Science Learning Packet

PHYS B:

Forces Unit Packet

Science learning activities for SPS students during the COVID-19 school closure.

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Due to the COVID-19 closure, teachers were asked to provide packets of home activities. This is not intended to take the place of regular classroom instruction but will help supplement student learning and provide opportunities for student learning while they are absent from school. Assignments are not required or graded. Because of the unprecedented nature of this health crisis and the District’s swift closure, some home activities may not be accessible.

If you have difficulty accessing the material or have any questions, please contact your student’s teacher.
Should seatbelts be required on school buses?

The topic of mandating seat belts on school buses has been up for debate in the United States for years. Some states have already mandated seat belts, but why are other states reluctant to require seat belts in school buses? SEAT BELTS SAVE LIVES. So why aren’t seat belts required on school buses? Perhaps it isn’t as straightforward of a question as one might initially think. Throughout Chapter F, you will be able to apply physics principles to seat belts and passenger safety. By the end of the chapter you will use your understanding of forces and motion to make a recommendation about whether seat belts should be mandated on school buses.

Before getting started with the chapter investigations:

☑️ Watch the clip from the Today Show about seat belts in School Buses: This video is a little bit graphic; if you have any trauma around car or bus crashes, please don’t watch it.

https://www.today.com/video/feds-every-child-should-have-a-seat-belt-on-the-school-bus-563393603940

☑️ Read the Newspaper article Required seat belts on school buses – Yay or Nay?

☑️ Respond to the Launching Questions

Launching Questions:
1. In the table below, list some of the costs and benefits of mandating seat belts in school buses.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

2. How do you think a seat belt changes the way(s) that a passenger’s body moves during a collision?

3. As of May 2018, seat belts were only mandated in school buses in eight states: Arkansas, California, Florida, Louisiana, Nevada, New Jersey, New York, and Texas.
   a. Does your state mandate seat belts in school buses?

   b. What has been your experience with wearing a seat belt on a school bus?

4. What questions or curiosities do you have about seat belts in general?
Required seat belts on school buses – Yay or Nay?

By ROBERT BOBSON III
Residents of Pleasantville were in an uproar about school bus safety in the last week and took their concerns to the city council. Although the National Transportation Safety Board (NTSB) recommended in 2015 that all new school buses be equipped with lap and shoulder belts, few states have worked this recommendation into state policy, and a crash in Pleasantville's downtown area last week has stoked parents' fears. The accident occurred when the driver lost control of the bus on a large patch of black ice, colliding head-on with a power line post only two blocks away from City Hall.

While no deaths were reported, four students were taken to the hospital for urgent care, and others were traumatized by their experience – one student later remarked that "suddenly, everyone was thrown out of their seats."

Mary-Sue Bobsey, mother of two and a bystander near the crash site, was upset and called for the council to do its duty: "I just don't understand. If we want our kids to use seat belts in the car, why not in the school bus too? The city council needs to do more."

However, solutions to the problem may not be so clear-cut. When asked for comment, City Council President Wilbur Bobbington remarked, "Of course we want to safeguard our kids. What people don't understand is that there's more to this issue, and retrofitting all our buses may not be the best solution."

ARE SCHOOL BUSES REQUIRED TO HAVE SEATBELTS?
U.S. federal regulations only mandate that buses under 10,000 pounds require lap-shoulder seat belts. Depending on what state you live in, your local school buses may require seat belts, but not all states agree on what kind should be required. For instance, California and Texas require 3-point seat belts (like those in cars), while Florida, Louisiana, New York, and New Jersey only require lap seat belts. According to the National Conference of State Legislatures (NCSL), dozens of states have recently introduced bills regarding school bus seat belts.

WHAT'S THE DEBATE?
According to the National Highway Traffic Safety Association (NHTSA), school buses weighing more than 10,000 pounds are among the safest vehicles on the road (see right column). It is argued that installing seat belts in the nation's school bus fleet would be prohibitively expensive, and that doing so would not meaningfully increase safety ratings. Other groups, such as the National Coalition for Seatbelts on School Buses, argue that the financial investment is warranted to increase safety, and that having seat belts on buses would help reinforce good habits in students.

DO SEATBELTS INCREASE SAFETY IN SCHOOL BUSES?
There is much debate surrounding the effectiveness of seat belts in school buses. Research conducted by a provider of school bus seat belts in the US, indicates that lap-shoulder belts can reduce injury and death by as much as 50%. Opponents of mandatory seat belts argue that depending on the age of the students, it can be even more dangerous to be in an accident and not be able to remove the seat belt. Furthermore, the NHTSA argues that more massive school buses are purposefully designed to reduce the impact from head-on collisions and therefore, seat belts should not be required in all cases. Proponents of seat belt installation argue that these measures only protect against collisions from the front, and that seat belts would also protect students in lateral and rollover collisions, which are statistically more dangerous.

According to the NCSL, 50% of the nation's K-12 student population takes the bus to school.

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**The Top Things you should know about buckling up**

Excerpts from an article by NHTSA

ONE Buckling up is the single most effective thing you can do to protect yourself in a crash

TWO Air bags are designed to work with seat belts, not replace them

THREE Guidelines to buckle up safely:

- The lap belt and shoulder belt are secured across the pelvis and rib cage, which are better able to withstand crash forces than other parts of your body.
- Place the shoulder belt across the middle of your chest and away from your neck.
- The lap belt rests across your hips, not your stomach.
- NEVER put the shoulder belt behind your back or under an arm.

**GLOBAL SEATBELT STATISTICS FROM THE WORLD HEALTH ORGANIZATION**

Wearing a seat-belt reduces the risk of a fatal injury by:

Up to **50%** for front seat occupants

Up to **75%** for rear seat occupants

Seat-belt laws should cover both front and rear seat occupants

111 countries have comprehensive seat-belt laws covering all car occupants.

This covers 4.8 billion people... or 69% of the world's population

To effectively increase seat-belt wearing rates, legislation must be supported with strong and sustained police enforcement:

Only a quarter of all countries report good enforcement of their seat-belt laws.

Countries with a national seat-belt law covering all car occupants

References:

PURPOSE:
In Chapter E you explored how to describe pushes and pulls in terms of energy transfers between objects. For example, when discussing a soccer player kicking a ball, you may have explained: energy is transferred from the player’s foot to the ball, causing the ball to increase in speed and kinetic energy. Scientists often use a different way of describing what causes motion to change – not in terms of energy, but in terms of forces.

Key Question: How do forces affect stationary objects and objects in motion?
INITIAL IDEAS: Complete the following questions individually in your lab notebook:

1. A student pushes a cart for the entire length of the track. Draw a velocity-time graph for the motion of the cart from when it was stationary until it reaches the end of the track. Describe how forces affect the motion of the cart.

2. The velocity-time graph on the right is for a cart that is given a quick tap from a hand. Draw the velocity-time graph in your laboratory notebook. Circle all the places where you think a force is acting on the cart to affect its motion. For each force you circled:
   a. Name the force.
   b. Describe the force.
   c. Describe how each force is affecting the cart’s motion.
As you go through the following experiments, fill in claims and evidence on this learning tracking tool:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Claim: What did we figure out?</th>
<th>Evidence: What did we do?</th>
<th>Self-Assess: Where am I with my understanding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: What happens to a cart’s speed when a constant strength push is continuously applied?</td>
<td>When a constant push is applied to an object, the object...</td>
<td>When we pushed the cart with a constant force from the fan, the cart...</td>
<td></td>
</tr>
<tr>
<td>#2: How do forces affect velocity?</td>
<td>When a force pushes an object the same direction it's moving... When a force pushes an object in the opposite direction it's moving... When an object is moving with NO forces on it...</td>
<td>[Sketch three velocity time graphs here]:</td>
<td></td>
</tr>
<tr>
<td>F.1 Math Exploration #1: How can you find acceleration from a velocity-time graph?</td>
<td>Acceleration can be found by... The steeper a line on a velocity-time graph...</td>
<td>[sketch how acceleration can be found on a graph]</td>
<td></td>
</tr>
<tr>
<td>F.1 Math Exploration #2: How do you find acceleration for an object slowing down?</td>
<td>When an object is slowing down, the acceleration...</td>
<td>[sketch graphs for objects slowing down while moving in both the positive and negative directions]</td>
<td></td>
</tr>
</tbody>
</table>
EXPERIMENT #1: WHAT HAPPENS TO A CART’S SPEED WHEN A CONSTANT STRENGTH PUSH IS CONTINUOUSLY APPLIED?

Step 1: Imagine that you used your finger to apply a constant strength push to a cart for the entire length of the track.

Q1. How do you think the cart will move when you push it: speed up, move at a constant speed, or something else?

Step 2: Test your prediction. Place the cart near one end of the track (or table). Using one finger, push the cart along the track (push the back of the cart as shown on the right, do not push down from the top of the cart). Keep your finger touching the cart the whole time and try to maintain a constant strength push as the cart moves. Each group member must try this.

Q2. How does the cart move when you push it? Q3. Were you able to exert a constant strength push on the cart the whole time?

See video here

Step 3: You probably noticed that it was challenging for your finger to keep up with the cart while you applied a constant strength force. For the next steps, you will use a fan to apply a constant strength force to the cart. Attach the fan to the cart.

Step 4: Place the cart on the track in front of the motion sensor so the fan pushes the cart away from the sensor. Begin collecting velocity-time data and then turn on the fan and let go of the cart (do not push or pull the cart).

See video here

Step 5: Draw a velocity-time graph for the motion of the cart. Q4. How does a constant strength force affect the motion of a cart?
EXPERIMENT #2: HOW DO FORCES AFFECT VELOCITY?

Step 1: Go to: http://phet.colorado.edu/en/simulation/forces-1d
- Click play button.
- Click the buttons Graph Applied Force and Graph Velocity.
- Take 5 minutes to experiment with the simulator.

Step 2: On the toolbar on the right of the simulator, uncheck the box Show Total Force and turn friction off. In this experiment you are only observing how horizontal forces affect motion on a frictionless surface. You will observe the effect of friction in an upcoming activity.

Step 3: Using the computer mouse, have the person in the simulation push the filing cabinet in the following ways:
- Push to the right until the cabinet starts to move.
- Once the cabinet starts to move, quickly let go.
- While the cabinet is moving, push opposite to the direction it is moving (and then quickly let go).

If you don't have java on your computer, see the video here

Step 4: Draw the velocity-time graph and the applied force-time graph.

Q1. According to the applied force-time graph, is a horizontal force acting on the filing cabinet after the person stopped pushing it?

Q2. How can you determine whether a horizontal force is acting on the filing cabinet by looking at its velocity-time graph?

Q3. According to the velocity-time graph, after the person stopped pushing the filing cabinet it continued to move at a constant speed. How can it be that the cabinet continues to move even though there is no force pushing it (use energy ideas to support your answer)?

Step 5: In your lab notebook, complete the statements below about force and motion.
- When a force is applied in the same direction an object is moving, the object will ____________________.
- When a force is applied in the opposite direction an object is moving, the object will ____________________.
- When an object is moving and no forces are acting on the object, the object will ____________________.
Step 6: The velocity-time graph generated by a motion sensor (shown on the right) is different from the one you just observed because after the hand is released, the cart is slowing down slightly.

Q4. Use ideas from the previous experiment about how force affects motion to describe why the cart slowed down.

Q5. Would you say that friction is a force? Describe your reasoning.
1. On the axes, graph the velocity of:
   a. A hockey puck that is pushed by a constant-strength force (applied only for 1 second).
   b. A hockey puck that is continuously pushed by a constant-strength force (for the entire time of the graph).
   c. Describe how and why the two graphs are different.

2. What evidence suggests:
   a. A force is acting in the same direction that an object is moving?
   b. A force is acting in the opposite direction that an object is moving?
   c. Friction is a force?

3. Suppose that while a cart was being pushed along the track by a fan, a wire suddenly broke and the fan stopped spinning.
   a. What do you think would happen to the speed of the cart? Describe your reasoning in terms of force and energy (graphs and diagrams may be helpful).
   b. Draw a diagram that shows the force acting on the cart and how the cart is moving.

4. For the velocity-time graph (shown below), draw a force-time graph for the cart. Hint: make sure to pay attention to the time(s) when you think a force is acting.

5. Three students were discussing an experiment in which a cart was given a quick tap and then the hand let go of the cart. They are discussing why they think the cart continues to move after it was released from the hand. Read their comments.
   How would you respond to these students in the discussion? Be sure to include evidence.

