PHYSICS UNION MATHEMATICS

Physics I

Work & Energy

Student Edition

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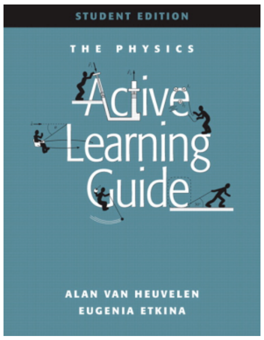
RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

PUM Physics I
Work & Energy



Most of the module activities were adapted from:

Van Heuvelen and Etkina, Active Learning Guide
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Lesson 1: Working Hard

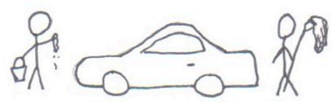
1.1. Car Washing Inefficiency Index

You're the manager of a chain of four Rutgers-area car washes in which teams of employees wash the cars by hand. You want to find out which locations are the most inefficient so that the teams there can be retrained. The teams don't all have the same number of people, however, *so how can you determine which location is the most inefficient?*

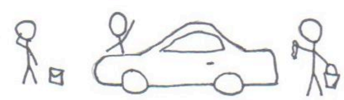
Shown below are times for how long it took to wash a Toyota Camry. You have data for two different teams from each of the four locations. Invent a procedure for computing a *car washing inefficiency index*. Write the results on the side margins for each car wash.

- *Bigger index values should correspond to more inefficient teams.*
- *Teams from the same location should have the same index value.*

