PHYSICS UNION MATHEMATICS

Physics I

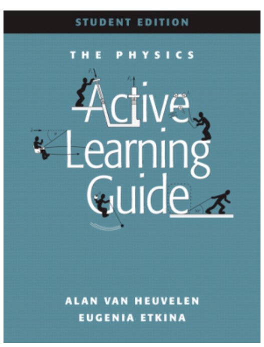
Dynamics

Student Edition

Supported by the National Science Foundation (DRL-0733140)

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

PUM Physics I
Dynamics



Adapted from:

A. Van Heuvelen and E. Etkina, *Active Learning Guide*,
Pearson, San Francisco, 2006.
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Additional materials designed by E. Etkina, S. Brahmia, J. Finley, J. Santonacita, T. Finley, H. Lopez, M. Michaelsen, M. Blackman, C. Soni, J. and many other NJ teachers.

This material is based upon work supported by the National Science Foundation under Grant DRL-0733140. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation (NSF).

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Lesson 1: Forces as Interactions

1.1 Observe and Describe

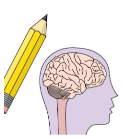
a) Pick up a tennis ball and hold it in your hand. Now pick up a different ball (medicine ball or other) and hold it. Describe the difference.

b) Think of a word that describes what your hand had to do to the tennis ball in order to hold it. Write possible words below:

c) In Physics, we use the word ***interaction*** to describe what the hand does to the ball. It interacts with the ball. In any interaction, there are always 2 objects involved. Give 2 examples of other interactions below, indicating the 2 interacting objects.

Need Some Help?

One example is a tennis racket hitting a tennis ball. You would say the tennis racket ***interacts*** with the tennis ball. Another situation could be pulling a sled with a rope. You would say the rope ***interacts*** with the sled when it pulls it.



1.2 Represent and Reason

In the last module on motion, we learned how to represent the motion of objects using data tables, graphs, equations, and motion diagrams. In this module, we can represent interactions with a new representation.

a) Let's choose the tennis ball to be our object of interest.
In the space to the right, represent the tennis ball with a dot, and label it "ball". Think of how your hand had to push on the ball. Then draw an arrow on your diagram (dot) to show how your hand pushes the ball.
Connect the tail of the arrow to the dot.
The arrow should point in the direction of the ***force*** your hand exerts.

b) How could you label this force arrow to show that it is the force your hand exerts on the ball? Add this label to your representation above.

Here's An Idea!

To show that the force arrow represents the push that the hand exerts on the ball, we can use a symbol *F* with two little words at the bottom on the right. These are called subscripts. You can then write the force that your hand exerts on the ball as $F_{\text{Hand on Ball}}$.

c) Why don't we add the force arrow for how the ball interacts with the hand?

Need Some Help?

In part (a), we chose the tennis ball as our object of interest, or "system". A ***system*** is an object or group of objects that we are interested in analyzing. When we draw force arrows, we only consider the forces that are *exerted ON the system object(s).*

d) What do you think would happen to the ball if your hand (pushing just as hard as before) were the only object interacting with it?

e) What does this tell you about other objects interacting with the ball?
Name/list any other objects interacting with the ball.

Did You Know?

In physics the word ***force*** is only used to note the physical quantity that describes how hard one object pushes or pulls another object. For a force to exist there must be two objects involved. **One object does not carry or possess a force.**

Remember that all physical quantities are measured in units. The **unit** of force is called the **newton** (N), where 1 N = (1 kg)(1 m/s^2). This unit will be explained later, but note that all units must be in kg, m, and s.

1.3 Test your Idea

a) In part 1.2 d, did you say that air interacts with the ball? How do you think air interacts with the ball?

b) What experiment can you perform to test you idea of how air interacts with the ball?

c) Use the video experiment on the website, if equipment is not available.

Experiment: *A sealed 2-L soda bottle is suspended from a spring inside a bell jar. A vacuum pump is connected to remove the air from the bell jar surrounding the bottle. A mark is made to indicate the suspended position of the bottle. What will happen when the air is removed from the jar?*

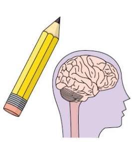
Before watching the video or performing the experiment, write a prediction of what should happen to the bottle, based on your hypothesis about how air interacts with an object.

Prediction:

d) Watch the video or perform the experiment:
http://paer.rutgers.edu/pt3/movies/bottle_in_vacuum.mov
Or go to http://paer.rutgers/edu/pt3 and click on Newton, then on Newton's second law and finally on The Effect of Air.

e) Summarize the effect the air has on the ball.

Note: We often simplify situations in physics by ignoring air resistance. ***So, unless stated otherwise, air resistance is not considered.***



1.4 Represent and Reason

a) In activity 1.2 (e), did you say that gravity interacts with the ball? Gravity is not an object; you cannot hold or touch it. So when we use the word gravity to note the downward pull on all objects on Earth, what is the object that exerts this downward pull?

b) Add another Force arrow on your diagram in 1.2(b), and draw it here:
Label the Force arrow with the appropriate subscripts.

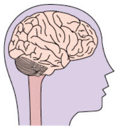
c) What do you notice about the length of the arrows on your diagram?

What do you think would happen to the ball if the arrow representing the interaction with your hand were *longer* than the arrow due to the interaction with the Earth?
What if it were the opposite --- *shorter*?

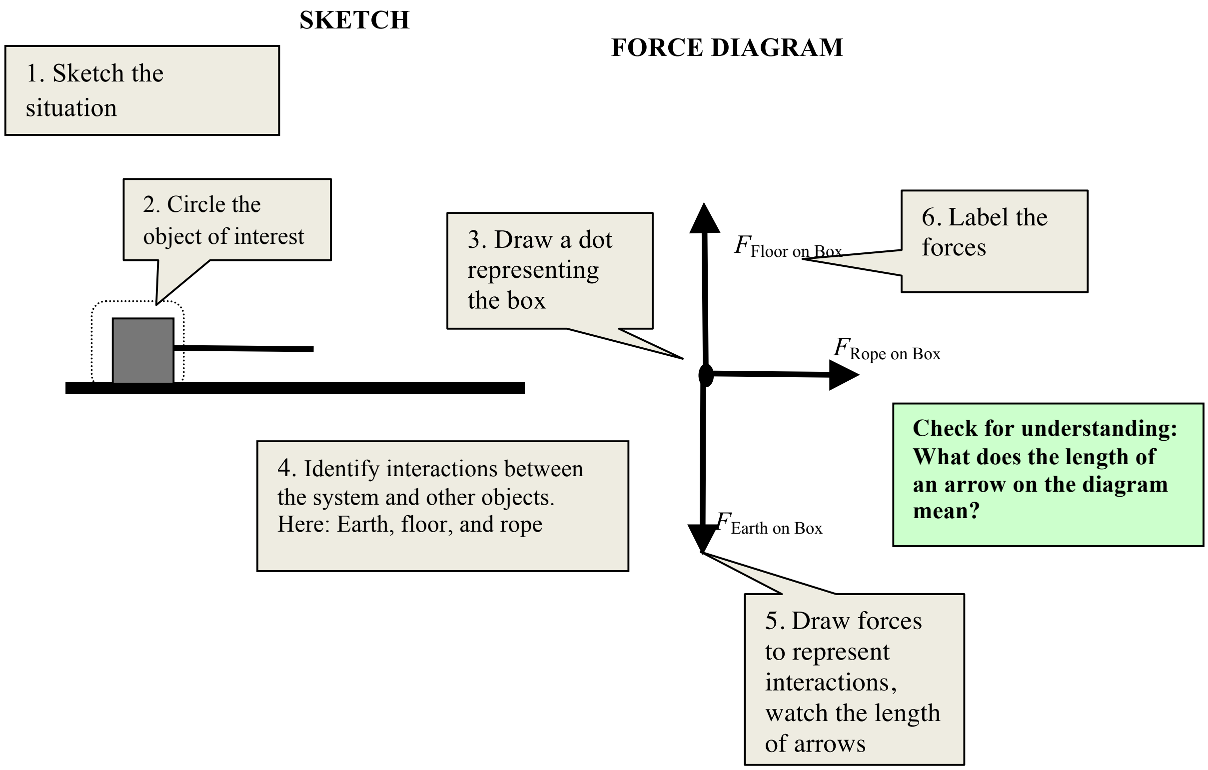
d) Now, draw a diagram for the second ball (medicine ball or other).
How are the force arrows different from the arrows on the diagram for the tennis ball?

Did You Know?
The diagrams you created in activity 1.4 are called ***force diagrams***. Force diagrams are used to represent the forces exerted on an object of interest (system) by other objects. Objects may be represented by a dot. The length of each arrow should correspond to the relative amount of force. (more force = longer arrow, etc.), and the direction of the arrow shows the direction of the force (push or pull). Draw the arrows coming outward from the object even when some objects are pushing on the object.

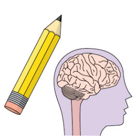
Reasoning Skill: Constructing a Force Diagram



A force diagram is a physical representation used to analyze and evaluate processes involving forces – you are pulling a box on a very smooth floor. Study the picture below that summarizes the steps we take to draw a force diagram.



1.5 Represent and Reason



a) (Refer back to the tennis ball questions in 1.4). How might we represent this force diagram with a mathematical representation or math statement (equation)? Write a math statement for the tennis ball. Read "Need some Help?"

Need Some Help?
In Physics, we are interested in determining the total force exerted on the system object.
In your own life, you determine the total amount of money you have. To do this, you would add the money you have as <u>*cash*</u> plus the money you have in the <u>*bank account*</u> plus the money you have in <u>*checks*</u> and <u>*gift cards*</u>, plus the money you <u>*owe your sister*</u>, plus the money you <u>*owe for a class field trip*</u>. As a math statement, you could write this as:

$$M_{\text{cash}} + M_{\text{bank}} + M_{\text{gift cards}} + (-M_{\text{sister}}) + (-M_{\text{field trip}}) = \text{Total Money}$$

Another name for "Total" of all of the pluses and minuses is "**net**", or the symbol sigma, **Σ,** which means "sum of", can be used.

$$\Sigma \text{ Money} = M_{cash} + M_{bank} + M_{gift\ cards} + (-M_{sister}) + (-M_{field\ trip})$$

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b) In your math statement, you represented one force with a positive number and one force with a negative number. How did you decide? What does the negative mean?

c) Imagine you let the positive direction be down and the negative direction be up. Write a math statement to represent your force diagram now.

d) Does the sum of the forces change? Explain.

Did You Know?