6. Describe why objects slow down due to friction, in terms of both energy transfer and force.
F.1 Scientists’ Ideas Reading

Instructions: As you read the Scientists’ Ideas, think about how they relate to the evidence you collected in the activity.

F.1a Force diagrams: Force diagrams use arrows to represent the forces acting on an object. The arrows show both the strength of the force and the direction it was applied; therefore, forces can be represented by vectors.

Just like we can describe pushes and pulls using energy diagrams, we can also draw a diagram to help us represent forces. These force diagrams are labeled to show where the force came from. The direction of the arrow represents the direction the force was applied. The length of the arrow shows the strength of the force: the longer the arrow, the stronger the force. Recall from Chapter E that the length of the arrow represents the magnitude (relative strength of the force). When you only consider the strength of a force and not the direction the force is applied, you are referring to the magnitude of the force. The force diagrams below show one of the objects involved in the interaction, the object applying the force is only mentioned in the label of the force arrow.

F.1b Forces cause changes in speed: Change in an object’s speed is evidence that a force is acting on the object.

When a force acts in the same direction as motion, the object will speed up. When a force acts in the opposite direction as motion, the object will slow down.

F.1c No force, no change in speed: Without a force acting on an object, the object will not change speed.

Scientists summarize the motion of objects without forces acting on them in the following ways:

- When no forces act on a stationary object, it will stay stationary.
- When no forces act on a moving object it will continue to move at a constant speed.
to move at a constant speed.

F.1: Forces and Motion

**Force of friction:** In the absence of any other horizontal forces acting on a moving object, friction will cause the object to slow down.

When an object is moving, friction always acts in the opposite direction as the velocity of the object. As long as no other horizontal forces are acting, friction will cause the object to slow down. Since friction causes a change in speed, this is evidence that friction is a force. The force vector for friction ($\vec{F}_{friction}$) is always in the opposite direction of the velocity vector when an object is moving.

It is challenging to think about a situation where friction is completely removed because as long as two objects are in contact, friction will be present. If it were possible to remove frictional forces once an object is already in motion, the object would move at a constant speed (after an initial push). Remember that scientists use the phrase “negligible friction” to indicate that friction is present, but it is so small in comparison to the other forces (pushes and pulls) that it can be ignored.

**Force-time graphs:** Force-time graphs express the time intervals when a force is acting on an object and the magnitude of the force.

The force-time and velocity-time graphs (below) confirm the idea that the force was only applied during the time intervals when the speed of the cart increased.

**Energy transfers when force is applied:** When a force acts on an object, energy is either transferred into or out of the object. Forces do not transfer.

This idea can also be thought about in terms of energy:

- When a force acts in the same direction an object is moving, the object’s speed increases and energy is transferred into the object (the object receives energy).
- When a force acts in the opposite direction an object is moving, the object’s speed
• When a force acts in the same direction an object is moving, the object's speed increases and energy is transferred into the object (the object receives energy).

• When a force acts in the opposite direction an object is moving, the object's speed decreases and energy is transferred out of the object (the object gives energy).

There are two different ways/models to explain why an object slows down:

**In terms of force:** The slowing of an object is associated with a force that acts in the direction opposite of motion. Friction is a force that acts in the direction opposite of motion when an object is in contact with a surface.

**In terms of energy:** The slowing of an object is associated with the decrease in kinetic energy. When a moving object is in contact with a surface, energy is transferred from the object to the surface and surroundings, and the object slows down.

Think about a stationary cart that is given a quick push with a hand and starts moving. Shown below is a velocity-time graph and a force-time graph: before the interaction, during the interaction, and after the interaction. Force and energy diagrams for each of these times are shown.

**Velocity-Time and Force-Time Graphs:**

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**Energy and Force Diagrams:**
F.1: Forces and Motion

Respond to the following questions **individually** in your lab notebook:

1. Summarize how forces affect an object’s speed by completing the statements below:
   a. When a **force** acts on a stationary cart, the cart will...
   b. When a **force** acts in the **same direction** as the motion of a moving cart, the cart will...
   c. When a **force** acts in the **opposite direction** as the motion of a moving cart, the cart will...
   d. When **no forces** act on a stationary cart, the cart will...
   e. When **no forces** act on a moving cart, the cart will...

2. Draw a **force-time graph** for the velocity-time graph that is shown on the right.

3. Is friction considered a force? Describe why or why not using evidence.

4. Use the force diagrams below to determine whether the cart is not moving, moving at a constant speed, speeding up, or slowing down.

   a. ![Diagrams](image)
   b. ![Diagrams](image)
   c. ![Diagrams](image)
   d. ![Diagrams](image)
   e. ![Diagrams](image)
   f. ![Diagrams](image)

5. Draw a **force diagram** for a cart moving to the right that is given a push in the same direction it is moving. Label the force arrow.

6. Draw a **force diagram** for a stationary cart that is hit from the left by a moving cart. Label the force arrow.

7. Is energy transferred **during** or **after** the time when the force is applied to an object?
6. Draw a force diagram for a stationary cart that is hit from the left by a moving cart. Label the force arrow.

7. Is energy transferred during or after the time when the force is applied to an object (or a combination of these)? Assume friction is negligible. Describe your thinking.

8. When a force acts on the cart in the same direction as its motion, is the cart the energy giver or the energy receiver? Describe using evidence.

9. When a force acts on the cart in the opposite direction to its motion, is the cart the energy giver or the energy receiver? Describe using evidence.

10. Think about a moving cart (launched cart) that hits a stationary cart (target cart). Complete the following for this scenario:

   a. A velocity-time graph for the target cart.
   b. A force-time graph for the target cart.
   c. An energy diagram for the energy transfer between the two carts.
   d. A force diagram for the launched cart during the collision.
   e. A force diagram for the target cart during the collision.
EXPLORATION #1: HOW CAN YOU FIND ACCELERATION FROM A VELOCITY-TIME GRAPH?

The graph on the right shows the velocity and time for a cart that is pushed continuously by a fan (like you explored in this activity).

Step 1: Use the graph to answer these questions:

Q1. What is the velocity at t=2 s?

Q2. What is the velocity at t=4 s?

Q3. How much does the velocity increase from t=2 s to t=4 s?

Q4. How much time passed from t=2 s to t=4 s?

Step 2: Use the velocity time graph and your responses to the previous questions to complete a table (like the one shown below) in your laboratory notebook.

<table>
<thead>
<tr>
<th></th>
<th>t=2s to 4s</th>
<th>t=0s to 3s</th>
<th>t=2s to 3s</th>
<th>t=1s to 5s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial velocity</td>
<td>(Q1)</td>
<td>0 m/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final velocity</td>
<td>(Q2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in velocity</td>
<td>(Q3)</td>
<td>2 m/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time that passed</td>
<td>(Q4)</td>
<td></td>
<td>4s</td>
<td></td>
</tr>
</tbody>
</table>

Step 3: Complete the following sentences:
From 2 seconds to 4 seconds, the velocity increases by _______ m/s in _______ seconds.
From 0 seconds to 3 seconds, the velocity increases by _______ m/s in _______ seconds.
From 2 seconds to 3 seconds, the velocity increases by _______ m/s in _______ seconds.
From 1 second to 5 seconds, the velocity increases by _______ m/s in _______ seconds.

Q5. Based upon how much the velocity increased from 2 to 4 seconds (in a total of 2 seconds), how much did the velocity increase each second?

Q6. Show the steps you used to answer the previous question.

Step 4: Find how much the velocity increases in one second for each time interval:
From 0 seconds to 3 seconds, the velocity increases by _______ m/s every second.
From 2 seconds to 3 seconds, the velocity increases by _______ m/s every second.
From 1 second to 5 seconds, the velocity increases by _______ m/s every second.

Q7. What do you notice about the increase in velocity every second for all three of the time intervals?

Q8. If the graph was not a straight line, do you think you would see the same pattern that you observed in question 7? Draw an example and discuss it with your group.

You have just calculated how fast an object’s velocity is increasing in one second. Scientists call this acceleration. The acceleration of an object is the amount that its velocity increases (or decreases) every second.

You found acceleration by finding how much the velocity increased/decreased and dividing it by the amount of time that passed.

\[
\text{Acceleration} = \frac{\text{Amount velocity increased/decreased}}{\text{Amount of time passed}}
\]

Q9. Based upon the way you calculated acceleration, what do you think the units should be? Describe your reasoning.

When scientists refer to the amount the velocity increases or decreases, they say “the change in velocity.” They abbreviate change in velocity with \( \Delta \vec{v} \). You can calculate the amount that the velocity changes \( (\Delta \vec{v}) \) by finding the difference between the velocity at the end of the time interval (final velocity, \( \vec{v}_f \)) and the velocity at the beginning of the time interval (initial velocity, \( \vec{v}_i \)).

\[
\Delta \vec{v} = \vec{v}_f - \vec{v}_i
\]

Q10. Using the equation for change in velocity, if \( \vec{v}_i = 5 \text{ m/s} \) and \( \vec{v}_f = 3 \text{ m/s} \), is the change in velocity positive or negative? Did the velocity increase or decrease?
EXPLORATION #2: HOW DO YOU FIND THE ACCELERATION FOR AN OBJECT THAT IS SLOWING DOWN?

The velocity-time graph (on the right) represents the motion of a cart.

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**Step 1: Analyze the graph.**

Q1. By looking at the graph, determine whether the object is speeding up, slowing down or moving at a constant speed during the following time intervals:

- $0 \text{ s} - 2 \text{ s}: \underline{\hspace{2cm}}$
- $2 \text{ s} - 4 \text{ s}: \underline{\hspace{2cm}}$
- $4 \text{ s} - 6 \text{ s}: \underline{\hspace{2cm}}$
- $6 \text{ s} - 8 \text{ s}: \underline{\hspace{2cm}}$

**Step 2: The tables below summarize information from the graph above. Analyze the tables and use them to respond to the following questions.**

**Q2.** By looking at the tables, determine whether the object is speeding up, slowing down or moving at a constant speed during the following time intervals:

- $0 \text{ s} - 2 \text{ s}: \underline{\hspace{2cm}}$
- $2 \text{ s} - 4 \text{ s}: \underline{\hspace{2cm}}$
- $4 \text{ s} - 6 \text{ s}: \underline{\hspace{2cm}}$
- $6 \text{ s} - 8 \text{ s}: \underline{\hspace{2cm}}$

**Q3.** Evaluate the acceleration values in the table. Summarize how you can tell (by looking at a velocity-time graph) whether the acceleration is

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<table>
<thead>
<tr>
<th>$t = 0 \text{ s}$ to $t = 2 \text{ s}$</th>
<th>$t = 2 \text{ s}$ to $t = 4 \text{ s}$</th>
<th>$t = 4 \text{ s}$ to $t = 6 \text{ s}$</th>
<th>$t = 6 \text{ s}$ to $t = 8 \text{ s}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Velocity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>$0 \text{ m/s}$</td>
<td>$8 \text{ m/s}$</td>
<td>$8 \text{ m/s}$</td>
</tr>
<tr>
<td>Final</td>
<td>$8 \text{ m/s}$</td>
<td>$8 \text{ m/s}$</td>
<td>$0 \text{ m/s}$</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$0 \text{ s}$</td>
<td>$2 \text{ s}$</td>
<td>$4 \text{ s}$</td>
<td>$6 \text{ s}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$t = 0 \text{ s}$ to $t = 2 \text{ s}$</th>
<th>$t = 2 \text{ s}$ to $t = 4 \text{ s}$</th>
<th>$t = 4 \text{ s}$ to $t = 6 \text{ s}$</th>
<th>$t = 6 \text{ s}$ to $t = 8 \text{ s}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta v = \vec{v}_f - \vec{v}_i$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$8 - 0 = 8 \text{ m/s}$</td>
<td>$8 - 8 = 0 \text{ m/s}$</td>
<td>$0 - 8 = -8 \text{ m/s}$</td>
<td>$-8 - 0 = -8 \text{ m/s}$</td>
</tr>
<tr>
<td>$\Delta t = t_f - t_i$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2 - 0 = 2 \text{ s}$</td>
<td>$4 - 2 = 2 \text{ s}$</td>
<td>$6 - 4 = 2 \text{ s}$</td>
<td>$8 - 6 = 2 \text{ s}$</td>
</tr>
<tr>
<td>$\vec{a} = \frac{\Delta v}{\Delta t}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\frac{8 \text{ m/s}}{2 \text{ s}} = 4 \text{ m/s}^2$</td>
<td>$\frac{0 \text{ m/s}}{2 \text{ s}} = 0 \text{ m/s}^2$</td>
<td>$\frac{-8 \text{ m/s}}{2 \text{ s}} = -4 \text{ m/s}^2$</td>
<td>$\frac{-8 \text{ m/s}}{2 \text{ s}} = -4 \text{ m/s}^2$</td>
</tr>
</tbody>
</table>
positive, negative, or zero.

