# How Are Force, Mass, and Acceleration Related?

## Why?

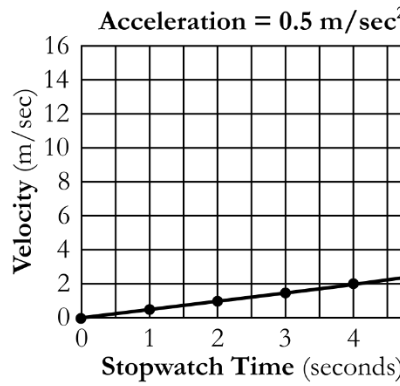
We have all pushed shopping carts, wagons, or toy cars. If we push for just a second and then let go, the object continues moving at a particular velocity. What if more people push the same object so the force increases? What if the object we are pushing has more mass? In this activity we will explore what happens in both these situations.

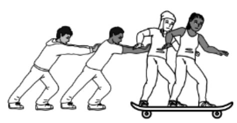
***As you work through the following questions, be sure to follow your team role(s).***

## Model 1 – Different numbers of people pushing two people on a skateboard

**Trial A**

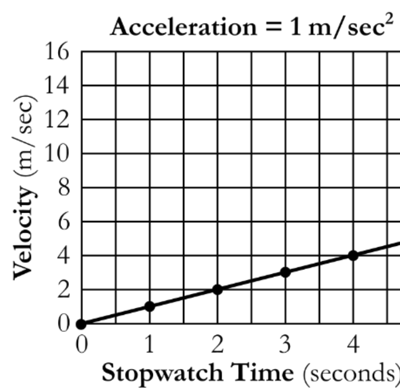
| Stopwatch Time (seconds) | Velocity (m/sec) |
|---|---|
| 0 | 0 |
| 1 | 0.5 |
| 2 | 1 |
| 3 | 1.5 |
| 4 | 2 |
| 5 | 2.5 |

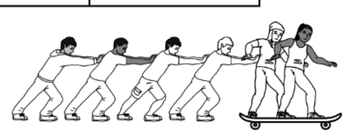


**Trial B**

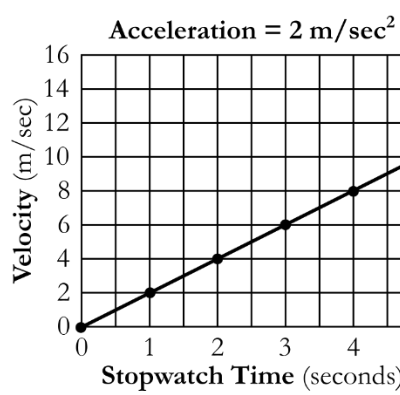
| Stopwatch Time (seconds) | Velocity (m/sec) |
|---|---|
| 0 | 0 |
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |



**Trial C**

| Stopwatch Time (seconds) | Velocity (m/sec) |
|---|---|
| 0 | 0 |
| 1 | 2 |
| 2 | 4 |
| 3 | 6 |
| 4 | 8 |
| 5 | 10 |



***Use the information in Model 1 to answer questions 1 – 8.***
***Reach agreement with your team before writing down your consensus answers.***

1. How many different trials are shown in Model 1?

2. How many people are standing on the skateboard in every trial?

3. How many people are pushing the skateboarders in each trial?

   a. Trial **A** includes ______ pusher(s).

   b. Trial **B** includes ______ pusher(s).

   c. Trial **C** includes ______ pusher(s).

## Read This!

| |
|---|
| Recall that we use the term **net force** to describe the overall pushing or pulling on an object. |

4. Which trial in Model 1 shows the **greatest force** acting on the skateboarders? **Explain** your answer. Include specific details from Model 1 in your explanation.

5. Look carefully at the data table and graph for **Trial A** in Model 1. Use either the data table or the graph to answer the following questions about Trial A.

   a. After one person pushes the skateboarders for 2 seconds, **how fast** will the skateboarders be moving? Circle your answer.

   0.5 m/sec 1.0 m/sec 1.5 m/sec 2.0 m/sec 2.5 m/sec

   b. If the pusher stops applying force to the skateboarders after 4 seconds, **how fast** will the skateboarders be moving?

   0.5 m/sec 1.0 m/sec 1.5 m/sec 2.0 m/sec 2.5 m/sec

STOP Check your team's answer to questions 4 and 5 with your teacher before you continue.