If you put the number line next to the dot, you can use (+) for some chosen direction and (-) for the opposite direction. For example, you can use (+) for the up direction and (-) for the downward direction. Then we can write the sum of the forces exerted on the ball by the hand and the Earth as:

$$F_{\text{Hand on Ball}} + (-F_{\text{Earth on Ball}}) = 0$$

Note: You can only add forces exerted on the same object along the same axis!
You add all of the horizontal forces together, or all of the vertical forces together.

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e) Now represent the force diagrams with number statements by assigning integers to the values of the forces in the math statements for each ball. Remember to include units with the number values.

Ball 1:

Ball 2:

f) How is the number statement for tennis ball different from the number statement for the medicine (or other) ball?

1.6 Concept of Zero

a) Look at your number statements in activity 1.5. You found that the total force exerted on the tennis ball is zero. What does zero mean in this situation?

b) How is this different from the meaning of zero as an absence (example: zero cookies, zero brothers or sisters)?

Need Some Help?
Zero often is used to represent balance or neutrality – an equal number of positive and negative quantities. It does not mean there are no forces; it means that the forces that are exerted on the object balance each other out.
Example: The senior class challenges the teachers to a game of tug-of-war. Each team pulls the rope exerting 25 newtons of force, and the rope doesn't move at all. Represent this event by using integers. Decide to which pull you will assign a positive number: to the right or to the left. Then see if adding these numbers gives you a zero.
For example, "pull to the right" can be represented by positive numbers and "pull to the left" can be represented by negative numbers.

Number statement: (+25 units) + (-25 units) = (0 units)

Although there is plenty of pulling going on, the net effect is that there is zero total pulling on the rope. The sum of the forces is zero.

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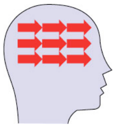
c) Devise 3 examples where you have two forces exerted on an object but the sum of the forces force is zero. Represent these examples with integers (number statements).

Homework (use a separate sheet of paper)



1.7 Represent Interactions with Arrows

Scenario - A jacket is hanging on a hook.

a) What are the objects with which the jacket interacts? What object is our system object?

b) Represent this situation with a force diagram.
Explain why you drew it the way you did.

c) You put a heavy book in one of the pockets of the jacket. How does the force diagram change?

1.8 Represent Interactions with Integers

You and your friend are helping each other hold a very heavy suitcase.

a) Draw a force diagram for the suitcase.
Represent the total force with a number statement.

b) What is the total force (sum of the forces) exerted on the suitcase if you and your friend are holding it still?

c) How did you decide which direction is positive and which is negative? What if you made the opposite choice?

Lesson 2: Can a Table Push?

2.1 Observe and Explain

Perform the experiments described in the first column of the table, record your data, and then fill in the empty cells. In this activity, we measure forces with scales. Recall that the unit of force is a newton.

a) Complete the table below.

For each part of the experiment below, record the spring scale reading and platform scale reading, list all object that interact with the block, draw a force diagram.

Then, explain what you observe, and state which object(s) exert a force to balance $F_{\text{Earth on Block}}$, and in what direction.

<table>
<tr><td rowspan="2">Hang object from spring scale</td><td><u>Spring Scale:</u></td><td>Interacting objects:</td><td><u>Force Diagram</u>:</td></tr>
<tr><td><u>Platform Scale:</u></td><td>Object that balances $F_{\text{Earth on Block}}$,</td><td><u>Explain observations:</u></td></tr>
</table>

Lower the object onto a platform scale so it touches the scale.	**<u>Spring Scale:</u>**	**Interacting objects:**	**<u>Force Diagram</u>**:

	Platform Scale:	**Object that balances $F_{\text{Earth on Block}}$,**	**Explain observations:**
Remove the spring scale and leave the object on the platform scale.	**Spring Scale:**	**Interacting objects:**	**Force Diagram**:
	Platform Scale:	**Object that balances $F_{\text{Earth on Block}}$,**	**Explain observations:**

For the experiments below, record your observations.

Place the object on a horizontal meter stick whose ends rest on two blocks. Record what happens.	
You place the object on a thick, foam cushion. Record what happens.	
You place the object on a tabletop. Record what happens.	

b) Some people think that only alive living? (animate) objects can exert forces. The table is not alive. How can a table push on an object?

2.2 Observe and Explain

Place an empty plastic bottle on the table.

a) Let's choose the bottle as our system. Represent the forces exerted on it with a force diagram. Write a number statement (like in 1.5 and 1.6) describing the forces exerted on the bottle. Explain why one number must be positive and the other one must be negative. Could you have made the opposite choice?

b) Hang an empty plastic bottle on a spring or a spring scale. Observe the stretch of the spring. Represent the situation with force arrows and write a number statement.

c) Add sand to the bottle. Observe the stretch of the spring now. Represent the situation with force arrows and write a number statement. How did you have to change the number statement from part b? Explain.

d) Create a rule for the stretch of a spring when an object is hung on it.

2.3 Test Your Idea

a) Consider the following experiment: *You hang a sand-filled bottle on a spring (or spring scale) and submerge half of it in a large container of water.*

   Using your rule from Lesson 2.2, predict what should happen to the stretch of the spring. Draw a force diagram to help explain your prediction.

b) What outcome of the experiment will convince you that your reasoning is not correct? Explain.

c) Perform the experiment and record the outcome.
   Did your prediction match the outcome of the experiment? If not, how can you modify your reasoning to account for the outcome?

d) Represent the outcome of the experiment with a force diagram and a number statement. Discuss how the spring and water are similar to or different from the table on which you placed the bottle at the beginning of the experiment.

Homework

2.4 Represent with Integers

Fill in the table below.

Experiment	List objects interacting with the book bag.	Draw a force diagram for the book bag.	Represent the forces with a number statement. Which direction did you choose as positive and which as negative?
(a) You hang a book bag from a spring scale; the scale reads 50 N.			
(b) You lower the bag onto a platform scale. The spring scale reads about 20 N, the platform scale reads about 30 N.			
(c) You remove the spring scale and leave the bag on the platform scale; it reads 50 N.			

(d) You place the bag on a horizontal meter stick whose ends rest on two blocks. The meter stick bends down before it can support the block.			
(e) You place the bag on a thick foam cushion; the object sinks into the cushion before it stops.			
(f) You place the bag on a tabletop.			

Lesson 3: Combining Math and Physics

3.1 Represent and Reason

<u>A person pushes a box along a very smooth floor.</u>

a) Examine the force diagram shown at right for the situation above.
Determine the length of each arrow in the vertical and horizontal directions.

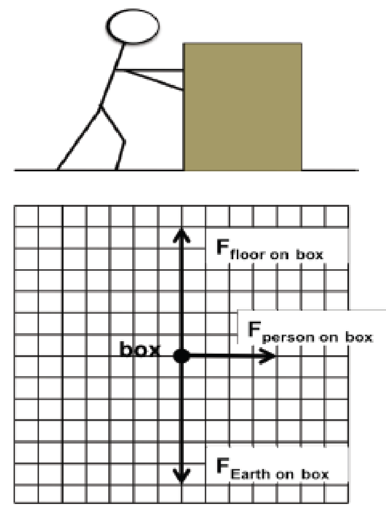
b) Do the vertical arrows add to zero, if you consider their directions?

Do the horizontal arrows add to zero?

c) Write separate number statements for the sum of the forces for the vertical direction and for the horizontal direction.

Vertical:

Horizontal:



3.2 Represent and Reason

a) Draw a force diagram for yourself sitting on a chair (you are the system). What forces add to zero? If Earth exerts a 300 N force on you, what is the force that the chair exerts on you? How do you know?

b) Now imagine a friend is pushing the chair so that it is sliding across the floor. Draw a new force diagram for the system. What forces exerted on the system add to zero? What forces do not add to zero?

3.3 Represent and Reason

Sketch each scenario below. Circle the object of interest (the system), and then draw a force diagram for each system. Make sure you label each arrow with the appropriate subscripts.

a) A framed picture is supported by two vertical strings.
Earth pulls on the picture exerting a 70 N force on it.
What is the force exerted by each string on the picture?

b) A ball that was thrown up: on the way up, after it has been let go. Be careful here!

3.4 Represent and Reason

Zara and Mona pull on cart A in opposite directions.

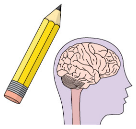
a) Zara pulls exerting a force of 3 N to the left, and Mona pulls exerting a force of 2 N to the right.
Laila and Yasmine pull on an identical cart B, also in opposite directions. Laila pulls exerting a force of 3 N to the left, Yasmine pulls exerting a force of 5 N to the right.

Draw force diagrams for each cart. Then represent these events with number statements for the horizontal direction only. Determine sum of the forces exerted on each cart in the horizontal direction.

b) Here are more experiments for Zara and Mona pulling in opposite directions. Represent these events with a force diagram for the horizontal direction only and with a number statement. Determine the result of each situation (the sum of the horizontal forces exerted on each cart).

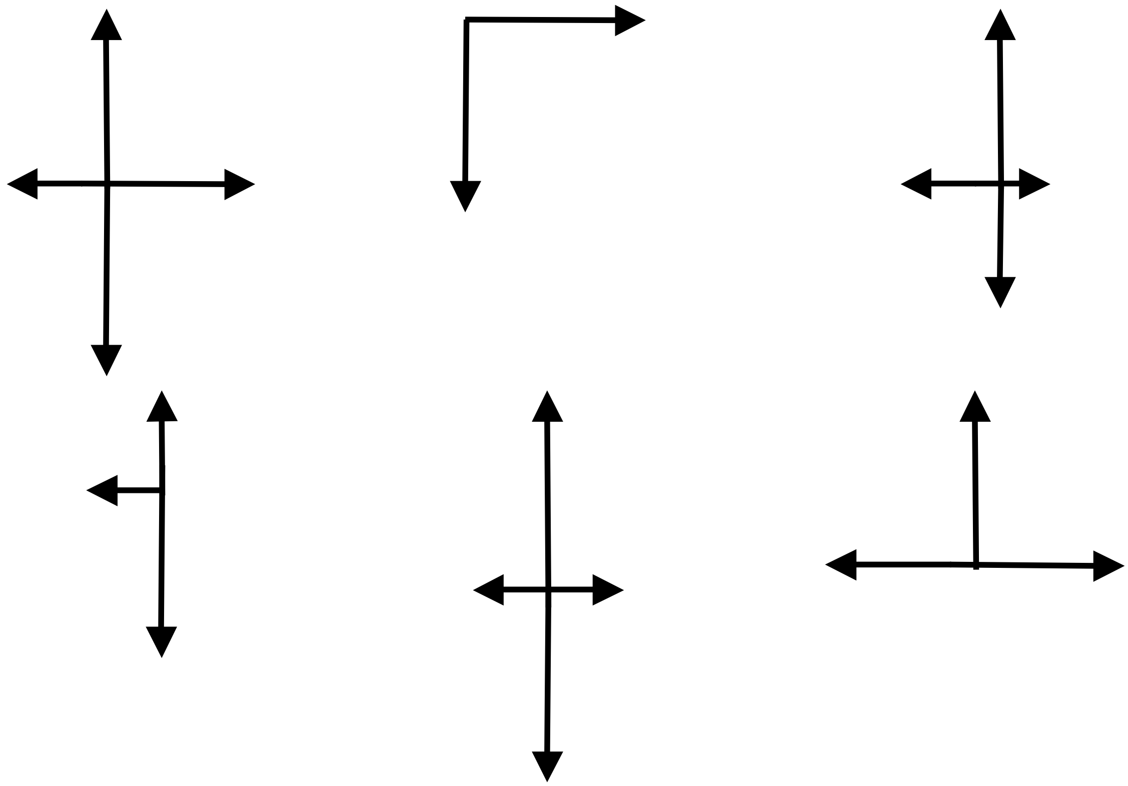
Zara pulls to the left	**Mona pulls to the right**	**Force Diagram**	**Number representation**	**Result**
3.5 N	4.5 N			
1.5 N	3/2 N			
3.25 N	3.75 N			
7/5 N	1.5 N			
0.8 N	0.8 N			