East Brunswick



Wash Time: 10.2 minutes

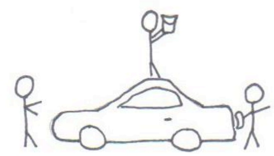


Wash Time: 6.8 minutes

Shimmy Shine

Piscataway

Wash Time: 9 minutes

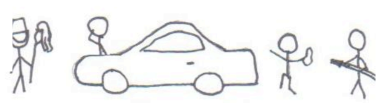


Wash Time: 12 minutes

Suds R Us

Franklin

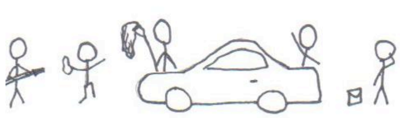
Wash Time: 11.8 minutes



Wash Time: 5.9 minutes

Klean Whips

New Brunswick



Wash Time: 8.4 minutes

Wash Time: 10.5 minutes

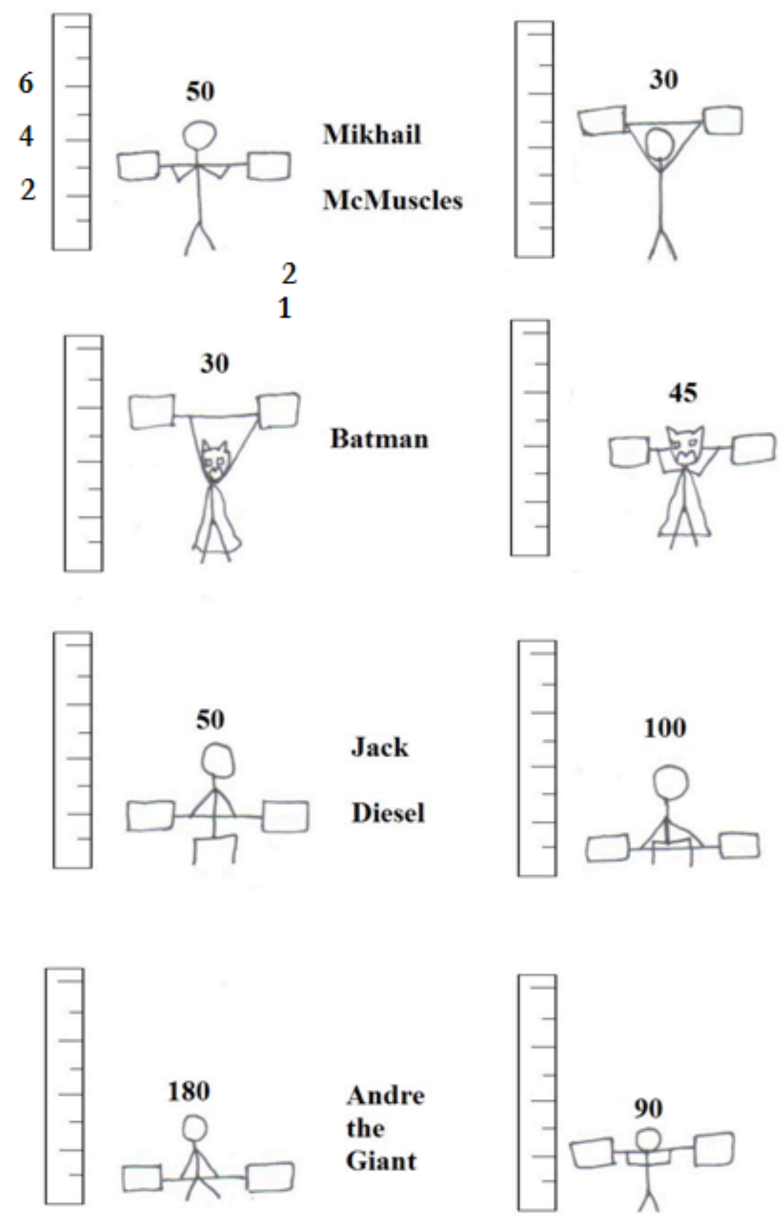
Sooper Sponges

1.2 The weightlifting index

Several of your friends have been bragging about how strong they are. To settle the matter, they have decided to hold a weightlifting contest. The problem is they don't agree on how to score the competition, since they all lift different amounts of weight and they lift the weights to different heights.

<u>Invent a procedure for computing a weightlifting index for each competitor (both trials should give the same index for that person). Remember: the bigger index means stronger.</u>

Write the formula you used to determine the weightlifting index: ______________________



1.3. Job Difficulty index

Some friends are complaining about their summer jobs. Each person thinks he works the hardest out of everyone. All their jobs are different, so it's difficult to tell. You've been asked to decide once and for all whose job is the most difficult.

Invent a job difficulty index for the workers, and rank them from hardest to easiest job.

Name	Job	Force (Monday)	Distance (Monday)	Force (Tuesday)	Distance Tuesday)	Job Difficulty Index
Burley	Lifts ice blocks in a meat packing plant	**1.8×10^3**	**70.5**	**1.41×10^3**	**90**	
Lug	Pushes a luggage cart at the airport		**360**	**6.0×10^3**		**1.44×10^5**
Monty	Rolls old computers to a storage facility	**2.5×10^3**	**100**		**500**	
Rollo	Rolls oil drums up a ramp to a truck bed		**270**		**180**	**4.455×10^5**

What was the formula for your Job Difficulty Index?

Rank the jobs from the *hardest to the easiest* job:

_____________ _____________ _____________ _____________

Reasoning Questions:

1. Refer to Exercise 1.1: Discuss in everyday language what the numeric value of the car washing inefficiency index tells you about each team. (Hint: Think about what the number means if the team has only 1 person, or, alternatively, what would it take to wash a car in 1 minute?)

2. Which car washing team is the most inefficient?

3. How many people would the New Brunswick location need to wash a car in 4 minutes? Support your answer.

4. Refer to Exercise 1.2: Discuss in everyday language what the numeric value of the weightlifting index tells you about each competitor.

5. Which competitor(s) won the competition?

6. If Batman had attempted to lift 150 weight units how far would he have lifted it? Support your answer.

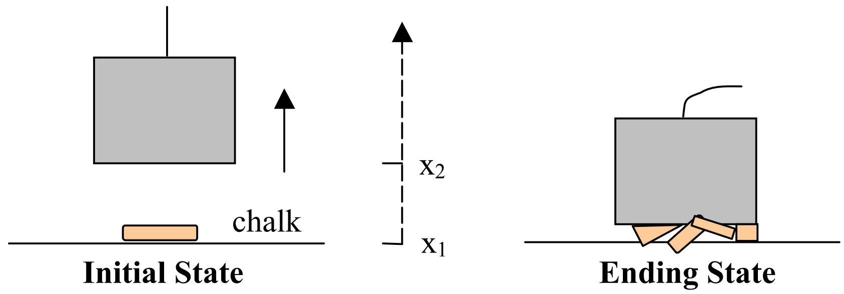
7. What weight could Mikhail McMuscles lift to 1.25 height units? Support your answer.