Q4. Describe how acceleration was calculated for each time interval using velocity and time values.

Q5. What is the sign (+ or -) of the acceleration when \( v_f \) is less than \( v_i \) (\( v_f < v_i \))?

Q6. Does negative acceleration always mean that the object is slowing down? Give an example from the graph and table provided in Steps 1 and 2.

**Step 3:** Look at the graph with your group members. Predict when you think the acceleration is positive and when the acceleration is negative. Record your ideas.

![Velocity-Time Graph](image)

**Step 4:** Copy the two data tables below in your lab notebook and use the graph to complete the tables.

<table>
<thead>
<tr>
<th>( t=____ ) s to ( t=____ ) s</th>
<th>( t=____ ) s to ( t=____ ) s</th>
<th>( t=____ ) s to ( t=____ ) s</th>
<th>( t=____ ) s to ( t=____ ) s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>Final</td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Initial</td>
<td>Final</td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td><strong>Velocity</strong></td>
<td>( ____ ) m/s</td>
<td>( ____ ) m/s</td>
<td>( ____ ) m/s</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>( ____ ) s</td>
<td>( ____ ) s</td>
<td>( ____ ) s</td>
</tr>
</tbody>
</table>

\[ \Delta v = v_f - v_i \]

\[ \Delta t = t_f - t_i \]

\[ a = \frac{\Delta v}{\Delta t} \]

Q7. When are the acceleration values positive and the object is speeding up? When are the acceleration values positive and the object is slowing down?
**F.1 Mathematical Ideas Reading**

*Instructions: Read the Mathematical Ideas, paying careful attention to each key idea.*

**F.1g** Acceleration can be determined from a velocity-time graph: Acceleration is the rate that the velocity changes (speeding up or slowing down).

In everyday language, the word “acceleration” is typically used when an object speeds up, and the word “deceleration” is used when an object slows down. In physics, we only need one word, **acceleration**, because the acceleration can be positive or negative. Positive acceleration means that the final velocity is represented by a larger number than the initial velocity. Negative acceleration means that the final velocity is a smaller number than the initial velocity.

**F.1h** Calculating acceleration:

Acceleration is the change in velocity ($\Delta \vec{v}$) divided by the amount of time that passed ($\Delta t$).

$\Delta \vec{v}$ is calculated by subtracting the initial velocity from the final velocity, and $\Delta t$ is calculated by subtracting the initial time from the final time.

$$ \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \frac{\Delta \vec{v}}{\Delta t} $$

To calculate **acceleration**, divide the change in velocity by the amount of time that passed. The next example shows how to calculate the acceleration from velocity and time values using a velocity-time graph.
Mathematical Models

**Question:** Use the velocity time graph (on the right) to calculate the acceleration:

a. From 0 s to 5 s
b. From 5 s to 10 s

From \( t = 0 \text{ s to } 5 \text{ s} \):
\[
\ddot{a} = \frac{20 \text{ m/s} - 60 \text{ m/s}}{5 \text{ s} - 0 \text{ s}} = \frac{-40 \text{ m/s}}{5 \text{ s}} = -8 \text{ m/s}^2
\]

From \( t = 5 \text{ s to } 10 \text{ s} \):
\[
\ddot{a} = \frac{60 \text{ m/s} - 20 \text{ m/s}}{10 \text{ s} - 5 \text{ s}} = \frac{40 \text{ m/s}}{5 \text{ s}} = 8 \text{ m/s}^2
\]

**Sign of acceleration:** Negative acceleration does not always mean slowing down. Positive acceleration does not always mean speeding up.

Mathematically speaking, the acceleration is negative when the final velocity is less than the initial velocity. This is because when subtracting a larger number from a smaller number, you get a negative number. Similarly, acceleration is positive when the final velocity is larger than the initial velocity. This is because when subtracting a smaller number from a larger number, you get a positive value.

The examples below show how an object can slow down or speed up with both negative and positive accelerations.

**EXAMPLE**

If an object **slows down** from 8 m/s to 4 m/s in 2 s, acceleration is calculated:
\[
\Delta \ddot{v} = \ddot{v}_f - \ddot{v}_i = 4 - 8 \text{ m/s} = -4 \text{ m/s}
\]
\[
\Delta \dddot{t} = \dddot{t}_f - \dddot{t}_i = 2 \text{ s}
\]
\[
\ddot{a} = \frac{\Delta \ddot{v}}{\Delta \dddot{t}} = \frac{-4 \text{ m/s}}{2 \text{ s}} = -2 \text{ m/s}^2
\]

If an object **speeds up** from 4 m/s to 8 m/s in 2 s, acceleration is calculated:
\[
\Delta \ddot{v} = \ddot{v}_f - \ddot{v}_i = 8 - 4 \text{ m/s} = 4 \text{ m/s}
\]
\[
\Delta \dddot{t} = \dddot{t}_f - \dddot{t}_i = 2 \text{ s}
\]
The example below shows how to calculate acceleration from velocity and time values on a velocity-time graph when the velocities are negative.

**Question:** Use the velocity-time graph (on the right) to calculate the acceleration:

a. From 0 s to 3 s
b. From 3 s to 10 s

From $t = 0$ s to 3 s:

\[
\begin{align*}
\Delta v &= \vec{v}_f - \vec{v}_i = 8 - 4 \text{ m/s} = 4 \text{ m/s} \\
\Delta t &= \vec{t}_f - \vec{t}_i = 2 \text{ s} \\
\vec{a} &= \frac{\Delta \vec{v}}{\Delta \vec{t}} = \frac{4 \text{ m/s}}{2 \text{ s}} = 2 \text{ m/s}^2
\end{align*}
\]

From $t = 3$ s to 10 s:

\[
\begin{align*}
\Delta v &= \vec{v}_f - \vec{v}_i = -8 - (-4) \text{ m/s} = -4 \text{ m/s} \\
\Delta t &= \vec{t}_f - \vec{t}_i = 2 \text{ s} \\
\vec{a} &= \frac{\Delta \vec{v}}{\Delta \vec{t}} = \frac{-4 \text{ m/s}}{2 \text{ s}} = -2 \text{ m/s}^2
\end{align*}
\]
MATHEMATICAL MODELS: PRACTICE

Respond to the following questions in your laboratory notebook. Show your work.

Support Questions: The first question includes fill-in-the-blank supports to help you learn how to set up the problems. If you already feel comfortable solving these problems, consider trying to solve them without using the fill-in-the-blank supports. You can check your work using the supports.

Use the velocity-time graph below to answer the following questions:

1. What is the acceleration from 0 s to 7 s?

\[ \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \frac{\Delta \vec{v}}{\Delta t} \]

\[ t_f = \underline{____} \quad (\text{final time?}) \quad t_i = \underline{____} \quad (\text{initial time?}) \]

\[ \vec{v}_f = \underline{____} \quad (\text{velocity at 7 seconds?}) \quad \vec{v}_i = \underline{____} \quad (\text{velocity at 0 seconds?}) \]

\[ \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \frac{m/s - m/s}{s - s} = \frac{m/s}{s} = \underline{____} \quad m/s^2 \]
2. What is the acceleration from 7 s to 9 s?

\[
\begin{align*}
\Delta a &= \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \\
&= \frac{\text{m/s}}{\text{s}} - \frac{\text{m/s}}{\text{s}} = \frac{\text{m/s}}{\text{s}} = \_\_\_ m/\text{s}^2
\end{align*}
\]

3. Use the velocity-time graph on the right to calculate the acceleration during the time intervals below:

a. 0 s to 2 s
b. 2 s to 6 s
c. 6 s to 10 s

4. What is the acceleration of an object that is moving at a constant speed?

5. Use the velocity-time graph on the right to answer the following questions:

a. What is the acceleration from t=0 s to t=2 s? Is this a speeding up or slowing down motion?

b. What is the acceleration from t=2 s to t=5 s? Is this a speeding up or slowing down motion?

c. What is the acceleration from t=5 s to t=10 s? Is this a speeding up or slowing down motion?

6. Compare your acceleration values in the previous question. Now evaluate the graph for velocity-time. In what two situations does an object have a negative acceleration?
6. Compare your acceleration values in the previous question. Now evaluate the graph for velocity-time. In what two situations does an object have a negative acceleration?

7. An object can have a positive acceleration when it is speeding up in the positive direction of the number line. What is another way an object can have a positive acceleration?

8. Use the velocity-time graph on the right to answer the following questions:
   a. In which time intervals is the acceleration (a) Positive, (b) Negative, (c) Zero?
   b. Calculate the acceleration for each of the time intervals you selected.

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Mathematical Models

F.1: Forces and Motion

Challenge Yourself! These problems are about the same mathematical ideas, but are more challenging. Respond to them in your laboratory notebook and show your work.

1. Write a step-by-step guide to help another student find the acceleration using velocity-time data. Feel free to use pictures.

2. Describe a situation in which an object that has a positive acceleration slows down.

3. A car has an acceleration of 2 m/s². The car started at a speed of 16 m/s. What is the car’s speed after 3 seconds? Hint: solve for \(v_f\).

4. A car is initially moving at 30 meters per second. The driver slams on the brakes and stops in 2 seconds.
   a. What is the acceleration of the car?
   b. If the car stopped in 4 seconds, rather than 2 seconds, what would be the acceleration?
   c. On one set of axes, draw two velocity time graphs: the first for the car stopping in 2 seconds and the second for the car stopping in 4 seconds.
   d. Answer a, b and c above using -30 m/s as your initial velocity.

5. A new Jeep model is advertised as going “zero to sixty miles per hour in four seconds.” Given that 60 mph is about 27 m/s, what acceleration are they claiming? How does this compare to the car in the previous question?
Given that 60 mph is about 27 m/s, what acceleration are they claiming? How does this compare to the car in the previous question?

6. A bicyclist slows down at a rate of $-0.5 \text{ m/s}^2$.
   a. If she starts with a velocity of 10 m/s, what is her velocity after 2 seconds?
   b. What is her velocity after 6 seconds?
   c. Could we use a negative initial velocity to describe this situation? Why, or why not?

7. Give an example of a case where the velocity is zero and the acceleration is zero.
   Give an example of a case where the velocity is zero and the acceleration is not zero.

8. Using the equation for change in velocity, if $\vec{v}_f = -5 \text{ m/s}$ and $\vec{v}_i = -3 \text{ m/s}$, is the change in velocity positive or negative? Did the velocity increase or decrease?
Apply physics principles developed in the activity by grappling with the questions below.

1. Think back to Chapter E. In terms of energy, why does a passenger in a car keep moving forward when the car stops very quickly in a car accident?

2. In terms of force, describe why a passenger will keep moving forward if he or she is not wearing a seat belt (discuss in terms of Key Ideas F.1b and F.1c).
PURPOSE:
In the previous activity you observed that forces can cause objects to either increase or decrease in speed. This change in speed depends on whether the force acts in the same direction as the motion, or opposite to it. How do you think the mass of the object or the strength of the force pushing the object affects its motion?

Key Question: How does the strength of a force acting on an object and the object’s mass affect the object’s motion?
INITIAL IDEAS: Complete the following questions individually in your lab notebook:

1. Imagine applying the same amount of force to a person on a skateboard and to a car (that doesn’t have its brakes on). Predict what the velocity-time graph would look like for the car and the skateboarder.

2. Now imagine trying to stop the person on the skateboard and the car (traveling at the same speed) by pushing against the motion. If you were to apply the same amount of force to each, would one slow down faster than the other? If so, which one? Describe your thinking.
As you go through the following experiments, fill in claims and evidence on this learning tracking tool:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Claim: What did we figure out?</th>
<th>Evidence: What did we do?</th>
<th>Self-Assess: Where am I with my understanding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: How does force STRENGTH affect an object's motion?</td>
<td>A cart with a stronger force will...</td>
<td>[sketch and label graphs for two objects being pushed by different forces]</td>
<td></td>
</tr>
<tr>
<td>#2: How does MASS affect acceleration?</td>
<td>A cart with a larger mass will...</td>
<td>[sketch and label graphs for two objects with different masses]</td>
<td></td>
</tr>
<tr>
<td>#3: Extension! What is another way of representing acceleration?</td>
<td>A strobe diagram shows acceleration by...</td>
<td>Speeding up looks like: Slowing down looks like:</td>
<td></td>
</tr>
<tr>
<td>F.2 Math Exploration Notes: How are Force, Mass, and Acceleration Related?</td>
<td>Force, mass, and acceleration are related by the equation...</td>
<td>Acceleration can be calculated by:</td>
<td></td>
</tr>
</tbody>
</table>
EXPERIMENT #1: HOW DOES FORCE STRENGTH AFFECT AN OBJECT’S MOTION?