c) If you were using a spring scale to measure the forces in the table, then how certain would you be in each value? Write the values of the forces using the experimental uncertainty, assuming that the smallest division on your spring scale is 0.1 N.



3.5 Represent and Reason

a) The unlabeled force diagrams below represent forces being exerted on different objects. Draw arrows to represent the sum of the forces in the horizontal direction and in the vertical direction.



b) What is meant by the term “sum of the forces”?

c) How did you determine the horizontal and vertical sums?

d) Can vertical forces cancel out horizontal forces? Explain.

Homework
(Complete on separate paper, for more space)

3.6 Represent and Reason
The following is a list of scenarios. Read the scenario, then follow the instructions below.

a) Make a force diagram for each situation.
b) Describe the sum of horizontal forces mathematically and calculate its value.
c) What do you think happens to each cart?
d) Which cart will change its motion more in 1 second? Which cart will not change its motion?

- Marwa pulls on a cart (cart A) in one direction, exerting a force of 41 N and Beth pulls in the opposite direction, exerting a force of 15 N.
- Ali pulls on a similar cart (cart B) in one direction, exerting a force of 26 N and Mark pulls in the opposite direction, exerting a force of 55 N.
- Shawn pulls on a similar cart (cart C) in one direction, exerting a force of 26 N and Taisha pulls in the opposite direction, exerting a force of 26 N.

3.7 Estimate Uncertainty

Rob and Tina collected data using a scale that had divisions every newton (N): 0 N, 1 N, 2 N, 3 N, etc. When Tina hung her bag on the spring scale, she wrote the reading of the scale as 2.2 N. Rob repeated the experiment and wrote the reading as 2.3 N. They used the same bag. Why are their numbers different? Who do you think is correct? Based on your answer and the information given, decide how precisely you can measure the force with this scale.

3.8 Represent and Reason A box sits on the floor. The Earth pulls on it exerting a force of 60 N.
a) Draw a force diagram for the box.
b) What is the force that the floor exerts on the box? Explain how you know.
c) What is the sum of the forces exerted on the box? Explain how you know.

3.9 Represent and Reason
A box sits on the floor. The Earth pulls on it exerting a force of 60 N. You push it horizontally exerting a 40 N force.
a) Draw a force diagram for the box.
b) What is the force that the floor exerts on the box? Explain how you know.
c) What is the sum of the forces exerted on the box? Explain how you know.

3.10 Estimate Uncertainty
Find three measuring devices in your house (each one needs to show the quantity that it measures, the units of measurement, and a scale).
a) Write down the experimental uncertainty for each instrument.
b) Now take a measurement with each instrument and write the result so that it incorporates the experimental uncertainty.

Lesson 4: Relating Motion Diagrams and Force Diagrams

4.1 Observe and Represent

a) Use a bowling ball and a board (or anything that rolls easily, a billiard ball or a low friction cart on a track, or other equipment as provided by the instructor).

Set the ball on the floor at rest and then continually push it with the board for a while. Try to push the same way and keep the ball moving along a straight line. Observe the motion of the ball. What kind of motion is it? How do you know?

b) After you agree on how the ball is moving, fill in the table below.

<table>
<tr><td>List all of the objects that interact with the object while it is being pushed. Describe these interactions in words.</td><td>Draw a force diagram for the ball.</td><td rowspan="2">What forces “cancel” or add to zero? Explain how you know.

What is the sum of forces exerted on the ball? Explain how you know.

If sum of the forces is not zero, indicate its direction.</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">Draw a motion diagram for the ball. Include v and Δv arrows.</td></tr>
</table>

c) Compare the direction of the $\Delta\vec{v}$ arrow on the motion diagram to the direction of the sum of the forces that you can infer from the force diagram.

4.2 Observe and Represent

a) Use a bowling ball and a board. This time, set the ball in motion by pushing it once. After it is already moving, push with the board very lightly in the opposite direction to the ball's motion. Try to push the same way. Observe the motion of the ball. What kind of motion is it? How do you know?

b) After you agree on how the ball is moving, fill in the table below.

<table>
<tr><td>List all of the objects that interact with the bowling ball while it is being pushed. Describe these interactions in words.</td><td>Draw a force diagram for the ball.</td><td rowspan="2">What forces add to zero? Explain how you know.

If the sum of the forces is no zero, indicate its direction.</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">Draw a motion diagram for the ball.</td></tr>
</table>

c) Compare the direction of the $\Delta\vec{v}$ arrow on the motion diagram to the direction of the sum of the forces on the force diagram.

4.3. Find a Relationship

a) Use your findings in activities 4.1 and 4.2 to formulate how a motion diagram and a force diagram for the same object are related.

b) Use this relationship to predict what will happen if you set the bowling ball in motion and do not touch it after that. Explain how your prediction is based on the relationship.

c) Perform the experiment and record the outcome. Did it match the prediction? What can you say about the relationship?

4.4 Test Your Idea

Hold a medicine ball. Imagine now that your friend drops the medicine ball vertically so you have to catch it before it touches the ground. Consider the motion of the ball *after* it touches your hands.

a) Predict what the motion of the ball will be like and draw a motion diagram. Explain why you drew it the way you did. Think of how you could convince your friend that your motion diagram describes the motion.

b) Now use the relationship you developed in 4.3 to draw a force diagram for the ball for an instant after it touches your hands. What can you say about the length of the force arrows?

c) Think of how you can experimentally check whether the force diagram you predicted is correct.

Here's An Idea!

You can do a qualitative check by actually performing the experiment as it is described. However to check the force diagram and the lengths of the force arrows, you can drop the medicine ball on a bathroom scale and observe the reading on the scale. View the following videos (the second one should be viewed frame by frame):

http://paer.rutgers.edu/pt3/movies/medballdrop1.mov
http://paer.rutgers.edu/pt3/movies/medballdrop2.mov

d) How is the dropping the medicine ball on the bathroom scale like dropping the medicine ball into your hands?

e) Now perform the experiment by letting your friend drop the medicine ball into your hands. What did you do to catch it before it touched the ground? What happened to the ball after it touched your hands?

f) What judgment can you make about your relationship between the motion diagram and force diagram for the same object?

Did You Know?

In the activities above, you determined that the sum of the forces exerted on an object points in the same direction as the delta v arrow on a motion diagram for that object. We can also say that when all the **forces** exerted on that object add to zero, the **delta *v* arrow is zero**. This is a part of the idea behind **Newton's first law**.

Newton's first law of motion: We choose a particular object as the object of interest—the system. If no other objects interact with the system object or if the sum of all the external forces exerted on the system object is zero (forces in the y direction add to zero and forces in the x direction add to zero), then the system object continues moving at constant velocity (including remaining at rest) as seen by certain observers.

Homework

4.5 Observe and Find a Pattern

Imagine that you performed the following experiments, and then fill in the table that follows.

Experiment	**Sketch a motion diagram for the cart.**	**Draw a force diagram for the cart.**	**Number description (make up numerical values and indicate which direction is positive)**
(a) You steadily push the back of a cart along a smooth surface so that it moves faster and faster.			
(b) You stop pushing the cart and let it coast. The cart does not slow down.			
(c) You push gently on the front of the moving cart so that it moves slower and slower and eventually stops.			

d) Examine the direction of the sum of the forces in each scenario and compare it to the direction of the $\vec{v}$ arrow. Do you see a pattern? Explain.

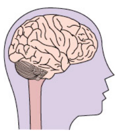
e) Examine the direction of the sum of the forces in each scenario and compare it to the direction of the $\Delta\vec{v}$ arrow. Do you see a pattern? Explain.

f) How do your answers to d and e relate to the rule you developed and tested in 4.3 and 4.4?

g) How do you understand the difference between the words "motion" and "change in motion"? Give an example. Do you think the forces exerted on an object cause motion or a change in motion?

4.6 Reason

You throw a ball upward.



a) Draw a motion diagram for the motion of the ball after it leaves your hand but before it reaches the top of its flight.

b) Draw force diagrams for two instances: right after the ball left your hand and when it is almost at the top of the flight next to the motion diagrams above.

c) Is the motion diagram consistent with each force diagram? Explain.

4.7 Reason

You are playing ice hockey. You hit a puck and it starts sliding.

a) Draw a motion diagram for the puck for two instances: right after the puck left the stick and after a short time interval.

b) Draw force diagrams for the puck for the same two instances next to the motion diagrams above.

c) Is the motion diagram consistent with each force diagram? Explain.

Lesson 5: What's a Force to Do?

5.1 Test an Idea

Aaron thinks that objects ***always*** move in the direction of the sum of the forces exerted on them by other objects.

a) Design an experiment in which an object moves in the direction of the sum of the forces. Describe, carefully, what you are going to do.

b) Draw a force diagram for the experiment you described.

c) Use the force diagram and **Aaron's hypothesis** to make a prediction about the object's motion.

Need Some Help?

Remember in our kinematics unit we spent some time talking about **hypotheses**, **predictions**, and **H-D statements**. Recall the difference between hypotheses and predictions. Also recall that the H-D statements are written in an *If-And-Then* statement.