8. Refer to Exercise 1.3: How do you know which summer job is the most difficult? Explain in everyday language how you decided whose was the most difficult job.

9. Discuss in everyday language what the numeric value of *job difficulty index* tells you about the job.

1.4 Observe and Find a Pattern

Experiment 1: Tie a string to a large block and place a piece of chalk on the table. Pull up on the string so that a large block is 0.5 (m) above the piece of chalk. After this lifting process, release the block.



a) Describe the outcome of the experiment.

b) Draw a force diagram for the **initial state** and then circle the arrow that represents "the force the **string** exerts on the **block**." ($F_{\text{string on block}}$)

c) Draw an arrow for the direction of displacement (Δx) that the block undergoes in the beginning state.

Need Some Help?

Remember from the previous units that **displacement** refers to the difference between the starting position and final position or the change in position. ($x_2 - x_1 = \Delta x$)

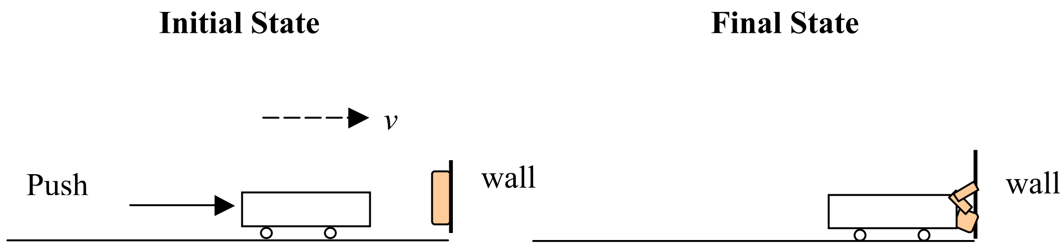
d) Relate the arrows in part (b) and (c).

e) What can you do to the block to increase its ability to smash the chalk?

f) Why is the block able to smash the chalk?
Could the block smash the chalk without Earth?

1.5 Observe and Reason

Experiment 2: Place a piece of chalk against a wall. Push a cart for 0.5 m so that it rolls faster and faster toward the chalk. Continue pushing the cart until it hits the wall.



a) Describe the outcome of the experiment.

b) Draw a force diagram for the **initial state** and then circle the arrow that represents "the force **you** exert on the **cart**." ($F_{\text{you on cart}}$)

c) Draw an arrow for the direction of displacement (Δx) that the cart undergoes in the beginning state.

d) Relate the arrows in part (b) and (c).

e) What could you do to the cart to increase its ability to smash the chalk?

Need Some Help?

When we analyze a process, we are interested in what happened along the way. This is especially true for the beginnings and the endings. We call these the **initial** and **final** states.

1.6 Hypothesize

a) In the previous examples, you performed some activities that increased the chances of smashing a piece of chalk. Look for a pattern of what was done to the objects to give them chalk-smashing ability.

b) Did these activities have something in common?

c) Develop a hypothesis that explains what must be done to increase the **"chalk-smashing ability."**

1.7 Test Your Idea

Imagine you have the following materials: a piece on chalk, a slingshot (ex: a rubber band), a wall.

a) Design an experiment that will test the hypothesis you devised in 1.6 above. Draw a picture of the initial and finial states.

b) Make a prediction about the outcome of the experiment. (Include a force diagram and indicate the direction the object will be displaced)

c) Ask your teacher to perform the experiment. Record the outcome.

d) Compare your prediction to the outcome of the experiment. What judgment can you make about your hypothesis? Revise your hypothesis as needed.

Did You Know?
Work done by a force on an object is what gives that object "chalk-smashing ability." The object gains chalk-smashing ability if the force and displacement are in the same direction.

Homework

1.8 Reason

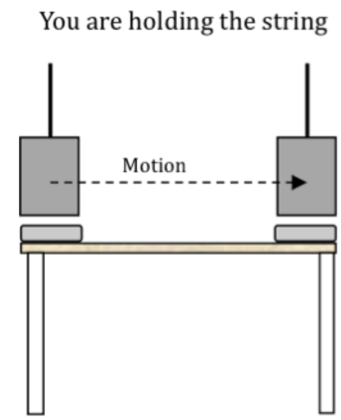
Complete the table below.

