful to ask students to relate this example to a previous example of horizontal forces and motion (e.g., balanced forces acting on a cart at rest).

Question 1c: Ideally, students will state that the forces are balanced because there is no change in upward or downward speed.

This scenario is likely to provoke some discussion, but should be resolved by reminding the class that when forces are balanced, motion (speed and/or direction of movement) does not change. This idea can be reinforced by reminding students of a previous example of horizontal forces and constant motion (e.g., video showing balanced forces producing no changes in the cart's motion in lesson U2C2 Exploration 2).

Question 1d: The two portions of this scenario require two different responses. First, forces are balanced when the beach ball is motionless. Then the forces must be unbalanced after the release because upward motion is starting



Science Vocabulary

The terms "**supporting force**" and "**buoyant force**" are introduced in this lesson. If students understand the meanings of these terms, it would be appropriate to add them to the word wall.

Making Sense

Your teacher will lead a class discussion about forces that act upward and downward on objects. Write answers to the following questions after each one is discussed.

1. For each of the following objects, state whether the upward and downward forces acting on it are balanced or unbalanced, and how you know.

   a) An airplane as it takes off.

   b) A book resting on a table.

   c) An elevator as it moves downward at a constant speed.

   d) A beach ball that is first held under water and then released.