***REMEMBER!* –** Your predicted outcome always must be based on your hypothesis.

---

d) Perform the experiment and record the outcome. Did it match the prediction? Can you say that you **proved** Aaron's hypothesis correct?

5.2 Test an Idea

a) Design an experiment in which you can exert a force on an already moving object in a direction that is different from the direction of its motion.

b) Draw a force diagram for the experiment you described.

c) Use the force diagram and **Aaron's hypothesis** to make a prediction about the object's motion.

d) Perform the experiment and record the outcome. Did it match the prediction? Now what can you say about Aaron's hypothesis?

e) Revise Aaron's hypothesis to show the relationship between **the sum of the forces** exerted by other objects on the system object and the **motion** (or **change in motion**) of the system object.

5.3 Test an Idea

James thinks that when *the sum of the forces exerted by other objects on the object of interest is zero, the object is at rest*.

Design two experiments whose outcomes might contradict James's idea.

Here's An Idea!

You can use a spring scale to lift an object.

Write your prediction for the two experiments based on James' hypothesis. Use the rubrics below to assist you with your reasoning.

Hypothesis-prediction rubric

Scientific Ability	Missing	An attempt	Needs some improvement	Acceptable
Is able to distinguish between a hypothesis and a prediction	No prediction is made. The experiment is not treated as a testing experiment.	A prediction is made but it is identical to the hypothesis.	A prediction is made and is distinct from the hypothesis but does not describe the outcome of the designed experiment.	A prediction is made, is distinct from the hypothesis, and describes the outcome of the designed experiment.
Is able to make a reasonable prediction based on a hypothesis	No attempt is made to make a prediction.	A prediction is made that is distinct from the hypothesis but is not based on it.	A prediction is made that follows from the hypothesis but does not have an if-and-then structure.	A prediction is made that is based on the hypothesis and has an if-and-then structure.

Did You Know?

Relationship between force and motion: If external objects exert **forces** on the system (object of interest) and the sum of these forces is not zero, the **motion** of the object of interest **changes** so that the $\Delta\vec{v}$ arrow (in a motion diagram describing the motion of this object) is in the **same direction** as the sum of the forces exerted on the object.

For example: when you throw a ball upward, it moves upward, although the only force exerted on it points downward. However, the ball is slowing down; the $\Delta\vec{v}$ arrow also points down.

5.4 Equation Jeopardy

The following mathematics statements describe the forces exerted on an object of interest either in the horizontal or in the vertical direction. For each statement, (1) describe a situation that this statement can describe, (2) draw a force diagram, and (3) a motion diagram.

a) Vertical direction: 5 N +(- 3 N)

b) Vertical direction: -3 N

c) Horizontal direction: -7 N + 4 N

d) Horizontal direction: 5 N + (-2 N)

e) Explain why some quantities are positive and some are negative in the statements above.

Homework (do on a separate sheet of paper)

5.5 Equation Jeopardy

The following mathematics statements describe the forces exerted on an object of interest either in the horizontal or in the vertical direction. For each statement, (1) describe a situation that this statement can describe, (2) draw a force diagram, and (3) a motion diagram.

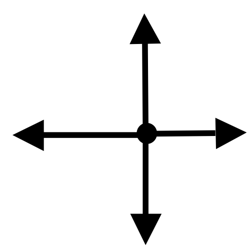
a) Vertical direction: -10 N +3 N

b) Vertical direction: 10 N

c) Horizontal direction: 5 N + (-4 N)

d) Horizontal direction: 2 N + (-2 N)

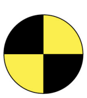
5.6 Diagram jeopardy



A friend proposes that the force diagram at the right describes the forces *exerted on a lawn mower during one instant while mowing the lawn*; the mower is **moving to the right**.

Could such a situation have occurred? If so, describe the situation and label the force arrows on the diagram. If not, explain why not.

5.7 Test an Idea



a) Design an experiment to test the following hypothesis*: a moving object stops instantly when it encounters resistance*.

b) Make a prediction based on the hypothesis.

c) Perform the experiment and record the outcome. Compare the prediction to the outcome. What judgment can you make about the hypothesis?

Lesson 6: Scales and the Earth

6.1 Reason

We know how to represent forces with arrows, but how do we *measure* forces?

a) How did we “measure” forces in activity 1.1?

b) Think about how hard you had to push up on the heavy ball to prevent it from falling. What would have happened to the ball if you pushed less?

c) How does a spring scale measure forces? Provide two examples.

6.2 Observe and Find a Pattern

a) Fill in the table that follows.

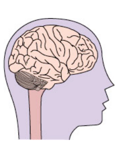
I	II	III	IV	V
Experiment	Reading of the scale in newtons, using experimental uncertainty (after the object comes to rest)	Force diagram	Magnitude of the force exerted by the Earth on the object, in newtons	Number description
Hang a 0.10 kg object				(+0.98 N) + (-0.98N) = 0
Hang a 0.20 kg object				
Hang a 0.30 kg object				
Stop and think: Do you see any pattern in the data?				

Hang a 0.50 kg object	
Hang a 0.70 kg object	
Hang a 1.00 kg object	
Hang a 1.20 kg object	

b) Does the pattern you found in the middle of the table work for the second half of the table? Did you have to make any slight adjustments?

c) What would you expect the force exerted by Earth on the object to be if the object's mass was 10 kg?

6.2 Reason

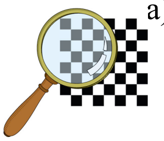


a) Draw a force diagram for an object of mass *m* hanging from a spring scale.

b) Compare the force a spring can exert on an object when the spring is stretched and when the same spring is unstretched. Explain which is larger and how you know.

c) What is the relationship between the length of the force arrow $F_{\text{Scale on Object}}$ and the length of the force arrow $F_{\text{Earth on Object}}$ when the object is at rest hanging from a spring?

6.3 Find a Pattern



a) Draw a graph for the data from columns **IV** and **I** from activity 6.1 (**force exerted by Earth on the object** versus the **object's mass**). What is the dependent variable and what is the independent variable on your graph?

b) Use the rubric below to help improve your graph.

c) What pattern do you see? Think of how you can show the uncertainty in your data on the graph.

d) Use the information you have to write an equation that describes how the force that Earth exerts on the object relates to the object's mass ($F_{\text{Earth on Object}}$ and m).

Ability	Missing	Inadequate	Needs some improvement	Acceptable
Is able to record and represent data in a meaningful way	Data are absent.	Data are present but impossible to understand. Units are missing.	Data are present and have units, but one needs to make a serious effort to understand the data.	Data are present, organized, and recorded clearly. A table is made.
Is able to analyze data using a graph	No graph is present.	A graph is present but the axes are not labeled. There is no scale on either axis.	The graph is present and axes are labeled but the axes do not correspond to the independent and dependent variables or the scale is not accurate.	The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate.

6.4 Reason

a) Estimate the reading of the scale if the object's mass was 25 kg. Explain how you made your estimate. What is the uncertainty in your estimate?

b) Estimate the force that Earth exerts on an object with a mass of 200 g. How certain are you in this value?

6.5 Reason

a) Attach a 100-g object to the scale and lift the scale slowly. Notice the reading of the scale.

b) Can you get it to read 1 N when the object is moving? What did you do to achieve this?

c) Can you get it to read more? Can you get it to read less? What do you have to do to the scale to achieve these?

d) Discuss how this experiment helps you understand what physical quantity the scale reads.

Homework (do on a separate sheet of paper)

6.6 Test Ideas

(You will need to perform this assignment with a group of friends. You will need a spring scale.)

Jim says: “The scale always reads how much *force Earth exerts on the object*”.

Erin says: “The scale always reads the *sum of the forces exerted on the object*”.

a) Think of what you can do to test their hypotheses.

b) Describe an experiment whose outcome you can predict using each hypothesis.

c) Make a prediction about the outcome of the experiment based on each person’s hypothesis.

d) Perform the experiment and record the outcome. Compare the outcome to each prediction. What is your judgment about each hypothesis?

e) Summarize what you learned about scale measurements. What does the scale actually measure when an object is placed on it?

6.7 Reason

a) Consider the following situation: You are standing on a bathroom scale. Use force diagrams and number statements to represent this situation.

b) The term “weight” in physics is reserved for the force that Earth exerts on an object. How is weight different from mass? How is weight different from what the scale reads?

6.8 Reason

Next to the statements or words below, write the term that best describes them using the following list: hypothesis, prediction, physical quantity, unit.

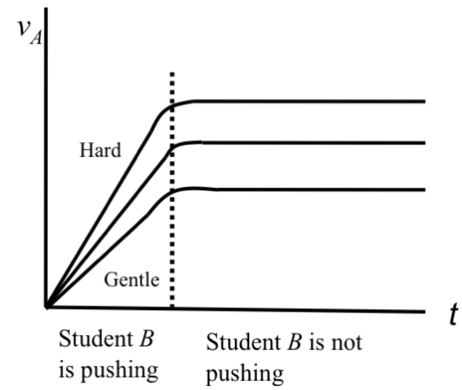
A couple of hints are given to you for help.

Word or Statement	**Term**
It will rain tomorrow.	*Prediction*
Objects change their motion in the direction of the sum of the forces.	
1 newton	
Mass	
Force	
1 meter	*Unit*
An egg should break if you drop it on the floor.	
The air pushes up on objects.	*Hypothesis*
The air pushes down on objects.	

Lesson 7: Newton's Second Law: Qualitative

7.1 Observe and Find a Pattern

Student A is on rollerblades and stands in front of a motion detector. The motion detector produces **velocity-versus-time** graphs. Student B (not on rollerblades) stands behind Student A and **pushes her forward**. Student A starts moving. The surface is **very smooth** (linoleum floor).



a) Describe any patterns you see on the graph.

b) Say all you can about the graph at the right. Focus on the slope, y-intercept, and the axes.

c) What happens to student A when student B stops pushing? Could the graph be a mistake? Think of other experiments that could be consistent with this part of the graph.

d) What is different about the motion of student A in the three cases? What is the same?

Need Some Help?

In order to solve problems, it is sometimes helpful to break the problem into parts. In this case you can break the motion down into two parts: when B is pushing and when B is not pushing.

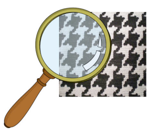
7.2 Observe and Represent

Imagine that after student A has moved for a while, as shown on the graph above, student B starts **pulling student A** in the directions **opposite to A's motion**. Eventually, student A comes to a stop.