6. Create a data table to show how **amount of net force** affects the acceleration of an object. Use information from Model 1.

| **Trial** | **Amount of net force** (number of people pushing the skateboarders) | **Acceleration** (m/sec$^2$) (how much faster the skateboarders move as each second passes) |
|---|---|---|
| **A** | | |
| **B** | | |
| **C** | | |

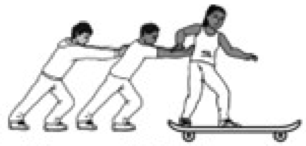
7. Complete the sentence below to describe how acceleration changes as you increase the amount of net force applied to an object. Use your data table from question 6.

As you <u>double</u> the **amount of net force** applied to an object, the acceleration of the object…

Send spies to check your team's answer to question 7 with two other teams before you continue.

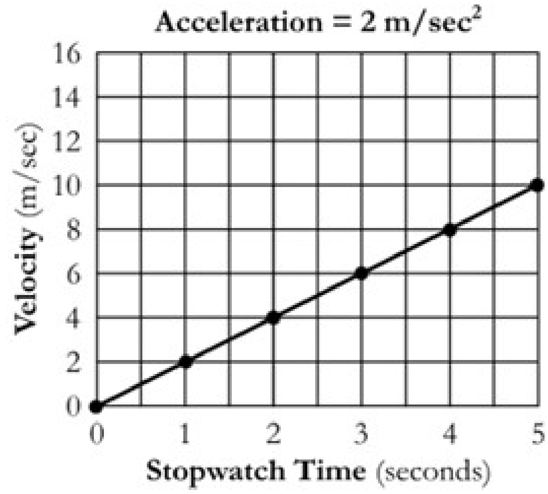
8. Look carefully at the acceleration values shown in Model 1. Discuss with your team. Predict the acceleration for **8 people pushing** the two skateboarders. Include the correct units.
**Explain** how you decided on your answer.

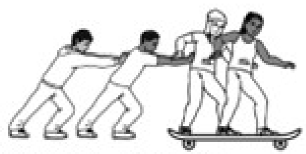
## Model 2 –
## Two people pushing different numbers of people on a skateboard



**Trial D**

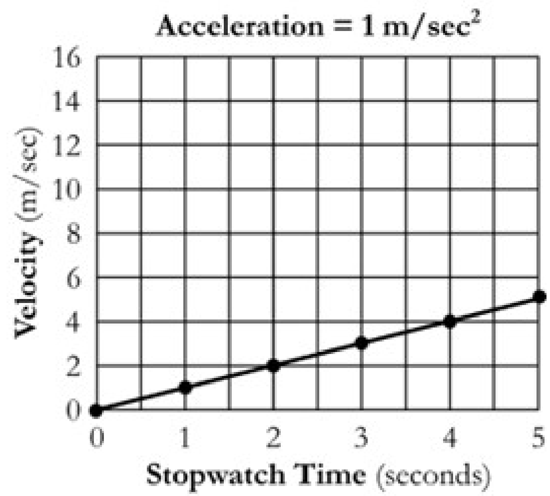
| **Stopwatch Time** (seconds) | **Velocity** (m/sec) |
|---|---|
| 0 | 0 |
| 1 | 2 |
| 2 | 4 |
| 3 | 6 |
| 4 | 8 |
| 5 | 10 |

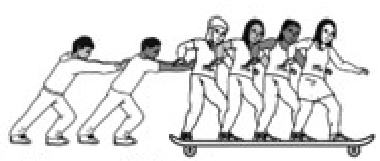


**Trial B**

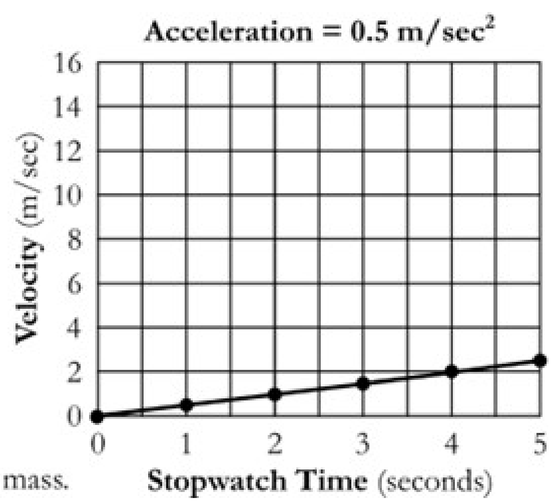
| **Stopwatch Time** (seconds) | **Velocity** (m/sec) |
|---|---|
| 0 | 0 |
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 4 |
| 5 | 5 |



**Trial E**

| **Stopwatch Time** (seconds) | **Velocity** (m/sec) |
|---|---|
| 0 | 0 |
| 1 | 0.5 |
| 2 | 1 |
| 3 | 1.5 |
| 4 | 2 |
| 5 | 2.5 |




In Model 2, we assume the skateboard has no mass.