Step 1: Imagine two carts with the same mass are pushed by forces of different strengths. The force on Cart 1 is twice the strength of the force on Cart 2. The force on each cart is in the same direction as its motion. Predict (draw and label) what the velocity-time graph will look like for Cart 1 and Cart 2.

Step 2: Be sure one of the fans has four batteries. In the other fan, replace two of the batteries with dummy slugs.

Step 3: Test your predictions. Place two carts on tracks that are side-by-side. Attach the fans to the carts so that the fans push the carts away from the motion sensors.

Step 4: Use a ruler to hold the carts in place and then turn on the fans so the carts push against the ruler. Start collecting data and then release the carts by lifting up the ruler.
Step 5: On one set of axes, draw the velocity-time graphs for each cart’s motion. Label the lines on your graph “stronger force” for the fan with 4 batteries and “weaker force” for the fan with 2 batteries.

Q1. How did your experimental graphs compare to your prediction graphs?

Q2. Describe how the strength of a force is related to changes in velocity.

Step 6: Imagine that you mount the fans on the carts so that they slow the carts down after an initial push. Predict (draw and label) what the velocity-time graph will look like for Cart 1 (fan with 4 batteries) and Cart 2 (fan with 2 batteries).

Step 7: Test your predictions. Return the carts to the starting position and turn them around so that the fans will cause the carts to slow down after an initial push. Start collecting data and then give the carts a quick push using a ruler.

At Home: Watch video here

Step 8: Draw the velocity-time graph for each cart’s motion. Label the lines on your graph “stronger force” and “weaker force.”

Q3. How did your experimental graphs compare to your prediction graphs?

Q4. Which cart slowed down at a slower rate? How does the velocity-time graph show the cart slowed down at a slower rate?
Step 9: In your lab notebook, complete the statements below about the relationship between motion, acceleration, and force (assume that the carts have the same mass).

- The cart with the _________________ (stronger/weaker) force of the fan increased speed at a greater rate.
- The cart with the _________________ (stronger/weaker) force of the fan decreased speed at a greater rate (had more acceleration).
- The steeper the slope of the line on the velocity-time graph, the _________________ (greater/lesser) the acceleration.
- The stronger the force, the ______________ (greater/lesser) the acceleration.

Q5. Using evidence from this lab, describe the relationship between force and acceleration.
EXPERIMENT #2: HOW DOES MASS AFFECT ACCELERATION?

Step 1: Imagine two identical carts with fans that push with the same strength force, but you add a metal block to one of the carts so that it has a greater mass. Predict (draw and label) what the velocity-time graph will look like for these two carts. Label the lines of your graph “Prediction: Less Mass” and “Prediction: More Mass”.

Step 2: Make sure you have two fans that provide the same strength of push. Do this by putting the carts on tracks that are side-by-side, turning the fans on and testing to see if the acceleration of each cart is the same.

Step 3: Add mass to one of the carts.

Step 4: Test your prediction. Turn on the fans, but hold the carts at rest. Start collecting data and then release the carts at the exact same time.

At Home: Watch Video Here

Step 5: Draw a velocity-time graph of each cart’s motion. Label the lines “more mass” and “less mass.”

Q1. How did mass affect the acceleration?

▪ The object with the greater mass will speed up __________________________ (slower/faster).
▪ The object with the greater mass will have a __________________________ (smaller/larger) acceleration.

Step 6: In your lab notebook, complete the statements below about the relationship between mass and speeding up.

▪ The object with the greater mass will speed up __________________________ (slower/faster).
▪ The object with the greater mass will have a __________________________ (smaller/larger) acceleration.

Step 7: Imagine that you mount the fans on the carts so that they slow the carts down after an initial push. One cart has a greater mass than the other. Predict (draw and label) what the velocity-time graphs will look like for the cart with more mass and the cart with less mass when they slow down.
Step 8: Test your prediction. Return the carts to the starting position and turn them around so that the fan will cause the cart to slow down after an initial push. Start collecting data and then give the carts a quick push using a ruler.

Step 9: Draw a velocity-time graph of each cart’s motion. Label the lines more mass and less mass.

Q2. How did mass affect the acceleration?

Q3. Previously you observed that the object with more mass had less magnitude of acceleration (sped up slower). Does mass affect acceleration the same way when the object slows down?

- The object with the greater mass will slow down __________________________ (slower/faster).
- The object with the greater mass will have a __________________________ (smaller/larger) acceleration.

Step 10: In your lab notebook, complete the statements below about the relationship between mass and speeding up.

- The object with the greater mass will slow down __________________________ (slower/faster).
- The object with the greater mass will have a __________________________ (smaller/larger) acceleration.

Step 11: Look back to your prediction about how two carts would increase/decrease in speed if one cart had more mass than the other.

Q4. How did your experimental graphs compare to your prediction graphs?

Step 12: Theo and Dee were discussing their observations and trying to describe why the cart with more mass had less magnitude of acceleration. Read their comments.
Q5. What do you think about how Theo and Dee are trying to describe their observations?

Theo: The object with more mass is more resistant to changing speed than the object with less mass. This is the case with speeding up or slowing down. Mass resists change in motion.

Dee: Yeah, I think more massive objects are harder to stop and harder to get going. Maybe mass has a property that resists change in speed. More mass, more resistance to change in motion.
EXTENSION EXPERIMENT: WHAT IS ANOTHER WAY OF REPRESENTING ACCELERATION?

Step 1: Think about a car that is moving down the highway at a constant speed of 25 meters per second (about 60 miles per hour). Imagine taking a picture of the car every second. If the car’s picture was taken every second for four seconds, it would look like this:

Q1. How much distance does the car travel each second?

Q2. Is the distance covered every second changing or does it remain the same? What does this tell you about whether the car is speeding up, slowing down, or moving at a constant speed?

A representation of an object’s position every second is called a **strobe diagram**. Strobe diagrams are useful for quickly identifying whether an object is speeding up, slowing down, or moving at a constant speed.

Step 2: Now imagine a car that is driving in a school zone at a constant speed of 11 meters per second (about 25 miles per hour). Imagine taking a picture of the car every second. If the car’s picture was taken every second for four seconds, it would look like this:

Q3. How much distance does the car travel each second?

Q4. Is the car speeding up, slowing down, or moving at a constant speed? How do you know?

Q5. Compare the picture showing the car moving at 25 meters per second with the car moving at 11 meters per second. How are they similar and different?
Q6. Using the pictures of the black car and the grey car (from the previous page), how can you tell which car is moving at a slower speed?

Step 3: Now think about two cars that are in a race down a straight track. If the race lasted three seconds, the strobe diagram could look like this:

![Strobe Diagram](image)

Q7. Based upon the strobe diagram, do you think the cars are speeding up, slowing down, or moving at a constant speed? What is your reasoning? Hint: is the distance between the pictures of each car changing or remaining the same?

Q8. Does the black car or the gray car have a greater magnitude of acceleration? Describe your reasoning. Check your idea with another group.

Step 4: Predict (draw and label) what a velocity-time graph would look like for each of the cars. If you feel comfortable with the strobe diagram, try to accurately label the axes with velocity and time values.

In this race between the gray car and the black car, you can tell that each of the cars are speeding up, because each car is traveling a greater distance every second. Because the black car gains more distance each second than the gray car, we can say that the black car has a greater magnitude of acceleration.

Step 5: In addition to speeding up, strobe diagrams can also be used to show an object slowing down. The Tools of the Trade below shows two strobe diagrams, one for a car speeding up and the other for a car slowing down.
Q9. Describe how strobe diagrams show speeding up and slowing down. Step 6: Read the Tools of the Trade about using dots instead of cars in strobe diagrams.

Step 6: Read the Tools of the Trade about using dots instead of cars in strobe diagrams

Step 7: Respond to the questions below about motion, acceleration, and force (for all of the questions below, assume the objects have the same mass). Q10. Describe the motion of the objects shown in each of the strobe diagrams below:

Q10. Describe the motion of the objects shown in each of the strobe diagrams below:

Q11. Use the strobe diagrams below to determine whether Object A or Object B has a greater magnitude of acceleration. Describe your thinking.
Q12. In the previous question, which object was acted upon by a greater force, Object A or Object B? Describe your thinking.

Q13. Draw two strobe diagrams:
- One for an object slowing down from the force of a fan with 2 batteries.
- One for object slowing down from the force of a fan with 4 batteries.

Step 8: Apply your understanding of the relationship between mass and acceleration by responding to the strobe diagram questions below.

Q14. The strobe diagrams below show the motion of two objects that are speeding up. Each object is pushed by exactly the same strength force. Which object has greater mass, Object A or Object B? Describe your choice.

Q15. The strobe diagrams below show the motion of two carts that are slowing down. Each cart is pushed by exactly the same strength force. Which cart has greater mass, Cart A or Cart B? Describe your choice.
### Summarizing Questions

<table>
<thead>
<tr>
<th>Question</th>
<th>My Answers</th>
<th>Added Ideas from the Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. What is the relationship between how strong a force pushes an object and the object’s acceleration? Is this true for both speeding up and slowing down? What evidence supports your answer?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Two carts (with the same mass) begin stationary and increase in speed because of a constant and continuous force on each. The force on Cart A is stronger than the force on Cart B.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. On the velocity-time graph (on the right), draw the graphs for each cart’s motion. Label the lines: Cart A (stronger force) and Cart B (weaker force).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Draw and label force diagrams for the two carts below.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. The graph (on the right) shows a cart that was given a quick push and then gradually slowed down. Which force do you think was stronger, the initial push or friction? Describe using the graph as evidence.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Imagine that you have a race between two carts that have different masses but the same strength force pushing them. If you wanted to make the race a tie, what would you need to do to the strength of the fan pushing on the cart with more mass?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Describe a general rule that relates force, mass, and acceleration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. (Extension) In order for the bowling ball and soccer ball to have the strobe diagrams below, what would have to be true about the force acting on the bowling ball compared to the force acting on the soccer ball? Describe your thinking.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
F.2 SCIENTISTS’ IDEAS READING

Instructions: As you read the Scientists’ Ideas, think about how they relate to the evidence you collected in the activity.

Acceleration: How an object changes velocity is described by its acceleration. The greater the rate of change of velocity, the greater the acceleration.

Acceleration and force: The greater the strength of the force on an object, the greater the acceleration. Acceleration is directly proportional to force ($\vec{a} \propto \vec{F}$). This relationship can be inferred from velocity-time graphs.

If the force on an object is doubled, its acceleration is also doubled. Similarly, if the force on an object is halved, the acceleration is also halved. Scientists say force and acceleration have a directly proportional relationship. Scientists use the symbol $\propto$ to represent a proportional relationship: $\vec{a} \propto \vec{F}$.

Since acceleration and force are related in this way, the strength of the force can be inferred from the slope of a velocity-time graph: a steeper slope means greater force (if the masses are the same). The slope describes how steep a line is, or how much $y$ (velocity) changes as $x$ (time) increases.

Resistance to change (inertia): Objects with greater mass have greater resistance to changes in speed and/or direction.

More massive objects require a greater force to accelerate at the same rate as less massive objects. Scientists call this resistance to change in velocity inertia. Inertia is the
"resistance to change in speed and/or direction of motion" property of objects – they want to keep moving in the way they are already moving. Moving objects “don’t want” to stop moving and stopped objects “don’t want” to start moving.

**F.2d**

**Acceleration and mass:** When a force acts on an object with greater mass, the object will have less acceleration magnitude than when the same force acts on an object with less mass. Acceleration is inversely proportional to mass (\( \vec{a} \propto \frac{1}{m} \)).

If a force is applied to an object and the same force is applied to another object with twice the mass, the object with twice the mass will have half the acceleration. Scientists say mass and acceleration have an **inversely proportional relationship.** Since mass and acceleration have an inversely proportional relationship (\( \vec{a} \propto \frac{1}{m} \)), a steeper slope implies less mass.