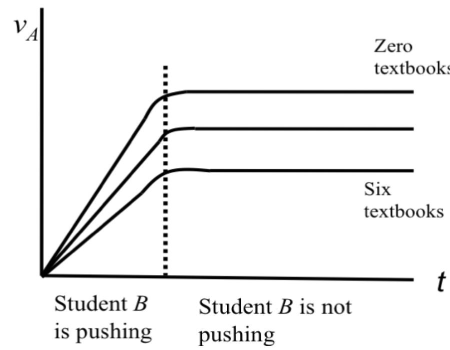
a) Represent this situation with a graph. On the graph, first show that student *A* moves at constant speed, and then that student *B* pulls on her in the direction opposite to her motion.

b) Imagine that after student *A* moves at constant speed, student *B* pulls even harder on student *A* in the direction opposite to her motion. Draw a new graph for this situation.

7.3 Observe and Find a Pattern



Student *A* is still on rollerblades but this time she is wearing a backpack filled with textbooks. Student *B* pushes student *A* several times; each time, student *A* adds three more books to the backpack. Student *B* pushes, exerting **the same force** each time.



a) Use the graph to find a qualitative pattern between the **change** in student *A*'s velocity and the **amount of stuff** in her backpack. Discuss the meaning of the slope and the y-intercept.

b) What can you say about the velocity of student *A* after student *B* has stopped pushing her?

c) Does the amount of stuff affect the **velocity** of an object or the **change in velocity** when the sum of the forces exerted on it is not zero?

d) How does the “amount of stuff” affect **the change in velocity** of an object if the sum of the forces exerted on it is **the same**?

Did You Know?

A physical quantity that is used to quantify “the amount of stuff” is called ***mass***.

Mass *m* characterizes the amount of matter in an object and the ability of the object to change velocity in response to interactions with other objects. The unit of mass is called a kilogram (kg).

7.4 Find a Relationship

Summarize how the change in the velocity of the object depends on the sum of the force exerted on it by other objects. Then summarize how the change in the velocity of the object depends on its mass. Use the words: more, less, and constant.

7.5 Test Your Idea

a) Use the relationship you formulated in activity 7.4 to predict the shape of the velocity versus time graph for an object that is dropped.

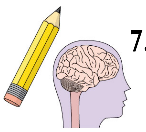
b) Use the relationship to predict the shape of the velocity versus time graph for an object that is thrown downward.

c) How can the shape of the graphs be explained by the relationship you are testing?

d) Conduct the experiments using *a motion detector*. If there is no motion detector in your classroom, use the graphs provided by your teacher to compare your prediction with the actual outcome.

e) Revise the relationship if the prediction does not match the outcome.

Homework



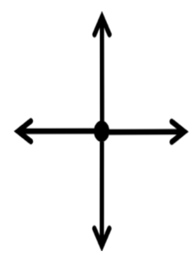
7.6 Represent and Reason

a) Draw motion diagrams and force diagrams for student *A* for the situations (1) when *B* is pushing and (2) when *B* is not pushing.

b) Are the force and motion diagrams for each case consistent? Explain how you understand the word "consistent" here.

7.7 Represent and Reason

Amy is pulling a box on a rough carpet. An unlabeled force diagram for the box is shown on the right.



a) Label the forces.

b) Draw a motion diagram for the box.

c) In which direction is the box moving? How do you know?

Lesson 8: Acceleration

8.1 Observe and find a pattern

Student *A* is wearing rollerblades, student *B* is not. Student *B* attaches a spring to student *A*'s belt and pulls on the spring, keeping the stretch of the spring constant. A motion detector collects position-versus-time data for student *A*.

Clock reading *t* (s)	Position *x* (m)
0 s	0.0 m
1 s	0.5 m
2 s	2.0 m
3 s	4.5 m
4 s	8.0 m
5 s	12.5 m
6 s	18.0 m

a) What can you say about the force student *B* exerts on student *A*? Does it change? How do you know?

b) Draw a picture of the experiment.

c) Draw a force diagram for student *A*. What is the sum of the forces exerted on *A* by all objects?

d) What should happen to her velocity during the experiment? Draw a motion diagram next to the force diagram above.

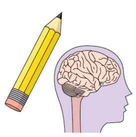
e) Draw a position versus time graph for student *A*. What can you say about her speed from this graph? Is your conclusion consistent with the answer you expected in part d?

f) Do you think that the data in the table are real or pretend? How do you know?

Average clock reading t (s)	Average speed v (m/s)
0.5 s	
1.5 s	
2.5 s	
3.5 s	
4.5 s	
5.5 s	
6.6 s	

g) Use the data in the table above to determine the speed of A during all of the time intervals. What can you say about the speed?

h) Complete the table for the average speed versus time data for this motion.



8.2 Represent and reason

a) Graph the average speed-versus-time data from the previous activity. Find the slope of the graph for the time intervals: 0-1 s; 2-3 s; 3-4 s.

b) What is the acceleration of student A?

c) How much did the speed of student A change during the experiment if you assume that she started at a zero speed? What time interval did it take for this change in speed to occur?

d) Imagine that the total change in the speed of student A is the same but it happens over the time interval of 8 seconds instead of 4. How would the average speed versus time graph be different?

e) Imagine that the total change in the speed of *A* is the same but it happens over the time interval of 2 seconds instead of 4. How would the average speed versus time graph be different?

8.3 Reason

a) The acceleration of an object is -3 (m/s)/s. Devise a number statement that would give you this acceleration if you know the initial and final velocity of an object and the time interval during which the velocity changed.

b) A hiker changed her velocity from -5.0 m/s to -3.0 m/s in 10 s. What was her acceleration? Was she speeding up or slowing down? Represent the motion with a motion diagram and sketch a velocity versus time graph. Can you say how long it would take her to stop?

c) Imagine that you are pushing a lawn mower exerting a 100–N force on it. The forces exerted on the lawn mower in the vertical direction add to zero. What can you say about the speed of the mower? What can you say about its acceleration?

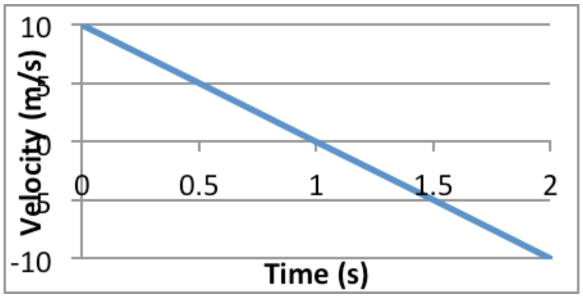
Homework

8.4 Represent and Reason

The graph below is velocity versus time graph for a water balloon thrown upward.

a) State everything you can about the motion of the water balloon.

b) Explain why the graph has this particular shape.



8.5 Reason

a) A runner changed his velocity from +3 m/s to +5 m/s in 3 s. What was his acceleration? What object makes the runner change his speed? (Think about this last question very carefully.)

b) A biker changed her velocity from +6.3 m/s to +2.7 m/s in 3 s. What was her acceleration? Was she speeding up or slowing down? Represent the motion with a motion diagram and sketch a velocity versus time graph. How is the motion of the biker different from the motion of the runner in part (a)?

c) A hiker changed her velocity from -2 m/s to -3 m/s in 10 s. What was her acceleration? Was she speeding up or slowing down? Represent the motion with a motion diagram and sketch a velocity versus time graph.

d) A hiker changed her velocity from -2.75 m/s to -0.5 m/s in 15 s. What was her acceleration? Was she speeding up or slowing down? Represent the motion with a motion diagram and sketch a velocity versus time graph. Can you say how long it would take her to stop?

8.6 Reason

a) Can you say that a positive acceleration means speeding up and negative acceleration means slowing down? How do you know?

b) On a motion diagram, we use Δv. How is the Δv different from acceleration? Discuss both the magnitude and the direction.

c) A biker moving at a velocity of 3 m/s starts accelerating with an acceleration of -2 (m/s)/s. What will be his velocity after 2 s? Explain your reasoning. You can use a graph to help.

d) Make a problem similar to each of the letter in activity 8.5. Make sure that your numbers are reasonable and you keep track of the units.

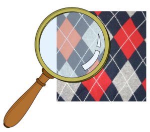
Lesson 9: Newton's Second Law: Quantitative I

For activities 9.1 through 9.5, use the PHET Simulation called: Forces in One Dimension. This can be accessed at: http://phet.colorado.edu/simulations/sims.php?sim=Forces_in_1_Dimension

Then change the settings:

- Turn friction off
- Select Graph Force, Graph Acceleration, and Graph Velocity
- Select "Show total force" only in upper right (deselect "Show horizontal forces")

(Note: If you do not have access to computers or the Internet, see the alternate activities below.)



9.1 Observe and Find a Pattern

Set the force to 100 N and click on "go".

a) Examine the velocity versus time graph and the acceleration versus time graph. Which one of these graphs is similar in shape to the force versus time graph?

b) For this scenario, how would you describe the force? How would you describe the acceleration? How would you describe the velocity? (Use constant, steadily increasing, steadily decreasing, etc.)

9.2 Observe and Describe

Keep the force at 100 N. This time when you click "go", watch what happens to the value of the velocity. Describe what happens to the velocity when the sum of the forces is constant.

9.3 Observe and Find a Pattern

Look at the force diagram in the upper right hand corner. The forces in the vertical direction balance each other out. F_N is the force the surface exerts on the object.

a) What does F_G represent?

b) Does the motion of the object **change** in the vertical direction?

c) There is a tiny arrow that points in the positive horizontal direction. What does this arrow represent?

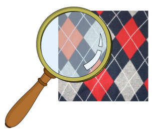
d) Is there any other arrow that adds to this arrow in the horizontal direction to make the sum zero?

e) Does the motion of the object **change** in the horizontal direction?

f) How is the direction of the sum of the forces related to the change in the velocity?

9.4 Observe and Find a Pattern

Keep the force at 100 N but set it for only about 4 sec. Then set the force to 0.



a) What happened when the man stopped pushing?

b) Look at the force diagram. What is F_{net} after the man stopped pushing?

c) Did the cabinet stop moving? Did it slow down? Explain.

d) What can you do to stop it?

9.5 Observe and Find a Pattern

a) Fill in the table below by changing the value of the force $F_{\text{man on object}}$ and finding the value of the acceleration.

Force (N)	**Acceleration (m/s/s)**
0	
20	
40	
60	
80	
100	

i. Describe the pattern from the table in words.

ii. Graph your data and draw a trendline.

iii. Describe the relationship between a and F with an equation.

c) This time, set the applied force to 100 N. Choose your object at the refrigerator. Run the simulation. How is the motion for the refrigerator different than the motion for the filing cabinet?

d) Fill in the table below for the different objects.