***Use the information in Model 2 to answer questions 9 – 17.***
***Reach agreement with your team before writing down your consensus answers.***

9. How many different trials are shown in Model 2?

10. Which trial is the same as one shown in Model 1?

11. How many people are pushing the skateboarders in every trial?

12. How many people are standing on the skateboard in each trial?

a. Trial **D** includes ___________________ standing on the skateboard.

b. Trial **B** includes ___________________ standing on the skateboard.

c. Trial **E** includes ___________________ standing on the skateboard.

## Read This!

| |
|---|
| Recall that we use the term **mass** to describe the amount of stuff in an object. |

13. Which trial in Model 2 shows the **largest mass** on the skateboard? **Explain** your answer. Include specific details from Model 2 in your explanation. Assume that each person standing on the skateboard has a mass of 50 kg.

14. Look carefully at the data table and graph for **Trial D** in Model 2. Use either the data table or the graph to answer the following questions about Trial D.

a. After two people push the skateboarder for 2 seconds, **how fast** will the skateboarder be moving? Circle your answer.

2 m/sec 4 m/sec 6 m/sec 8 m/sec 10 m/sec

b. If the pushers stop applying force to the skateboarder after 4 seconds, **how fast** will the skateboarder be moving?

2 m/sec 4 m/sec 6 m/sec 8 m/sec 10 m/sec

STOP Send spies to check your team's answers to questions 13 and 14 with two other teams before you continue.

15. Create a data table to show how the **mass of an object** affects its acceleration.
Use information from Model 2.

| **Trial** | **Mass of object** (total kg – assume each person has a mass of 50 kg) | **Acceleration** (m/sec$^2$) (how much faster the skateboarders move as each second passes) |
|---|---|---|
| **D** | | |
| **B** | | |
| **E** | | |

16. Complete the sentence below to describe how acceleration changes as the mass of the object changes. Use your data table from question 15.

As you <u>double</u> the **mass** of an object being pushed by the same net force, the acceleration of the object…

17. Look carefully at the acceleration values shown in Model 2. Discuss with your team. Predict the acceleration for **8 people standing** on the skateboard. Include the correct units.
**Explain** how you decided on your answer.

Check your team's answer to questions 16 and 17 with your teacher before you continue.

## Read This!

Physicists use a unit called the **Newton** to measure the pushing or pulling force acting on an object. A Newton is abbreviated as **N**.

## Model 3 – How are force, mass, and acceleration related?

| **Situation** | **Net force** (N) | **Mass** (kg) | **Acceleration** ($m/sec^2$) |
|---|---|---|---|
| **F** | 50 | 100 | 0.5 |
| **G** | 100 | 100 | 1 |
| **H** | 200 | 100 | 2 |
| **I** | 400 | 200 | 2 |
| **J** | 600 | 300 | 2 |

***Use the information in Model 3 to answer questions 18 – 23.***
***Reach agreement with your team before writing down your consensus answers.***

18. Add the following abbreviations to the data table in Model 3. Write each abbreviation above the correct column.

| **Variable** | **Abbreviation** |
|---|---|
| Net force | $\mathbf{F_{net}}$ |
| Mass | **m** |
| Acceleration | **a** |

19. **Highlight** the headings of all columns in Model 3 that contain numerical values.

20. Discuss with your team. What patterns do you see among the **numbers within each row** of the data table in Model 3? You do not need to write anything down.

## Read This!

You may recall that mathematicians have different ways to write statements about multiplication. For instance, you can write the sentence "6 times 5 equals 30" in any of these three ways:

$6 \times 5 = 30$ or $6 \bullet 5 = 30$ or $(6)(5) = 30$

When mathematicians use symbols as placeholders for numbers, they also have different ways to write statements about multiplication. You can usually write the statement "X times Y equals Z" in any of these ways:

$X \times Y = Z$ or $X \bullet Y = Z$ or $(X)(Y) = Z$ or $XY = Z$

21. Have each member of your team choose a different trial in Model 3. Team members will use the number values from their chosen trial to test each of the equations below.
Determine whether each equation works to define the relationship among $\mathbf{F_{net}}$ and **m** and **a**.
If an equation works, the values on each side of the = sign will, indeed, be equal.

| **Possible equation** | **Equation with values substituted in** | **Does the equation define a valid relationship among the variables?** | |
|---|---|---|---|
| | | **Yes** | **No** |
| $\mathbf{F_{net} \bullet m = a}$ | | | |
| $\mathbf{F_{net} \bullet a = m}$ | | | |
| $\mathbf{F_{net} = m + a}$ | | | |
| $\mathbf{F_{net} = m \bullet a}$ | | | |
| $\mathbf{\frac{F_{net}}{a} = m}$ | | | |
| $\mathbf{\frac{F_{net}}{m} = a}$ | | | |

22. Look carefully at your answers to question 21.

a. Circle the **three mathematical equations** in the data table that are valid for showing the mathematical relationship among net force, mass, and acceleration.

b. Which of the three equations seems easiest to use? Write it here.

c. Explain why this equation seems easiest to use.