**Newton’s Second Law:** If a force acts on an object, its velocity will change continuously as long as the force is acting (it will accelerate). The object's acceleration is directly proportional to the strength of the force and inversely proportional to the object's mass. The arrows above acceleration and force indicate that these quantities are vectors.

\[
\text{acceleration} = \frac{\text{force}}{\text{mass}} \quad \vec{a} = \frac{\vec{F}}{m}
\]
Respond to the following questions individually in your lab notebook:

1. What does the term slope mean?
2. What is acceleration?
3. Using the graph on the right, which object was pushed by a greater force (both have the same mass)? How do you know?
4. What evidence did you collect that supports the idea that force and acceleration are directly proportional?
5. What is an example of a directly proportional relationship in your life?
6. What evidence did you collect that supports the idea that mass and acceleration are inversely proportional?
7. What is an example of an inversely proportional relationship in your life?
8. Summarize Newton’s Second Law in your own words.
9. Why is it harder to stop a semi-truck than it is to stop a small car if they are both traveling at the same speed?
10. Complete the following sentences:
   If the force is held constant, doubling the mass will cause the acceleration to...
   If the force is held constant, halving the mass will cause the acceleration to...
11. Copy the velocity-time and force-time graphs (on the right) into your laboratory notebook.
   a. Circle each part on the velocity-time graph that shows a force was acting on the cart.
   b. Describe how you are able to tell if a force is acting on an object by looking at the velocity-time graph.
12. Describe how you are able to tell if no forces are acting on an object by looking at the velocity-time graph.
13. Describe how the force-time graph supports your ideas from the previous two questions. Hint: use the time intervals to help you.
14. Based upon the velocity-time graph and the force-time graph, how does the slope of the velocity-time graph relate to the strength of the force acting on the cart? Why does this make sense?
15. What does the slope on a velocity-time graph tell us about acceleration?
EXPLORATION #1: HOW ARE FORCE, MASS, AND ACCELERATION RELATED MATHEMATICALLY?

Step 1: The graph on the right shows the velocity versus time for two objects (Object A and Object B). Use the graph to answer the questions below:

Q1. Does Object A or Object B have a greater acceleration magnitude? How do you know from looking at the graph?

Q2. Assume that Object A and Object B have the same mass. What can you say about the strength of the force on Object A compared to the strength of the force on Object B?

Q3. Now assume Objects A and B are being pushed by the same force. What can you say about the mass of Object A compared to the mass of Object B?

Step 2: Review the Calculating Acceleration Idea (from the F.1 math activity):

Q4. Using the graph in Step 1, calculate the acceleration for Object A.

Q5. Using the graph in Step 1, calculate the acceleration for Object B.

Step 3: For the questions below, use this table:
Q6. When the force pushing an object is doubled (and mass is held constant), what happens to the acceleration?

Q7. When the mass is doubled (and force is held constant), what happens to the acceleration?

Step 4: Complete the two tables below (in your laboratory notebook):

<table>
<thead>
<tr>
<th>Force</th>
<th>Mass</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 N</td>
<td>15 kg</td>
<td>1 m/s²</td>
</tr>
<tr>
<td>30 N</td>
<td>15 kg</td>
<td></td>
</tr>
<tr>
<td>45 N</td>
<td>15 kg</td>
<td></td>
</tr>
<tr>
<td>60 N</td>
<td>15 kg</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Force</th>
<th>Mass</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 N</td>
<td>10 kg</td>
<td>8 m/s²</td>
</tr>
<tr>
<td>80 N</td>
<td>20 kg</td>
<td></td>
</tr>
<tr>
<td>80 N</td>
<td>40 kg</td>
<td></td>
</tr>
<tr>
<td>80 N</td>
<td>80 kg</td>
<td></td>
</tr>
</tbody>
</table>

Q8. Explain how you found acceleration when mass was constant and force was changed.

Q9. Explain how you found acceleration when force was constant and mass was changed.
F.2 Mathematical Ideas Reading

Instructions: Read the Mathematical Ideas, paying careful attention to each key idea.

**Force, mass, and acceleration relationship:** Acceleration is inversely proportional to mass and directly proportional to force. Acceleration is equal to the force divided by the mass.

\[ \vec{a} = \frac{\vec{F}}{m} \]

You have just determined the mathematical relationship between force and acceleration (when mass is held constant) and the relationship between mass and acceleration (when force is held constant).

Scientists say that the acceleration is proportional to the force (\( \vec{a} \propto \vec{F} \)), and that the acceleration is inversely proportional to the mass (\( \vec{a} \propto \frac{1}{m} \)).

By combining these two relationships, scientists are able to relate force, mass, and acceleration:

\[ \vec{a} = \frac{\vec{F}}{m} \]

This equation is the mathematical expression of **Newton's Second Law**.

**Units of force:** The unit for force is the “Newton” (N), named after Sir Isaac Newton for his work with force, mass, and acceleration.

We can better understand the units of force by rearranging the relationship for acceleration, force, and mass so that it solves for force.

\[ \vec{F} = m \cdot \vec{a} \]

By plugging in the units for mass and acceleration, we can evaluate the units for force and see the fundamental units of a Newton.

\[ \text{Units for } \vec{F} = \text{kg} \cdot \frac{m}{s^2} \]

So a “Newton” is just a shortened way of saying a “kilogram meter per second squared.”

\[ 1 \text{ Newton} = 1 \text{ kg} \cdot \frac{m}{s^2} \]
MATHEMATICAL MODELS: PRACTICE
Respond to the following questions in your laboratory notebook. Show your work.

Support Questions: The first two questions include fill-in-the-blank supports to help you learn how to set up the problems. If you already feel comfortable solving these problems, consider trying to solve them without using the fill-in-the-blank supports. You can check your work using the supports.

1. What is the acceleration of a 22 kg object with a 4 N force pushing it?

\[
\vec{a} = \frac{\vec{F}}{m}
\]

Optional Fill-in-the-Blank Supports

\[
\begin{align*}
\vec{F} &= \underline{\text{What is the force acting on the object?}} \\
\underline{m} &= \underline{\text{What is the object’s mass?}} \\
\vec{a} &= \frac{\vec{F}}{m} = \underline{\text{_____}} = \underline{\text{m/s}^2}
\end{align*}
\]

2. What is the force that causes a 5 kg object to accelerate at 8 m/s²?

\[
\vec{F} = m \cdot \vec{a}
\]

\[
\begin{align*}
\underline{m} &= \underline{\text{What is the object’s mass?}} \\
\underline{\vec{a}} &= \underline{\text{What is the object’s acceleration?}} \\
\vec{F} &= m \cdot \vec{a} = \underline{\text{_____}} \cdot \underline{\text{_____}} = \underline{\text{_____ N}}
\end{align*}
\]

3. A 15 N force is exerted on a 45 kg punching bag. What is the acceleration of the bag?

4. Find the acceleration of a 10 kg object that is pushed by the following forces:
3. A 15 N force is exerted on a 45 kg punching bag. What is the acceleration of the bag?

4. Find the acceleration of a 10 kg object that is pushed by the following forces:
   a. 20 N
   b. 60 N
   c. 90 N

5. Use the velocity-time graph to find the acceleration of the cart during the following time intervals:
   a. 0 to 4 seconds
   b. 4 to 6 seconds
   c. 6 to 12 seconds

6. The cart (from the velocity-time graph) has a mass of 0.25 kg. Find the force exerted on the cart during each of the time intervals.
   a. 0 to 4 seconds
   b. 4 to 6 seconds
   c. 6 to 12 seconds

7. What do you think it means for a force to be negative?

8. Use the graph on the right to answer the following two questions:
   a. Assuming that Object A has a mass of 20 kg, what is the strength of the force pushing this object?
   b. Assuming that Object B is being pushed by a force of 35 N, what is the mass of Object B?
8. Assuming that Object B is being pushed by a force of 35 N, what is the mass of Object B?

9. Use the velocity-time and force-time graphs to find the mass of the cart. Hint: use the velocity-time graph below to find the acceleration.

![Graphs showing Velocity-Time and Force-Time for a Cart Without Friction]

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Mathematical Models

F.2: Force, Mass, and Acceleration

10. A player has a mass of 93 kilograms. When stationary, another player collides with him causing him to accelerate at 6 m/s². What force did the player hit him with to cause this acceleration?

11. A hockey puck accelerates at 30 m/s² when hit by a hockey player. The puck has a mass of 0.15 kg. With what force did the player hit the puck?

Challenge Yourself: These problems are about the same mathematical ideas, but are more challenging. Respond to these questions in your laboratory notebook and show your work.

1. Use the equation that relates force (F), mass (m), and acceleration (a) to complete the table on the right. Show your work.

2. A player has a mass of 93 kilograms. When stationary, another player collides with him, causing him to speed up to 2 meters per second in 0.5 seconds.
   a. What is the acceleration of the player during the collision?
   b. What force did the player hit him with (to cause this acceleration)?
   c. What is the acceleration of the player after the force stops?

<table>
<thead>
<tr>
<th>Force</th>
<th>Mass</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 N</td>
<td>200 kg</td>
<td></td>
</tr>
<tr>
<td>4530 N</td>
<td></td>
<td>10 m/s²</td>
</tr>
<tr>
<td>8988 N</td>
<td></td>
<td>14 m/s²</td>
</tr>
<tr>
<td>2000 kg</td>
<td></td>
<td>25 m/s²</td>
</tr>
</tbody>
</table>
Forces

Experimental Questions Page 54

3. A hockey player hits the puck (making contact for only 0.1 seconds). The puck speeds up to 35 m/s during this contact.
   a. What is the acceleration of the puck during the collision?
   b. The puck has a mass of 0.15 kg. With what force did the player hit the puck?

4. The velocity-time graph (shown below) is for a cart without friction. The cart has a mass of 3 kg. Use the mass and acceleration to find the forces acting on the cart. Then draw a force-time graph for the cart.

5. A 60 kg ice-skater is moving at 1 m/s. She is pushed for 0.5 s and reaches a speed of 3 m/s. What was the strength of the push force?

6. A 1,000 kg car is travelling at 20 m/s when a deer jumps out in front of it. The driver slams on the brakes, exerting a stopping force of –10,000 N.
   a. What is the acceleration of the car?
   b. How long will it take to stop?
   c. Bonus: if the deer was 10 m away when the car started braking, will the car hit it? Hint: think about how fast will the car be going after 1 second and before 1 second.
Apply physics principles developed in the activity by grappling with the questions below.
1. In a car accident, the passenger will stay in motion until a force is applied to stop the person. What are some of the possible forces that could be applied on a passenger that will result in the passenger stopping? List some ideas.

2. Which do you think would cause the most damage to the passenger and why?

3. The graph on the right shows velocity vs. time for a passenger who is wearing a seat belt and a passenger without a seat belt during a car accident. Each passenger is initially moving at 16 m/s and eventually comes to a complete stop.

   ![Velocity-Time graph](image)

   Graph adapted from: Vehicle design and the physics of traffic safety. Physics Today

   a. How long does it take each passenger to stop?
   Passenger wearing seat belt:

   Passenger without seat belt:

   b. Based on your response to question a, which passenger is experiencing a greater acceleration? Describe your reasoning.

   c. Based on your response to question b, which passenger is acted upon by a greater force? Describe your reasoning.

4. Use Newton’s Second Law to defend your response to the previous question. (In other words, how is the acceleration of each passenger related to the strength of the force on each passenger?)

Math Extension:
5. Recall Key Idea F.1h (from F.1 mathematical models) about calculating acceleration. Calculate the acceleration for each of the passengers in the graph from question 3.

6. If each passenger is approximately 140 pounds (63.5 kilograms), calculate the force that acts on each passenger.
F.3 Combinations of Forces

PURPOSE:
Up until now you have only examined situations in terms of a single force acting on an object. But what if there are multiple forces? In this activity, you will investigate how combinations of forces affect the motion of objects.

Key Question: How do combinations of forces affect the motion of stationary and moving objects?
INITIAL IDEAS: Complete the following questions individually in your lab notebook:

1. Two boys are pushing on a box, but it is moving at a constant speed. Friction is present in this situation. If they are each pushing with 200 N, how strong do you think the friction force would be? Draw a force diagram that supports your idea.