Object	**Acceleration (m/s/s)**	**Force (N)**
400 kg refrigerator		100
300 kg crate		100
200 kg cabinet		100
25 kg dog		100
10 kg book		100

i. Describe the pattern from the table in words.

ii. Graph your data and draw a trendline.

Did You Know?

The type of relationship we see between *a* and *m* is called **inversely proportional.**

Alternative Version of Lesson 9: Newton's Second Law: Quantitative I

9.1 Observe and Find a Pattern

In an experiment similar to lesson 8, student *B* pulls student *A* in a few different ways. Student *B* collects data to determine student *A*'s acceleration using a motion detector.

- When student *B* pulls exerting force *F*, student *A* accelerates at 0.5 m/s per second (0.5 m/s/s). (vertical forces exerted on *A* add to zero)
- When student *B* pulls exerting half as much force (1/2 *F*), student *A* accelerates at 0.25 m/s per second (0.25 m/s/s).
- When *B* pulls exerting twice as much force, *A* accelerates at 1.0 m/s/s.
- When *B* pulls exerting three times as much force, *A* accelerates at 1.5 m/s/s.

a) Represent these verbal statements with one picture, and three force diagrams.

Force	Acceleration

b) Complete the data table using the verbal statements above.

c) Create a graph using the data table you completed. What is your independent variable and what is your dependent variable? Explain your choice.

d) How does the acceleration of student *A* depend on the total force exerted on her by other objects?

9.2 Observe and find a pattern

Situation 1: Imagine student *A* is a small child with half as much mass as adult *A*. Student *B* would have to exert half as much force for child *A* to have the same acceleration as adult *A*.

Situation 2: Imagine student *A* is a Rutgers linebacker with twice as much mass as adult *A*. Student *B* needs to exert twice as much force for linebacker *A* to have the same acceleration as adult *A*.

How does the **acceleration** of the different objects depend on their **masses** when the same sum of the forces is exerted on them?

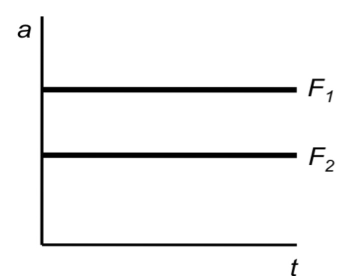
Need Some Help?

Let's think about an equality $a = b \times c$. In this situation, if we increase *c* and keep *b* constant, than *a* will increase. If we decrease *c* and keep *b* constant, than *a* will decreases.

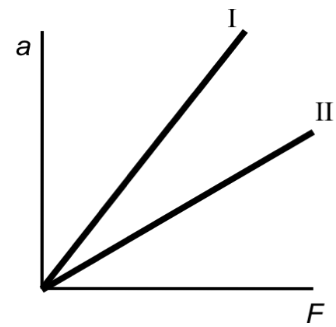
Now think about an equality $a = \frac{b}{c}$. In this situation, if we increase *c* and keep *b* constant, than *a* will decrease. If we decrease *c* and keep *b* constant, than *a* will increase. Think about how this is different than if we increase or decrease *b*.

9.3 Reason

a) The two lines on the graph show the acceleration versus time for the same object. F_1 is the sum of the forces in the first case, F_2 is the sum of the forces in the second case. What can you say about the forces? Draw a velocity versus time graph for the object for the two different situations. Assume the object starts from rest both times.



b) The two lines on the graph show how the acceleration of two objects when the same forces are exerted on them (I and II). What can you say about the acceleration of each object when the same force is exerted on them? What can you say about these two objects based on the graph?



Need Some Help?

In the previous activity, we saw that the acceleration depends on both the sum of the forces exerted on the object and the mass of the object. Think about how each graph relates to these different variables.

c) Write a mathematical statement that will summarize that the acceleration of an object is directly proportional to the sum of the forces exerted on it by other objects and inversely proportional to its mass.

d) We can now redefine the unit of force (1 N) as the amount of sum of the forces that needs to be exerted on an object of 1 kg to accelerate this object at the rate of 1 m/s/s = 1m/s^2 or $1\text{N} = 1\dfrac{\text{kg} \times \text{m}}{\text{s}^2}$. Explain how we obtained this expression.

9.4. Reason

a) The sum of the forces exerted on an object of mass 5 kg is 10 N. What can you say about the object's acceleration?

b) The sum of the forces exerted on an object is 20 N. What can you say about the object's acceleration?

c) Does the acceleration for part b depend on the mass of the object? Explain.

Lesson 9 Continued

Did You Know?

Newton's Second Law of Motion: We choose a particular object (objects) as our object of interest — the system. The acceleration a of the system is directly proportional to the sum of the forces exerted on the system by other objects and inversely proportional to the mass m of the system object:

$$a_s = \frac{\text{sum of} F}{m_S}$$

The unit of force is called the newton (N) where 1 N = (1 kg)(1 m/s^2).

Homework (use a separate sheet of paper)

9.5 Represent and Reason

a) You are pushing on a box on a smooth floor exerting a 12.5 N force on it. The mass of the box is 3.6 kg.

b) Draw a force diagram for the box assuming that other forces exerted on the box add to zero. Draw a motion diagram.

c) Are the two diagrams consistent? Explain.

d) What is the acceleration of the box?

e) What if you put a book of 0.7 kg on top of the box? What would change in your answers to questions a-d?

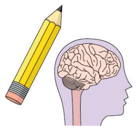
9.6 Represent and Reason

Consider the scenario of the box in the previous problem. You push on the box for 2 seconds.

a) What is the speed of the box at the end of these 2 seconds?

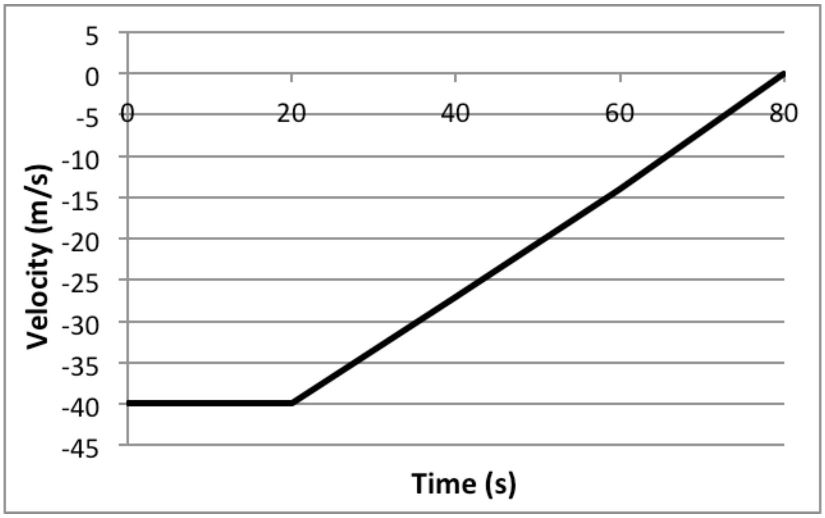
b) Imagine that after these 2 seconds you stop pushing; what will happen to the box? Explain. Draw a motion diagram and a force diagram to support your answer.

c) What if you put a book of 0.7 kg on top of the box while you were pushing it? What would change in your answers to questions a and b?



9.7 Represent and Reason

Use the velocity versus time graph for an object to find its acceleration and determine the sum of the forces exerted on it. Assume the mass of the object is 2.0 x10^4 kg.



Lesson 10: Newton's Second Law: Quantitative II

10.1 Reason

You are pulling a garbage container to the curb exerting an 80 N force on it. The rough sidewalk exerts a friction force on it that is equal to an 80 N in the direction opposite to the motion of the container. The mass of the container is 20 kg.

a) Draw a force diagram for the container; draw all forces to scale.

b) What are possible motion diagrams for the container?

c) What is the container's acceleration?

10.2 Reason

This time you pull a little harder, exerting an 85-N force on the container. The sidewalk pulls back the same way.

a) Draw a force diagram for the container; draw all forces to scale.

b) What are possible motion diagrams for the container?

c) What is the container's acceleration?

10.3 Reason

a) You continue to pull exerting an 85-N force on the container for 2 seconds. What is the box's speed at the end of these 2 seconds?

b) Imagine that after 2 seconds you stop pulling. What will happen to the box? Explain as completely as possible.

10.4 Observe and Explain

Hold a birthday balloon filled with helium by the string.

a) Draw a force diagram for the balloon.

b) Release the balloon and observe its motion. Draw a motion diagram and a force diagram for the balloon just after you release it.

c) Think of what you can do to the balloon to prevent it from accelerating towards the ceiling when you let it go. Check if your idea works.

Homework (use a separate sheet of paper)

10.5 Reason

A sled is moving on ice at a constant speed of 3 m/s. Your friend tries to slow it down by exerting a constant 15-N force in the direction opposite to the sled's motion. Draw a motion diagram and a force diagram for the sled.

10.6 Reason

Refer to the sled in activity 10.5. What is the acceleration of the sled if its mass, including the passengers, is 30 kg?

10.7 Observe and Find a Pattern

Student *A* is moving at constant speed on rollerblades. Student *B* starts pulling on student *A* in the direction opposite to student *A*'s motion. Position versus time data for student *A* is given in the table.

Clock reading t (s)	Position x (m)
0	0
1	6.5
2	12
3	16.5
4	20
5	22.5
6	24

a) Draw a picture of the experiment and a force diagram for student *A*. What is the direction of the sum of the forces exerted on student *A* by all objects?

b) Draw a motion diagram and a position-versus-time graph for student *A*. What can you say about her speed?

c) Use the data in the table to determine the speed of student *A* during the following time intervals: 0-1 s; 1-2 s; 2-3; 2-4 s; 1-4 s. What can you say about the speed?

d) What is the acceleration of student *A*?

e) Are the data in the table real or pretend? How do you know?

f) Imagine that the stopwatch that you used to collect the time data had the smallest division of 0.1 seconds. How would you write the data in the table differently? How would the graphs be different?

g) Imagine that the positive direction of the x-axis was chosen differently in this activity, exactly in the opposite direction. The origin is at the same point. How would the data in both tables be different? What would be the acceleration of student *A*?

Lesson 11: Force Exerted by the Earth on Objects

11.1 Reason

In activity 6.1 you found that the **force the Earth exerts on an object** is equal to the **mass** of the object times **9.8 N/kg**. Explain the meaning of the **quantity** 9.8 N/kg. Why is it the same for all objects?

Need Some Help?

We defined the unit of force 1 N, as the amount of force (assuming that here is only one force exerted on the object) that needs to be exerted on an object of 1 kg to accelerate this object at the rate of 1 m/s^2. Another way to say this is that 1 N = 1 kg x 1 m/s^2.