23. In physics there are many problems that explore the relationships among net force, mass, and acceleration. Use your ideas from question 22 to answer the following questions.

a. An object is traveling with an **acceleration** of 2 m/sec$^2$. The object has a **mass** of 40 kg. What amount of **net force** must be pushing or pulling the object?
Show your setup and calculations. Include the correct units for each number.

b. Imagine that you **keep the net force the same** but **increase the object's mass**. What will happen to the object's **acceleration**? Will acceleration increase, decrease, or remain the same? Explain your answer.

c. Imagine that you **keep the object's mass the same** but **increase the net force**. What will happen to the object's **acceleration**? Will acceleration increase, decrease, or remain the same? Explain your answer.

STOP Check your team's answer to question 23 with your teacher before you continue.

## What I Still Wonder…

24. Write one additional question you have about the relationships among net force, acceleration, and mass of a moving object.

# Extension Questions

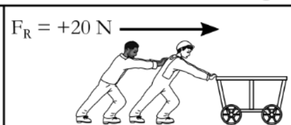
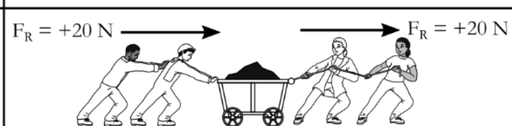
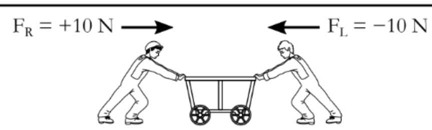
## Read This!

Before answering questions 25 and 26 you may want to check CP Activity 5 to review:
1. how to analyze a force vector diagram
2. the difference between balanced and unbalanced forces
3. the process of vector addition to calculate net force

## Read This!

One Newton is defined as the amount of force it takes to make a one-kilogram object move 1 meter/second faster every second.
A Newton is abbreviated as **N**. $1\ N = \frac{1\ \text{kilogram} \cdot 1\ \text{meter}}{\text{sec}^2}$

25. Fill in the empty boxes in the data table. Use your new concepts and skills to solve for the missing values.

| Trial | Diagram | Mass (kg) | Acceleration (m/sec$^2$) | Net Force (N) |
|---|---|---|---|---|
| **K** |   | 5 | | |
| **L** |   | 10 | | +40 |
| **M** |   | 5 | | |

**KEY**
− = Push or pull to the left + = Push or pull to the right

26. Look closely at your data table in question 25.

a. Circle the one example of **balanced forces** in the data table above.

b. What kinds of forces result in acceleration of an object – balanced or unbalanced forces?

27. Use the equation $\mathbf{F_{net} = m \bullet a}$ to solve the problems below. Include correct units for each number.

a. An object is traveling with an acceleration of 2 $m/sec^2$. The object has a mass of 40 kg. What amount of **net force** must be pushing or pulling the object?
Show your setup and calculations.

b. An object is traveling along at a steady velocity (the acceleration is 0 $m/sec^2$). The object has a mass of 20 kg. What amount of **net force** must be pushing or pulling the object?

c. A 10 kg object experiences a net force of 5 N pushing it.
What is the **acceleration** of the object?

d. An object is moving along with an acceleration of 30 $m/sec^2$.
If the net force pushing the object is 90 N, what is the **mass** of the object?

28. Look carefully at the vector diagram below. Use its information to complete questions a – e.

| Situation | Diagram | Mass (kg) | Acceleration ($m/sec^2$) | Net Force (N) |
|---|---|---|---|---|
| **N** |  | 15 | | −10 |

**KEY**

− = Push or pull to the left        + = Push or pull to the right

a. Calculate the **acceleration** for the cart shown above. Show your work.

b. Discuss with your team. What does the negative value in acceleration seem to mean, based on the force vector diagram? What might be confusing about your answer?

c. Are the forces applied to the cart balanced or unbalanced? Explain.

d. What happens to the cart as a result of the applied force?
Answer in terms of the object's velocity.

e. What other forces does your team think might be acting on the object?