2. The boys decide to push the box so that it speeds up. Draw a force diagram that shows all the forces when the box is speeding up.
As you go through the following experiments, fill in claims and evidence on this learning tracking tool:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Claim: What did we figure out?</th>
<th>Evidence: What did we do?</th>
<th>Self-Assess: Where am I with my understanding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: How can you find the sum of the forces when multiple forces act on an object?</td>
<td>To find the &quot;sum of forces&quot;/net force...</td>
<td>When we applied more than one force to the cart...</td>
<td></td>
</tr>
<tr>
<td>#2: How do combinations of forces affect an object’s motion?</td>
<td>Unbalanced forces cause an object to...</td>
<td>The cart with the larger net force...</td>
<td></td>
</tr>
<tr>
<td>#3: How do balanced forces affect an object’s motion?</td>
<td>When an object has zero net force, it must ____ OR _____.</td>
<td>When two forces with the same strength act on an object in opposite directions, the object...</td>
<td></td>
</tr>
<tr>
<td>#4 How does a cart move if a fan force balances the force from friction?</td>
<td>When the force of a fan balances the force of friction on a cart, the cart...</td>
<td>[Draw a graph of a cart with balanced forces]</td>
<td></td>
</tr>
</tbody>
</table>
EXPERIMENT #1: HOW CAN YOU FIND THE SUM OF THE FORCES WHEN MULTIPLE FORCES ACT ON AN OBJECT?

Step 1: Imagine a cart on wheels that can be pulled by a rope to the left and to the right (like shown in the picture below). Your instructor will give you a handout that includes several different scenarios where the cart is pulled by different strengths either to the left, to the right, or both directions.

Step 2: On the handout, predict how the cart will move (speed up to the right, speed up to the left, or remain stationary) and describe your reasoning in terms of force.
Q1. How did you use the forces acting on the cart to decide how the cart would move?

Q2. In what situations did you predict the cart would remain stationary? Describe your reasoning.

Step 3: Go to: https://phet.colorado.edu/en/simulation/forces-and-motion-basics
- Open the simulation by clicking the play button in the middle of the screen.
- Select the option Net Force.
Step 4: In the upper right corner of the simulation, check Sum of Forces and Values.

Step 5: Check each of your predictions on the handout by moving the blue and red people up to the rope and then pushing GO.

From Home: Watch video here

When more than one force is acting on an object, you can calculate the total force that is applied to the object. Scientists call this the net force.

Step 6: On your handout, draw and label a single arrow that represents the net force acting on each cart.

Q3. Summarize how to calculate net force.

Step 7: Theo and Raquel were making predictions about net force acting on the cart shown on the right. Read their comments.
Q4. Who do you agree with and why? Include observations from the simulation to justify your reasoning.

Theo: I think that the force from Fan A takes over, so the total (net) force is just the force from Fan A. The acceleration of the cart would be the same as if it were only had Fan A.

Raquel: I disagree. I think that the total (net) force on the cart is greater than just the force from Fan A. I think it is the force of Fan A plus the force of Fan B. So the acceleration would be greater than with just Fan A.
EXPERIMENT #2: HOW DO COMBINATIONS OF FORCES AFFECT AN OBJECT’S MOTION?

Step 1: Your instructor will give you a handout that includes two blank graph axes. On the first graph axes, predict the velocity-time graphs for Cart 1 and Cart 2 (shown in the table below).

Step 2: On the second graph axes, predict the velocity-time graphs for Cart 3 and Cart 4 (shown in the table below).
**HANDOUT – F.3 (Expt.#2)**

**Situation:** Cart 1 and Cart 2 are stationary (at rest) for 2 seconds and then the fans are turned on.

![Velocity-Time Graph](image)

**KEY:**
- = Cart 1
- = Cart 2

**Situation:** Cart 3 and Cart 4 are stationary (at rest) for 2 seconds and then the fans are turned on.

![Velocity-Time Graph](image)

**KEY:**
- = Cart 3
- = Cart 4
Step 3: Your instructor will show you a video in which velocity-time data is collected for the graphs you predicted.
Watch video here

Step 4: Use a different-colored pen to record your observations from the video on your handout.

Q1. What happens to the motion of a stationary object when it is acted on by forces that are unbalanced?

Q2. If you were to push the cart shown below with only 1 force, how strong would that force need to be in order for the cart to have the same acceleration as with the two forces shown?

Q3. If you were to push the cart shown below with only 1 force, how strong would that force need to be in order for the cart to have the same acceleration as with the two forces shown?
EXPERIMENT #3: HOW DO BALANCED FORCES AFFECT AN OBJECT’S MOTION?

Step 1: On a handout provided by your instructor, graph whether the cart will speed up, slow down, move at a constant speed, or not move at all for the following situations (involving the picture above). The force of Fan A is equal to the force of Fan B.

- Situation 1: The cart is stationary (at rest) for 2 seconds and then the Fan A and Fan B are turned on.
- Situation 2: Fan A and Fan B are turned on and then the cart is given a quick push to the right (predict how the cart will move after the push).
- Situation 3: Fan A and Fan B are turned on and then the cart is given a quick push to the left (predict how the cart will move after the push).
**HANDOUT – F.3 (Expt.#3)**

**Situation 1:** The cart is stationary (at rest) for 2 seconds and then the Fan A and Fan B are turned on.

**Situation 2:** Fan A and Fan B are turned on and then the cart is given a quick push to the right *(predict how the cart will move after the push)*
Step 2: Using one cart equipped with two fans that are powered by 4 batteries of the same strength, your instructor will lead a class demonstration to collect velocity-time data for the three situations in which you made predictions.

Situation 3: Fan A and Fan B are turned on and then the cart is given a quick push to the left (predict how the cart will move after the push)

At Home: Watch Video Here
Step 3: Use a different colored pen to record your observations from the class demonstration on your handout.

When two forces with the same strength act upon an object in opposite directions, scientists say the forces are balanced. When forces are balanced, they cancel each other out, so in these cases, there is no net force acting on the object.

Q1. What happens to the motion of a stationary object when it is acted on by two forces of equal magnitude in opposite directions (balanced forces)?

Q2. What happens to the motion of an object with an initial velocity that it is acted on by two forces of equal magnitude in opposite directions (balanced forces)?

Step 4: In your lab notebook, complete the statements below.

- When two forces of the same strength are acting on an object in opposite directions, the net force is equal to ________________.
- For an object to remain stationary, the net force must be equal to ________________.
- For objects moving at a constant speed, the net force must be equal to ________________.
- For accelerating objects, the net force is NOT equal to ________________.
EXPERIMENT #4: HOW DOES A CART MOVE IF A FAN FORCE BALANCES THE FORCE FROM FRICTION?

**Step 1:** Imagine balancing the force from friction on a cart with the force of a fan.

![Diagram of forces](image)

Q1. List two different ways to determine whether a cart is acted upon by forces that are balanced.

**Step 2:** Using a low-friction cart (with a friction pad and fan), motion detector, and data collection device, balance the force from friction with the force of the fan on the stationary cart.

At Home: Watch video here

**Step 3:** Draw the velocity-time graph for the stationary cart acted on by the balanced forces (of the friction pad and the fan).

![Velocity-Time Graph](image)

Q2. Describe how your velocity-time graph demonstrates that the forces are balanced.

**Step 4:** Once you balance the strength of the friction pad force with the strength of the fan force on the stationary cart, give the cart a quick push and then release your hand. Collect velocity-time data for the cart’s motion.

At home: Watch video here

Q3. Did the force from the fan balance the force from the friction pad? Describe how you know by using velocity-time graph to support your response. (Note: if the velocity-time graph did not suggest the forces of the fan and the friction pad were balanced on the moving cart, adjust either the friction pad or the fan so the forces balance one another.)

**Step 5:** Draw the velocity-time graph for the moving cart acted on by the balanced forces (of the friction pad and the fan).

Q4. Describe how your velocity-time graph demonstrates that the forces are balanced.
1. A group of students collected the following velocity-time data for a cart with a fan and a friction pad.

   a. Describe why the cart moved at a constant speed after the finger from the initial push was removed.

   b. Draw a force diagram for the cart:
      
      (1) when it is speeding up (around 2 seconds) and

      ![Speeding Up Diagram]

      (2) when it is moving at a constant speed (around 3 seconds)

      ![Constant Speed Diagram]

2. Two boys are pushing on a box so that it moves across a wooden floor.

   a. If the box is moving at a constant speed and each boy is pushing with 200 N, what is the force of friction? Draw a force diagram that includes all of the horizontal forces acting on the box.

   b. After the box moves at a constant speed for a while, one boy increases the strength he pushes to 270 N while the second boy decreases the strength he pushes to 110 N. Using the friction force you determined in the previous question, make a claim about whether the box will speed up, slow down, or continue moving at a constant speed. Describe your reasoning using the net force acting on the box.

3. Two students were discussing their ideas about balanced forces:

   How would you respond to Dee and Theo with evidence?

   \[ \vec{a} = \frac{\vec{F}_{\text{total}}}{m} \]

4. Using Newton’s Second Law, describe why objects acted upon by forces that are balanced move at a constant speed or remain stationary.

5. Think about a cart that is pushed by two fans (Fan A and Fan B) pushing in opposite directions. The cart is initially stationary. Complete the table below:

<table>
<thead>
<tr>
<th>Force Strengths</th>
<th>Force Diagram</th>
<th>Acceleration: The mass of the cart with the fans is 1.2 kg. Calculate the acceleration using Newton’s Second Law.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan A = 30 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan B = 15 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan A = 10 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forces</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>---------------</td>
<td></td>
</tr>
<tr>
<td>Fan A = 10 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan B = 10 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan A = 20 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan B = 10 N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan B = 30 N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
F.3 Scientists’ Ideas Reading

Instructions: As you read the Scientists’ Ideas, think about how they relate to the evidence you collected in the activity.

Balanced and unbalanced forces: Objects that are acted on by balanced forces do not accelerate. Objects that are acted on by unbalanced forces accelerate in the direction of the net force.

Imagine four children who are pulling on a box, two on each side. Each child is pulling with the same strength force. Since there are two children on each side, the force pulling left on the box is exactly the same as the force pulling to the right.

When the total strength of all the forces one way is exactly the same as the total strength in the opposite direction, we say that the forces on the object are balanced.

Now imagine another child starts pulling the box to the left with the same strength force as each of the other children. Since there are more children pulling to the left than to the right, there would be more force to the left. In this case, the forces are unbalanced.

In summary, an object will move in the following ways when acted on by forces that are balanced or unbalanced:

- When the forces on a stationary object are balanced, the object will remain stationary.
- When the forces acting on a stationary or moving object are unbalanced, the object will accelerate in the direction of the total force.
- When the forces acting on a moving object are balanced, the object will move at a constant speed.
- When the forces acting on a moving object are unbalanced and the total force is in the direction of motion, the object will speed up (accelerate in the same direction as motion).
- When the forces acting on a moving object are unbalanced and the total force is in the opposite direction of motion, the object will slow down (accelerate in the opposite direction of motion).
Net force: The sum of all the forces acting on an object is called the Net Force ($F_{NET}$).

The net force is important for understanding the motion of objects. The net force, like all forces, can be represented by vectors. A vector is expressed by an arrow and provides information about direction and magnitude (size). When looking at force diagrams, we will use the convention that forces pushing/pulling to the right are positive and forces pushing/pulling to the left are negative.

Using this convention, net force is calculated in the following way: add up the positive forces (pushing/pulling to the right) and the negative forces (pushing/pulling left). For example, the net force for the box shown on the right is:

$$F_{NET} = 500 \text{ N} + (-400 \text{ N}) + (-300 \text{ N}) = -200 \text{ N}$$

This means that the net force acting on the box is 200 N to the left.

Think back to the Initial Ideas where two boys were each exerting a force of 200 N on a stationary box. When the friction force is $-400$ N, the forces on each side of the box are equal and the forces are balanced. This means the net force is zero ($F_{NET} = 0$) and the box will not move.

However, once the boys push harder than the friction force, the forces are unbalanced and the sum of the forces is no longer zero ($F_{NET}$ not equal to 0). The box will then accelerate in the direction of $F_{NET}$. Since the acceleration is in the same direction as the motion, the box speeds up. An object will only accelerate when there is a non-zero net force acting on it.
Once the box is moving, the boys again push with a force equal to the friction force, balancing the forces and making the sum of the forces zero ($\vec{F}_{\text{NET}} = 0$). The box will move at a constant speed.

\[ \vec{F}_{\text{NET}} = 0 \]

**Net force and Newton's Second Law:** When multiple forces act on an object, the net force is used to determine the acceleration of the object.

\[ \vec{a} = \frac{\vec{F}_{\text{NET}}}{m} \]

The box shown on the right has a mass of 100 kg and is moving to the right. The net force acting on it is -200 N (200 Newtons to the left).

The acceleration of this box is:

\[ \vec{a} = \frac{-200 \text{ N}}{100 \text{ kg}} = -2 \text{ m/s}^2 \]  \text{(the box is accelerating at 2 m/s}^2 \text{ to the left)}

Since the box was already moving to the right, this acceleration will cause the box to slow down. When the net force is in the direction opposite to the direction of motion, the object will slow down.