11.2 Test Your Idea

a) Describe an experiment you can design to test your reasoning in activity 11.1 List all the equipment you will need.

b) Write down your prediction based on your hypothesis/reasoning from 11.1.

c) Consider uncertainty. How close should the experimental results be to your prediction for you to be convinced? Explain.

d) Compare your prediction to the outcome. What judgment can you make about your hypothesis from 11.1?

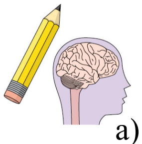
Here's An Idea!

If you do not have available equipment to test your idea, you can use the experiments at:

http://paer.rutgers.edu/pt3/experiment.php?topicid=2&exptid=38

http://paer.rutgers.edu/pt3/experiment.php?topicid=2&exptid=43

http://paer.rutgers.edu/pt3/experiment.php?topicid=2&exptid=17



11.3 Represent and Reason

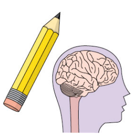
a) Draw a motion diagram for a ping-pong ball and a golf ball dropped simultaneously from the same height.

b) Then draw force diagrams for them next to the motion diagrams

c) What is the same about the motion diagrams? What is different?

d) What is the same about the force diagrams? What is different?

e) What assumptions did you make?



11.4 Represent and Reason

a) Draw a motion diagram for a ping-pong ball and a golf ball thrown simultaneously upward at the same initial speed from the same level above ground.

b) Then draw force diagrams for them next to the motion diagrams.

c) What is the same about the motion diagrams? What is different?

d) What is the same about the force diagrams? What is different?

e) What assumptions did you make?

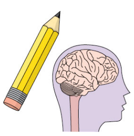
11.5 Observe and Explain

a) Drop a piece of paper and a book from the same height. Describe what happens to the two objects when they fall. Explain your observations using force diagrams.

b) Decide what you can do to make the paper and book move the same way.

c) Then perform your experiment and record the results. Did the idea work? Explain why it did or did not work.

Homework



11.6 Represent and Reason

You throw a small ball upward. It has a speed of 5 m/s when it leaves your hand.

a) Draw motion diagrams and force diagrams next to each other for the following 5 cases:

1) The ball before it leaves your hand;
2) After it leaves your hand and is going up;
3) At the top of its flight;
4) On the way down;
5) When you are catching it with your hand.

b) Draw a velocity versus time graph for the ball and use it to find out how long it takes for the ball to come back to your hands.

c) If you neglect air resistance, when is the acceleration of the ball the largest: on the way up, on the way down, or at the top of its flight? Explain.

d) If you do not neglect air resistance, when is the acceleration of the ball the largest: on the way up, on the way down, or at the top of its flight? Explain.

11.7 Plan

Tomorrow in class you will receive a set of large coffee filters. Decide what questions you can pose about the motion of coffee filters that you might be able to answer. Think of three experiments you can design to learn about the motion of the coffee filters when you drop them. Decide what equipment you would need that might be available in class. Plan your experiments carefully. Write clear notes. Tomorrow you will need to convince your classmates that these are good experiments.

Lessons 12: Coffee Filters Lab Investigation

12.1 Design an Experiment

Discuss with your group members the questions you wish to investigate. As a group, choose one question.

a) Describe the question you wish to investigate. Draw a picture of the experiment that might help you answer your question. Discuss how you are actually going to do it.

b) Make a list of equipment you will need for your experiment.

c) What type of experiment are you going to conduct: an observational or a testing experiment? How are these two different?

d) What quantities are you going to measure? What are your dependent and independent variables? Do you expect any relationship between these quantities? Explain your answer.

e) Perform the experiment and record your data.

f) How certain are you in each data point? Think of the experimental uncertainty of different instruments. Will your measurements be the same if you repeat the experiment? Repeat the experiment.

g) Think of how you might want to represent the data to find a pattern or to test your hypothesis. Represent the data with the representation of your choosing.

h) Discuss any patterns that emerged from your data or discuss whether the outcome of the experiment matched your prediction. Were you able to answer your question?

Homework

12.2 Write a Report

Reflect on the experiment you performed in class. Write a scientific report about your investigation (use separate sheets of paper). The report should describe what you did and what you found so that other scientists can repeat your experiment and obtain the same results.

Use the rubrics on the following page to help you write the report.

Ability	Missing	An attempt	Needs some improvement	Acceptable
Is able formulate the question to be investigated	The question to be investigated is not mentioned.	The question is posed but it is not clear.	The question is posed but it involves more than one variable.	The question is posed and it involves only one variable.
Is able to design an experiment to answer the question	The experiment does not answer the question.	The experiment is related to the question but will not help answer it.	The experiment investigates the question but might not produce the data to find a pattern.	The experiment investigates the question and might produce the data to find a pattern.
Is able to decide what is to be measured and identify independent and dependent variables	It is not clear what will be measured.	It is clear what will be measured but independent and dependent variables are not identified.	It is clear what will be measured and independent and dependent variables are identified but the choice is not explained.	It is clear what will be measured, independent and dependent variables are identified, and the choice is explained.
Is able to use available equipment to make measurements	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.
Is able to describe what is observed in words, pictures, and diagrams.	No description is mentioned.	A description is mentioned but it is incomplete. No picture is present.	A description exists, but it is mixed up with explanations or other elements of the experiment. A labeled picture is present.	Clearly describes what happens in the experiments both verbally and by means of a labeled picture.
Is able to construct a mathematical (if applicable) relationship that represents a trend in the data	No attempt is made to construct a relationship that represents a trend in the data.	An attempt is made, but the relationship does not represent the trend.	The relationship represents the trend but no analysis of how well it agrees with the data is included (if applicable) or some features of the relationship are missing.	The relationship represents the trend accurately and completely and an analysis of how well it agrees with the data is included (if applicable).

Lesson 13: Peer Evaluation

13.1 Evaluate

Review the experiment report of one of your classmate using the rubrics in the previous lesson. Write a report describing your review without giving any scores. Think of the strong sides of the report. Think of what could be improved. After you receive the review of your report written by your classmate, revise it based on the review, and hand it in to your teacher.

Lesson 14: Newton's Third Law

14.1 Observe and Explain

Both student *A* and student *B* wear rollerblades or sit on office chairs with wheels. Student *B* pushes student *A* (or the chair that student A is sitting on) abruptly.

a) Draw force diagrams for both students. What do you think the length of the force arrows should be on the diagrams?

b) Perform the experiment. Use the diagrams to explain the observations.

If you do not have people on rollerblades in class, use the videos at

http://paer.rutgers.edu/pt3/experiment.php?topicid=3&exptid=37

c) Refer to the experiments in 7.1 and 7.3. Why did student *B*'s velocity NOT change in those activities?

d) Give examples of three situations where two interacting objects exert forces on each other (for example, a tennis racket hits a ball, a person pushes a vacuum cleaner, the Earth pulls a leaf). **Draw force diagrams for both objects separately and use the labels to find the forces that those objects exert on each other.**

e) What can you say about the forces that they exert on each other? What can you say about the accelerations of those two objects?

14. 2 Test Your Idea

Student *A* and student *B* are both on rollerblades. The mass of student *A* is smaller than the mass of student *B*. Use what you learned in activity 14.1 to predict what will happen if students *A* and *B* start throwing a heavy medicine ball back and forth to each other. Check whether your prediction matches the outcome at:
http://paer.rutgers.edu/pt3/experiment.php?topicid=3&exptid=30

14.3 Observe and Find a Pattern

You and your friend each hold a spring scale and you hook the scales to each other.

a) Observe what your friend's spring scale reads if you pull yours, exerting a force of 3 units. Record here.

b) Observe what your spring scale reads if she pulls, exerting a force of 5 units. Record here.

c) What can you say about the forces that the springs exert on each other?

d) Express the rule using mathematical symbols for forces and then as a number rule (invent numbers).

14.4 Test Your Idea

Consider the following experiment: You and your friend hold a spring scale and you hook the scales to each other. You pull with 5 units of force and your friend tries to pull with 3 units of force.

a) Use your rule to predict whether it is possible to achieve this.

b) Perform the experiment. Revise your hypothesis if your prediction did not match the outcome.

14.5 Observe and Explain

Student *A* and student *B* are on rollerblades. They each have one end of a rope tied around their waist. Student *B* pulls on the rope, which in turn pulls on student *A*.

a) Perform the experiment or watch the video at:
   http://paer.rutgers.edu/PT3/experiment.php?topicid=3&exptid=36

b) Use your revised hypothesis to explain what you observed.

c) If the force student *A* exerts on student *B* is equal in magnitude and opposite in direction, why don't the forces cancel out? Draw a force diagram for each student to answer this question.

Did You Know?

You have just developed the idea of **Newton's third law:** When objects A and B interact, the force that A exerts on B is **always the same in magnitude** and **opposite in direction** to the force that B exerts on A. These forces are exerted on **different objects** and cannot be added to find a total force.

Homework

14.6 Reason

Two students sit on office chairs on wheels. Student A pushes student B away from him. Student B does nothing. Does student B exert a force on A? How do you know?

14.7 Reason

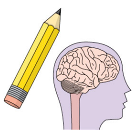
a) You hit a stationary puck with a hockey stick. The stick exerts a 100-N horizontal force on the puck. What is the force exerted by the puck on the stick. How do you know?

b) A truck rear ends a small sports car that is moving in the same direction as the truck. The collision makes the truck slow down and the sports car is propelled forward. What object exerts a larger force on the other object: the truck on the car or the car on the truck. Explain how your answer reconciles with Newton’s third law and with the fact that the sports car is damaged more than the truck.

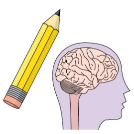
c) The Earth pulls on apple exerting a 1.0 N force on it. What is the force that the apple exerts on the Earth? Why does the apply fall towards the Earth but the Earth does not move towards the apple?

d) The tree branch exerts a 1.0 N force holding the apple. What is the force that the apple exerts on the tree branch?

14.8 Reason



Use Newton’s third law to predict what will happen if you try to open a door wearing rollerblades. Draw a force diagram for yourself to help make the prediction.

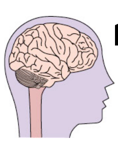


14.9 Represent and Reason

Your friend says that if Newton’s third law is correct, no object would ever start moving. Here is his argument: You pull a sled exerting a 50 N force on it. According to Newton’s third law the sled exerts the force of 50 N on you in the opposite direction. The total force is zero, thus the sled should never start moving. But it does. Thus Newton’s third law is wrong. What is your opinion about this answer? How can you convince your friend of your opinion?