**Newton's First Law:** When a stationary object has zero net force ($\vec{F}_{\text{NET}} = 0$), it will remain stationary. When a moving object has zero net force ($\vec{F}_{\text{NET}} = 0$), it will continue to move in a straight-line path at a constant speed.

Newton's First Law takes *inertia* into account, the idea you explored in the previous activity. Remember that objects tend to resist change in motion (both speed and direction). Unless there is a non-zero net force, speed and direction will not change. You may have heard Newton's First Law stated as: "An object in motion remains in motion unless acted on by a non-zero net force."
Respond to the following questions individually in your lab notebook:

1. Draw a force diagram for an object that is acted upon by multiple forces where \( \vec{F}_{\text{NET}} = 0 \) (the forces are balanced).

2. Draw a force diagram for an object that is acted upon by multiple forces where \( \vec{F}_{\text{NET}} \) is not equal to zero (the forces are unbalanced).

3. When the forces on a stationary object are unbalanced, how does the object move (discuss speed and direction)?

4. What is net force? How do you calculate net force?

5. Four people push on a large box with the forces shown on the right. Will the box accelerate? If so, in what direction?

6. Complete the following sentences by filling in the blank with how the object's speed changes.

   When the forces acting on a stationary object are balanced, the object will __________.

   When the forces acting on a stationary object are unbalanced, the object will __________.

   When the net force acting on a moving object is zero, the object will __________.

   When the net force acting on a moving object is non-zero and in the opposite direction as the object's motion, the object will __________.

7. Imagine you want to push a heavy sofa across a carpeted floor. Answer the following questions:

   a. If the sofa were stationary, would you have to push with a force less than, equal to, or greater than the friction force resisting the movement of the sofa?

   b. After you start moving the sofa, what would you have to do to make it move across the floor at a constant speed? Briefly describe your reasoning.

8. Summarize Newton's First Law in your own words.

9. What evidence have you collected that supports Newton's First Law?

10. Describe how Newton's First Law is just a special case of Newton's Second Law (when \( \vec{F}_{\text{NET}} = 0 \)). Remember, Newton's Second Law states:

\[
\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}
\]
F.3 Mathematical Models: Combinations of Forces

F.3 MATHEMATICAL IDEAS READING
Instructions: Read the Mathematical ideas, paying careful attention to each key idea.

| Remember! The sum of all the forces acting on an object is called the Net Force ($\vec{F}_{\text{NET}}$). (Key Idea F.3b: Net force) |

When more than one force acts on an object, scientists add up all the forces to find the Net Force ($\vec{F}_{\text{NET}}$). Remember that forces are vectors because they give information about both the size (magnitude) and the direction of the force. This means that it is important to take into account the direction of the force vector when finding the net force. When forces are acting in opposite directions, they will be subtracted (or you can think of it as adding a negative force vector). This idea is shown in the example below where the force of the fan is acting in the opposite direction as the friction force and the force from the hand.

Question: Calculate the net force acting on the cart shown on the right: it is moving to the left, pushed by a fan. Its motion is opposed by both a hand and the force of friction.

\[
\vec{F}_{\text{NET}} = 5\,N + 1\,N + (-3\,N) = 3\,N
\]

In the previous math activity, you explored the mathematical relationship between force, mass, and acceleration and found:

\[
\vec{a} = \frac{\vec{F}}{m}
\]
Even when there are many forces acting on an object, scientists use this same equation to find acceleration. The net force and the mass of the object are used to find the acceleration.

\[
\vec{a} = \frac{\vec{F}_{\text{NET}}}{m}
\]

**Question:** The box shown below is pushed by four forces and has a mass of 25 kg. Find the acceleration of the box.

\[
\vec{F}_{\text{NET}} = 270 \text{N} + 430 \text{N} + (-500 \text{N}) + (-250 \text{N}) = -50 \text{N}
\]

We used a positive sign for forces acting to the right, and a negative sign for forces acting to the left. This means that the box is acted upon by a net force of 50 N to the left.

\[
\vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \frac{-50 \text{N}}{25 \text{ kg}} = -2 \text{ m/s}^2
\]

This means that the box is accelerating 2 m/s every second to the left.
Mathematical Models: Practice

Respond to the following questions in your laboratory notebook. Show your work.

Support Questions: The first question includes fill-in-the-blank supports to help you learn how to set up the problems. If you already feel comfortable solving these problems, consider trying to solve them without using the fill-in-the-blank supports. You can check your work using the supports.

1. Five children are pulling on a 20 kilogram box (as shown in the picture on the right). What is the acceleration of the box?

Choose a positive sign for forces that are pulling to the right.

\[ \vec{F}_{\text{NET}} = \text{______} + \text{______} + \text{______} + (-\text{______}) + (-\text{______}) = \text{______ N} \]

\[ m = \text{______} \]

\[ \vec{a} = \frac{\vec{F}_{\text{NET}}}{m} = \text{______} = \text{______ m/s}^2 \]

2. A steel box is being pushed to the right across a wooden floor with 30 Newtons of force. A 5 Newton friction force opposes the box's motion.
   a. Draw a force diagram for this situation.
   b. Find the net force on the box. Be sure to show all your steps.
   c. The box has a mass of 50 kg. What is the acceleration of the box?

3. Four dogs are pulling a dog sled across the snow. Each dog is pulling to the right with a force of 34 Newtons. The loaded dog sled has a mass of 104 kilograms. The frictional force that opposes the dog sled's motion is 102 Newtons.
   a. Draw a force diagram for the dog sled when the dogs are pulling it.
Forces

opposes the dog sled's motion is 102 Newtons.

a. Draw a force diagram for the dog sled when the dogs are pulling it.
b. What is the net force acting on the dog sled?
c. What is the acceleration of the dog sled?
d. The force of friction does not change and each dog continues to pull with a force of 34 Newtons. Describe the motion of the dog sled.

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Mathematical Models

Challenge Yourself: These problems are about the same mathematical ideas, but are more challenging. Respond to these questions in your laboratory notebook and show your work.

1. A cart is given a quick tap and then gradually slows down due to friction. The strength of the friction force acting during the time of the tap is the same as the friction force acting after the tap.

   a. The table (on the right) gives velocity-time data for the cart. Use this data to plot a velocity-time graph of the cart's motion.
   
   b. Calculate the acceleration of the cart during the tap (from 1 s to 1.5 s).
   
   c. Calculate the acceleration of the cart after the tap (from 1.5 s to 4.0 s).
   
   d. The cart has a mass of 0.25 kg. Calculate the net force acting on the cart when it is speeding up.
   
   e. Calculate the net force acting on the cart when it is slowing down.
   
   f. Given your calculated value of friction force (and remember that the same strength friction force is acting when the cart is given a tap to speed up), find the strength of the tap force.
   
   g. Draw a force diagram for the time when the cart is speeding up. Label the force arrows with the strength of each force.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 s</td>
<td>0 m/s</td>
</tr>
<tr>
<td>0.5 s</td>
<td>0 m/s</td>
</tr>
<tr>
<td>1 s</td>
<td>0 m/s</td>
</tr>
<tr>
<td>1.5 s</td>
<td>3 m/s</td>
</tr>
<tr>
<td>2.0 s</td>
<td>2.8 m/s</td>
</tr>
<tr>
<td>2.5 s</td>
<td>2.6 m/s</td>
</tr>
<tr>
<td>3.0 s</td>
<td>2.4 m/s</td>
</tr>
<tr>
<td>3.5 s</td>
<td>2.2 m/s</td>
</tr>
<tr>
<td>4.0 s</td>
<td>2.0 m/s</td>
</tr>
</tbody>
</table>

2. A person is trying to move a dresser (60 kg) across a carpeted room. When the dresser is moving, the friction force acting on the dresser is 6 N. It takes you 2 seconds to get the dresser to reach a speed of 1 m/s.

   a. What was the acceleration of the dresser during the 2 seconds it took for it to speed up to 1 m/s?
a. What was the acceleration of the dresser during the 2 seconds it took for it to speed up to 1 m/s?

b. What was the net force acting on the dresser during this time?

c. How strong of a force did you apply to the dresser during the time it was speeding up to a velocity of 1 m/s?

d. What is the velocity after 1 second?

3. An airplane (100,000 kg) in flight feels a drag (air friction) of 200,000 N. If the pilot wants to slow down from 120 m/s to 90 m/s in 1 minute, what force should he have the engines exert?
Apply physics principles developed in the activity by grappling with the questions below.

1. In the Today Show clip you watched before starting the chapter, you learned that lap seat belts alone were inefficient and actually dangerous. Since 2007, all cars that are sold in the United States are mandated to include a lap and a shoulder belt in all seats. In terms of Newton's First Law – Inertia (Key Idea F.3d), discuss why the shoulder belt is important in reducing injuries to passengers during car accidents.
PURPOSE:
Imagine that two trucks are in a head-on collision. When the trucks are in contact with one another, how do the strengths of the forces acting on each truck compare? As each truck changes speed as a result of the collision, how do the trucks’ accelerations compare?

Key Question: When two objects are in contact, how does the strength of the pushing force compare to the strength of the pushing back force?
INITIAL IDEAS: Complete the following questions individually in your lab notebook:

Imagine two trucks that are involved in a head-on collision...
1. Which truck would experience the greatest force by the other vehicle, if either?

2. Which truck would you rather be in? Describe why.
As you go through the following experiments, fill in claims and evidence on this learning tracking tool:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Claim: What did we figure out?</th>
<th>Evidence: What did we do?</th>
<th>Self-Assess: Where am I with my understanding?</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: Do objects push back?</td>
<td>When pushing on an object, the object...</td>
<td>When two bathroom scales are pushed together...</td>
<td></td>
</tr>
<tr>
<td>#2: How does the strength of the pulling force compare to the strength of the pulling back force?</td>
<td>When pulling on an object, the object...</td>
<td>When two spring scales are pulled apart...</td>
<td></td>
</tr>
<tr>
<td>#3: How do forces compare during a collision?</td>
<td>When two objects collide, the forces...</td>
<td>[Draw the force-time graph for the two carts]</td>
<td></td>
</tr>
<tr>
<td>#4: Why might people think a more massive object exert a greater force during a collision?</td>
<td>People might think that more massive objects push harder because...</td>
<td>When two objects collide, their accelerations...</td>
<td></td>
</tr>
</tbody>
</table>
EXPERIMENT #1: DO OBJECTS PUSH BACK?

At Home: Watch Steps 1-3 Video here

Step 1: Place the rubber band on your thumb and index finger so that the band is stretched tight and the rubber band is horizontal.

Step 2: Have one group member push down gently on the rubber band.

Q1. Does the rubber band exert a force on the person pushing down? If so, in what direction does this force act?

Step 3: Have the same group member push down harder on the rubber band so that it is stretched more.

Q2. What happens to the strength of the force exerted by the rubber band on the finger when you push down harder on the rubber band? How can you tell?

Q3. Draw two force diagrams, one for the forces acting on the rubber band and the other for the forces acting on the pushing finger. Include force arrows for the force of the finger pushing on the rubber band and for the force of the rubber band pushing on the finger.

Q4. Are the sizes of the force arrows for the force of the finger pushing on the rubber band and for the force of the rubber band pushing on the finger the same or different? Explain your reasoning.

Step 4: Place two bathroom scales back-to-back vertically (as shown in the picture on the right). You may find it helpful for the bottom of the scales to sit on a table. Without pushing on the scales, calibrate each scale so that it reads 0 pounds.

At home: Watch Step 4-6 Video Here

It is very important that the scales are calibrated before moving on in the experiment. If you are having difficulty calibrating your scales, ask your instructor or another group to help.

Stop

Step 5: Once the scales are calibrated, have two group members each push on the face of the bathroom scales. Observe the measurements on the two scales. Note: it is very important that you only push on the face of the
scales and do not squeeze the scales from the side. Q5. How do the measurements on each of the scales compare? Hint: there is some degree of error within the scales, so if the measurements are approximately the same, you can report them as equal.

Step 6: One group member should now hold steady without pushing, while the second group member pushes on his/her scale.

Q6. How do the measurements on each of the scales compare?

Q7. Can one group member ever push in a way that will produce a higher reading on one scale than the other?

Q8. Imagine that you remove the scales so that the two group members are just pushing on one another. What would be true about the strength of the pushing force compared to the pushing back force? What evidence supports your idea? Is this a surprise to you? Why or why not?

Step 7: In your lab notebook, complete the statement below about how the strength of a pushing force compares to the strength of a pushing back force.