14.10 Reason

The Sun’s mass is 2.00 x 10^{30} kg. It pulls on the Earth, exerting a force of about 10^{20} N. What is the force that the Earth exerts on the Sun?

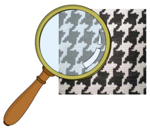


14.11 Reason

The moon orbits the Earth because the Earth exerts a force on it. The Moon, therefore, has to exert a force on the Earth. What is the visible result of this force?

Lesson 15: Friction

15.1 Observe and Find a Pattern



Create a ramp and put a small block at the top. Release the block and observe its motion when it slides onto your smooth desk.

a) (1) Record your observations in words and with a picture. (2) Draw a motion diagram and a force diagram for the block as it moves *across the desk*. (3) What makes the block move forward? Why does the block slow down?

b) Put some sand on the desk and repeat the experiment. (1) Record your observations in words and with a picture. (2) Draw a motion diagram and a force diagram for the block as it moves *across the desk*. (3) What makes the block move forward? (4) Why does the block slow down more than in the first experiment?

c) Put more sand on the desk and repeat the experiment. (1) Record your observations in words and with a picture. (2) Draw a motion diagram and a force diagram for the block as it moves *across the desk*. (3) What makes the block move forward? (4) Why does the block slow down more than in the second experiment?

15.2 Reason

a) Summarize your observations and analysis to describe how the roughness of the surface affects motion.

Did You Know?

The term **friction** refers to the resistive force the **surface exerts on a moving object**. This force is exerted on an object in the direction opposite to its motion.

b) Carefully observe what happens to your feet when you walk. Analyze what happens when you walk using motion diagrams and force diagrams. Consider the beginning and the end of each step separately. Does the friction force exerted by the surface on your feet help you walk or is it better if there were no friction?

c) What would happen if there were no friction between a road's surface and a car's tires?

Homework

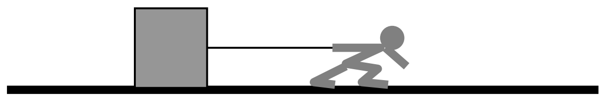
15.3 Reason

Write a story about living in a world that has no friction.

Lesson 16: Practice

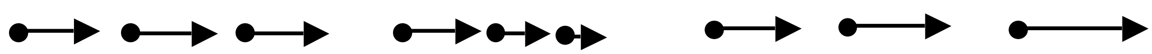
16.1 Represent and Reason

A person pulls a rope, which in turn pulls a crate across a horizontal, rough surface, as shown below.



Three motion diagrams are shown below for the crate (with velocity arrows only). In the table that follows, construct a force diagram for the crate and make the horizontal arrows the correct relative lengths.

(a) (b) (c)



(a)	(b)	(c)

16.2 Represent and reason

Some students are trying to move a heavy desk across the room. Diana pushes it across the floor at the same time that Omar and Jeff pull on it. Omar pulls on the desk, exerting a 150-N force, and Jeff pulls exerting a 125-N force. There is also a 200-N friction force exerted by the floor on the desk. The net force exerted on the desk is 275 N.

a) Make a sketch of the situation.

b) Draw a force diagram for the desk. Draw a motion diagram.

c) Write an algebraic statement that describes force diagram.

d) How hard is Diana pushing?

e) Is the desk moving with a constant velocity or is it speeding up?

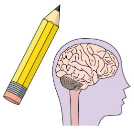
f) What will happen after a few seconds if the boys stop pulling?

16.3 Represent and Reason

You are pulling up on a suitcase, exerting an upward force of 200 N on it. The mass of the suitcase is 15 kg. Draw a force diagram for the suitcase; make sure the lengths of the arrows represent the relative magnitudes of the forces. Use the force diagram to draw the motion diagram for the suitcase. If the suitcase is accelerating, what is its acceleration? (Hint: think about all the forces exerted on the suitcase.)

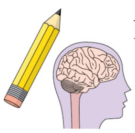
16.4 Represent and Reason

In the previous problem, what is the force that the suitcase exerts on your hand? Why can you lift the suitcase but the suitcase does not lift you?



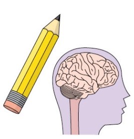
16.5 Represent and Reason

You continue lifting the suitcase, but now you are exerting an upward force of 147 N on it. Draw a force diagram for the suitcase; make sure the lengths of the arrows represent the relative magnitudes of the forces. Use the force diagram to draw the motion diagram for the suitcase. If the suitcase is accelerating, what is its acceleration?



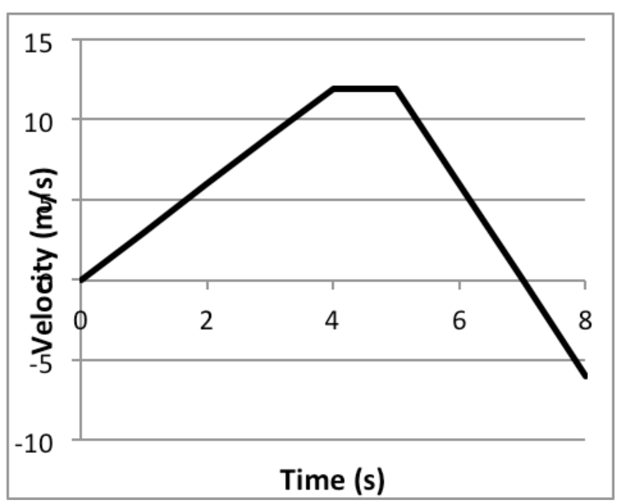
16.6 Represent and Reason

You continue lifting the suitcase, but now you are exerting an upward force of 100 N on it. Draw a force diagram for the suitcase; make sure the lengths of the arrows represent the relative magnitudes of the forces. Use the force diagram to draw the motion diagram for the suitcase. If the suitcase is accelerating, what is its acceleration? In which direction is the suitcase moving?



16.7 Represent and Reason

The speed of an object changes, as shown in the graph below. The mass of the object is 5 kg.



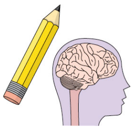
a) Describe the object's motion in words, as fully as possible.

b) Determine the sum of the forces exerted on the object for each segment of the graph.

c) Write a mathematical function

describing the first segment of the graph.

d) Devise a story about the object's motion.



16.8 Represent and Reason

You throw a tennis ball upward.

Draw a motion diagram for the ball when (a) it is still in contact with your hand, about to leave it, (b) when it is moving up, (c) when it is at the top of its flight, (d) when it is moving down, and (e) when you catch it.

Then draw a force diagram for (a) – (e).

Estimate the ball's acceleration for (a) – (e).

16.9 Explain

Give an example for (a) when an object is moving to the right but the sum of the forces exerted on it is pointing to the left, (b) when an object is moving down but the sum of the forces exerted on it is up, and (c) when an object is moving down but the sum of the forces exerted on it is zero.

16.10 Argue

Jake says that cars move because the engines push them. Do you agree with Jake? Explain your opinion; use force diagrams. How can you convince Jake of your opinion?

Lesson 17: Summary and Review

17.1 Equation jeopardy

Four mathematical statements are listed below. For each statement, describe a problem for which this statement could be a solution. Then represent the statement using a force diagram and a motion diagram.

a) $F_{\text{sum of all forces on object}} = 9.8$ N/kg x 3 kg.

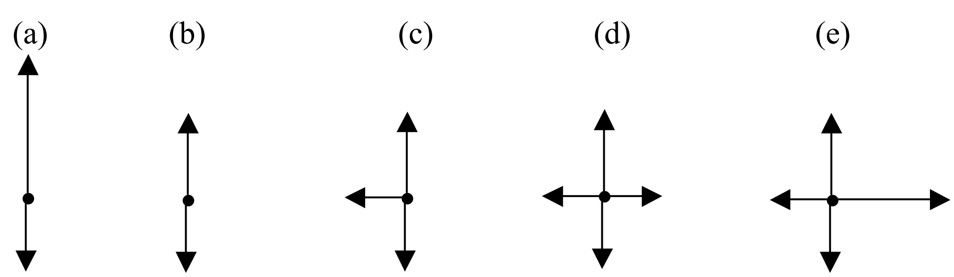
b) 7 m/s – 2 m/s = 3 s x a

c) 1 kg x a = 35 N – 9.8 N

d) 35 kg x 0 m/s^2 - $F_{\text{rope on sled}} - F_{\text{Jake on sled}}$

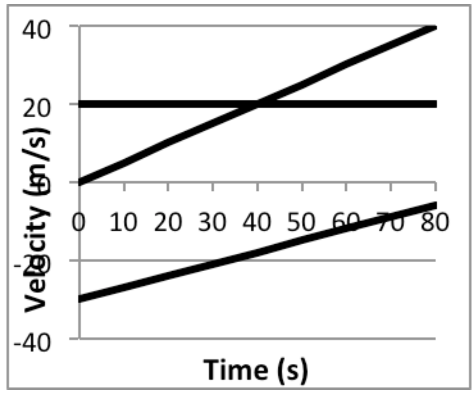
17.2 Diagram jeopardy

Five force diagrams are shown below. Describe a situation that each diagram can describe. In which direction is each of the objects moving? How many answers can you have? Draw a matching motion diagram and write a number statement that can represent the situation. How many number statements can you write?



17.3 Graph jeopardy

The three lines on the graph below describe three different motions of an object. Tell a story about each motion. Draw a motion diagram and a force diagram. How many answers can you have? Determine the sum of the forces in each case if the mass of the object is 250 kg.



17.4 Explain

When a hammer hits a nail, it exerts a 100-N force on the nail. Does the nail exert a smaller or larger force on the hammer, or does it exert no force at all? Explain.

17.5 Represent

Dimitri pulls on a cart, exerting a 50-N force to the right. There is a 35-N friction force exerted to the left. The cart has a mass of 20 kg.

a) In which direction is the object moving? How do you know?

b) In which direction is the object accelerating? How do you know?

c) Draw a force diagram and a motion diagram for the cart. Are they consistent? Explain.

d) Write a number statement for the total force exerted on the cart.

e) Determine the acceleration of the cart.

f) What would happen to the acceleration if the cart's mass were to double?

17.6 Explain

You may have observed how a locomotive (or train engine) pushes train cars: the cars sit on tracks, the locomotive moving slowly hits the cars and pushes them in the original direction of its motion.

a) What happens to the motion of cars after the locomotive hits them?

b) What happens to the motion of the locomotive?

c) Represent both motions with motion diagrams.

d) If the locomotive exerts a 10^5 N force on the car, what is the force that the car exerts on the locomotive?