- When pushing on an object, the object pushes back with a force that is _____________________________ (greater than/less than/equal to) the pushing force.
EXPERIMENT #2: HOW DOES THE STRENGTH OF THE PULLING FORCE COMPARE TO THE STRENGTH OF THE PULLING BACK FORCE?

Step 1: Link two spring scales together so that each spring scale is held by a different group member. Group member #1 should then gently pull on his/her spring scale while group member #2 holds his/her scale stationary. Observe the measurements on the two scales.

At home: [Watch video here](#)

Q1. What can you say about the strength of the pulling force compared to the pulling back force?

Q2. Can you and your partner pull in a way that will cause each scale to have a different measurement? Can you and your partner pull in a way that will produce a measurement of zero on one scale but not on the other? Explain your reasoning.

Q3. Imagine that you remove the spring scales and instead, two people link fingers and gently pull. What would be true about the strength of the pulling force compared to the pulling back force?

Step 2: In your lab notebook, complete the statement below about how the strength of a pulling force compares to the strength of a pulling back force.

- When pulling on an object, the object pulls back with a force that is _____________________________ (greater than/less than/equal to) the pulling force.
EXPERIMENT #3: HOW DO FORCES COMPARE DURING A COLLISION?

Up until now, you have only evaluated pushing and pushing back forces for objects that are stationary. In this activity you will explore how the pushing and pushing back forces compare during collisions. This will allow you to make some inferences about the strength of the forces acting during the collision between the two trucks that you considered in the Initial ideas.

Step 1: Before thinking about a collision between two objects with different masses, first consider a collision between two objects with the same mass. Imagine two carts are going approximately the same speed toward one another and they collide.

Q1. Predict what the force-time graph would look like for each of the carts during this collision. Draw your prediction in your lab notebook.

Step 2: Imagine two carts with different masses going approximately the same speed toward one another and they collide.

Q2. Predict what the force-time graph would look like for each of the carts during this collision. Draw your prediction in your lab notebook and label the lines of your graph so you know which is for the cart with more mass and which is for the cart with less mass.

Step 3: Your instructor will show you slow motion videos (or a demonstration) of these two collisions and the force-time graphs for the two carts.

At home: watch video here (cars with equal mass)
At home: watch video here (cars with different masses)

Q3. Draw the force-time graphs in your lab notebook.

Q4. What do you notice about the strength of the force on each cart during the collision?

Q5. Compare the force-time graphs from the experiment to your prediction graphs.

Step 4: In your lab notebook, complete the statement below.

- When the two carts collide, the more massive cart pushes with a force that is
(greater than/less than/equal to) the pushing force from the less massive cart.
EXPERIMENT #4: WHY MIGHT PEOPLE THINK A MORE MASSIVE OBJECT EXERTS A GREATER FORCE DURING A COLLISION?

Step 1: Look back to your initial idea about the two trucks that were involved in a head-on collision.

Q1. How did you predict the strength of the force from the large truck on the small truck compared to the strength of the force from the small truck on the large truck?

Q2. Did you collect any evidence in the previous experiment that caused you to change your idea(s)? If so, what was it, and why did it cause you to change your idea(s)?

It is not uncommon for people to have the intuition that a larger object will exert a larger force than a smaller object in a collision. However, as you just observed, this is not the case. There is a reason this is a common intuition.

In the remainder of this activity, you will develop an explanation for why it is a common intuition that a larger truck would exert a larger force in a collision than a smaller truck.

Step 2: Imagine the following set up: two carts are placed on a track, about 20 cm apart. One cart has an added 500 g mass on the top. There are motion sensors on both ends of the track that will collect velocity-time data for each cart.

Step 3: The two carts are given a quick and gentle push toward one another so that they both have approximately the same initial velocity.

Q3. Using what you know about Newton’s Second Law, predict how the acceleration of each cart will compare during the collision.

Step 4: Your instructor will show you a slow motion video of the collision between these two carts. At home: watch video here

Q4. Which cart had the greatest magnitude of acceleration during the collision? Describe how you know using the velocity-time graph to support your claim.

Q5. (Extension) Use velocity and time data for the two carts at the beginning and end of the collision as
shown in the two graphs below to calculate the acceleration for each cart. Note: this extension should be completed by students who have done the mathematical models activities from F.1, F.2, and F.3.

Q6. Use Newton’s Second Law to defend why the more massive cart and the less massive cart had different accelerations during the collision. Keep in mind that the strength of the force acting on each cart during the collision is the same.

Q7. Why might it be a common intuition that the larger object exerts a greater force than the smaller object during a collision? Hint: think about the accelerations of the two objects in the collision.
### SUMMARIZING QUESTIONS

<table>
<thead>
<tr>
<th>SUMMARIZING QUESTIONS</th>
<th>MY ANSWERS</th>
<th>ADDED IDEAS FROM THE READING</th>
</tr>
</thead>
</table>
| 1. A small bug collides with a massive truck.  
   a. Which will experience the greatest force: the bug, the truck, or neither? What evidence supports your idea?  
   b. Which will have the greatest acceleration? What evidence supports your idea? | | |
| 2. Think again about the collision between the two trucks that you thought about in the Initial Ideas. It is a very common idea to think that the large truck exerts a greater force on the small truck (than the small truck exerts on the large truck). Based upon your observations from this activity, describe why people might think this. | | |
| 3. Use the mathematical form of Newton’s Second Law to describe how it is possible that a large truck and a smaller truck exert the same strength force on one another (in opposite directions) when they collide. | | |
| 4. For each of the situations below, identify the force pair:  
   a. A snowball hits a girl in the back.  
   b. A baseball player catches a ball.  
   c. A swimmer pushes off of the wall of a pool.  
   d. A soccer player kicks a ball. | | |
| 5. How is a force pair different from two balanced forces? | | |
F.4 Scientists’ Ideas Reading

Instructions: As you read the Scientists’ Ideas, think about how they relate to the evidence you collected in the activity.

Newton’s Third Law: When one object exerts a force on a second object, the second object exerts a force on the first object that is the same strength, but in the opposite direction.

For every acting force, there is always a “reaction” force that is the same strength (magnitude), but in the opposite direction. These two forces are called a force pair.

Force pairs also exist during collisions. During a collision between a big truck and a little truck, the force pair is the force the big truck exerts on the little truck and the force the little truck exerts on the big truck. Newton’s Third Law says that these forces are equal in magnitude (size), but act on different objects and in opposite directions.

A force pair is different than balanced forces: A force pair is a set of two forces of the same strength that are acting in opposite directions on two different objects. Balanced forces describe two forces of the same strength in opposite directions that are acting on one object.

It is not uncommon to confuse two balanced forces with a force pair. However, there is one key difference that will help you keep the ideas separated. Balanced forces involve forces acting on one object. For example, think about a person pushing a cart at a constant speed: the force with which the person pushes the cart and the force of friction on the cart are the same strength. Both of these forces are acting on the same object (the cart). Balanced forces occur when two forces of the same size are acting in opposite directions on one object (remember that balanced forces can also occur with more than two forces as long as the sum of the forces in one direction equals the sum of the forces in the opposite direction).
Now think about the hand pushing the cart in terms of force pairs. **With a force pair, the forces are being exerted by, and acting on, two different objects.** When the person pushes the cart, the cart pushes back on the person with the same strength force. This is an example of a force pair.

**Same strength force on objects with different mass:** When two objects are acted on by same strength forces, but the objects have different masses, they will have different accelerations.

To understand how the trucks accelerate differently, it is necessary to think about Newton’s Second Law:

\[
\vec{a} = \frac{\vec{F}}{m}
\]

We can rearrange this equation to solve for force:

\[
\vec{F} = m \cdot \vec{a}
\]

Since the magnitudes of the two forces are the same, \(|\vec{F}_{big\ truck}| = |\vec{F}_{little\ truck}|\), we can just compare their masses and the magnitude of their accelerations:

\[
m \cdot |\vec{a}_{big\ truck}| = m \cdot |\vec{a}_{little\ truck}|
\]

Since their masses are different, we know that the magnitude of their accelerations must also be different. The mathematical equations below visually represent (with the size of the font) how this can be.

\[
\vec{F} = m \vec{a}
\]

\[
\vec{F} = m \vec{a}
\]

\[
m \vec{a} = m \vec{a}
\]

The mass (m) is much greater for the big truck and the magnitude of acceleration is much smaller for the big truck. This is why the little truck slows down so much more quickly in the accident than the big truck.
Respond to the following questions **individually** in your lab notebook:

1. When two objects collide, how does the strength of the pushing force compare to the pushing back force? When the mass of one of the objects is larger, will it apply a stronger force? Draw a force diagram to support your response.

2. For each of the situations below, identify the force pair:
   a. A person pushes a sofa.
   b. A baseball bat hits a ball.
   c. A student jumps off the ground.
   d. One car “rear ends” another car.

3. Draw force diagrams for each of the following force pairs:

   a. Two cars collide.  
   b. A person pushes on a wall.

![Car Collision Diagram]

4. Describe the difference between a force pair and two balanced forces.

5. Give one example of a force pair and one example of an object acted on by two balanced forces.

6. When discussing why an object moves at a constant speed, is it appropriate to describe the reason as balanced forces or force pairs? Describe your thinking.

7. For each of the following situations, identify if it is a force pair or two balanced forces:
   a. When a bowling ball hits a bowling pin, the force from the ball on the pin is the same as the one from the pin on the ball but in the opposite direction.
   b. When a man pushes on a filing cabinet, the filing cabinet pushes back on the man with the same strength force in the opposite direction.
   c. A filing cabinet doesn’t move when a man pushes it because the force from the man’s push equals the force from friction on the cabinet.

8. You may have heard of Newton’s Third Law phrased as “every action produces an equal and opposite reaction.” Describe what this means in terms of the evidence you collected in this activity.
9. This Scientists’ Ideas Reading discussed how you might use font size to visually represent how the force pairs are equal when objects of different mass collide, but the accelerations are different. Summarize this idea in your own words.

10. Use Newton’s Second Law and Newton’s Third Law to describe why a bowling pin goes flying and the bowling ball hardly changes speed when the bowling ball collides with the bowling pin.

Assume friction is negligible for the following questions:

Two students, Daryl and Dave, are each sitting on identical wheeled office chairs. Daryl has the same mass as Dave.

11. If Daryl pushes off of Dave’s knees, how do you think each of them will move?

12. What forces do you think are acting on each person? Which one of these forces is larger, if either?

Now two students, Luis and Dave, are facing one another on identical wheeled office chairs. Luis has twice the mass as Dave.

13. When Luis pushes off of Dave’s knees, how do you think each of them will move?

14. What forces do you think are acting on each person? Which one of these forces is larger, if either?

15. How is the comparison between these forces different from the situation with Daryl and Dave?
Apply physics principles developed in the activity by grappling with the questions below.

1. In this activity, you considered both the force and acceleration for collisions between objects. Imagine a car accident involving a school bus with a mass of 13,600 kilograms (roughly 30,000 pounds) that collides with a smaller car with a mass of 1,270 kilograms (roughly 2,800 pounds). The bus and the car were each traveling at exactly the same speed when they collided “head on.”
   a. Compare the strength of the force from the car on the bus with the strength of the force from the bus on the car. Draw a force diagram to support your response. Be sure to label all force arrows.

   b. How will the acceleration of each vehicle compare in this collision? Use Newton’s Second Law to justify your response (you may find it helpful to look at Key Idea F.4c).

2. Why is it that in an accident where each vehicle is initially traveling at the same speed, the passengers in the “less massive” vehicle may sustain greater injuries in the accident. Discuss in terms of your responses to the previous two questions.

3. Read the quote below from an article published by CNN.

   “… federal law requires smaller school buses — those weighing 10,000 pounds or less — to have lap-shoulder belts, according to the National Conference of State Legislatures. School buses above that weight are not mandated to provide seat belts for passengers.” Use Newton’s Third Law to explain why school buses greater than 10,000 pounds have not been required to include seat belts by federal law.
Respond to the questions below to demonstrate your understanding of the physics of seat belts.

1. Use Newton’s Law(s) to describe why a passenger without a seat belt keeps moving.

2. Imagine a car accident where the driver is wearing a seat belt, but the passenger is not. Draw a velocity time graph for a passenger who slows down when wearing a seat belt in a car compared to a person who slows down without a seat belt (i.e. from hitting the dashboard of the car). Remember that seat belts have some “stretch” in them.

3. People who are not in support of adding seat belts to school busses claim that busses do not need seat belts because in an accident, passengers will stop by hitting the soft padded seat in front of them. How do the padded seats serve a similar purpose as a seat belt during an accident?