Describe the Process.	Identify (describe) the initial and final state.	
Hector lifts a heavy television off the ground and places it on the TV stand.		
Jeff starts at the top of a hill and slides down on his snow sled. At the bottom of the hill, Jeff is moving really fast.		
Maria pulls a pendulum bob sideways and lets it go, the bob passes through the bottom of the swing		
The pendulum bob passes through the bottom of the swing and rises to its highest point.		

Lesson 2: Back to Work

2.1 Reason

Imagine that you performed the block experiments again but this time you only lift (displace) the block vertically by 1(cm). The block is not able to break the chalk.



a) Explain why this occurred.

b) Did the block gain or lose **any** "chalk smashing ability" due to being lifted? Explain.

c) How would you move the block in order to gain enough "chalk smashing ability" to break the chalk?

Now imagine that you slowly move that block 2 m to the right so that it hangs over a second identical piece of chalk. You keep the block 1 cm above the surface the whole time. When you released the block, the new piece of chalk did not break.

d) Draw an arrow to represent the force the string exerts on the block and compare it to the direction of displacement.

e) Did the block gain or lose **any** "chalk smashing ability" although it moved and you pulled up on it? How is this experiment different form the first experiment in the previous lesson (1.4)?

2.2 Represent and Reason

Your friend Tessa really likes chalk and does not want you to smash it. During the cart experiment she puts her hand in front of the cart and **exerts a small force** in the **direction opposite** the cart's displacement. The cart slows down. The chalk is saved!

a) Draw an arrow to represent the force that Tessa exerts on the cart and compare it to the direction of displacement.

b) Did the cart gain or lose **any** "chalk smashing ability" by moving it? Use the comparison in part (a) to help you explain why this occurred.

Did You Know?

Throughout this lesson we have been discussing processes. Scientists define a **process** as a change from some initial state to some final state. One way that scientists analyze a process is by examining how energy changes.
<u>When a system or object has "the ability" or "potential" to do something, we say that it has **energy**</u>.

When an external influence changes the energy of the system (increases or decreases), scientists say that **work** has been done on the system. For the work to be done on the system an object outside the system has to exert a force on one of the objects in the system. However, the force is not enough. One of the system's objects has to change its position due to this force in the direction of the force (or in the opposite direction).

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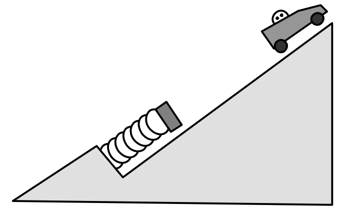
a) What situations above show an increase in ability?
Which show a decrease?

b) When can we say positive/negative work is done?

c) What would be a case where no work is done? Why?

2.3 Reason



Examine the picture to the right.
One of your classmates says, *"When the car gets to the edge it will have 'the ability to fall' or 'falling ability.'"*

a) If Earth weren't there, would the car still have "falling ability?" Explain.

b) Should we include or exclude Earth with the car in the system when we analyze this problem if we want it to have "falling ability"?

Did You Know?

We have been examining a series of **systems** and analyzing the changes that occur to them. A **system** is an object or group of objects that we are interested in analyzing. ***REMEMBER!*** *When we determine the objects in our system, we might need to include objects that aren't in direct contact, like Earth.*

Work can only be done by external objects **outside** the system.

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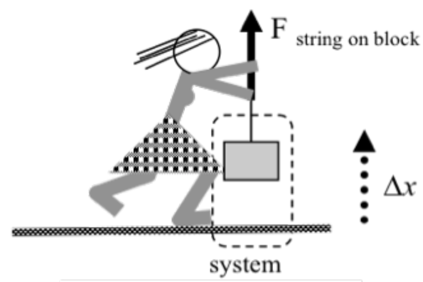
c) Create a story for what happened to the cart.

d) Decide what to include in your system. How did you decide?

e) Consider the situation. Is there a way this could be the final state of a process? Could it be the initial state of a process? Explain.

2.4 Explain

We have been talking about "work" conceptually throughout the last two lessons.
But how do we represent it mathematically?
Examine the following picture.



$$W = F_{string\ on\ block} \times \Delta x$$

a) Explain what is happening in the picture.

b) Compare it to the mathematical expression below the picture. Do you think this makes sense? Why?

Here's an Idea!

If you have difficulty determining the objects are in your system, you can try drawing a circle around those items you're interested in analyzing. This is your system. However, be careful of special cases like Earth!

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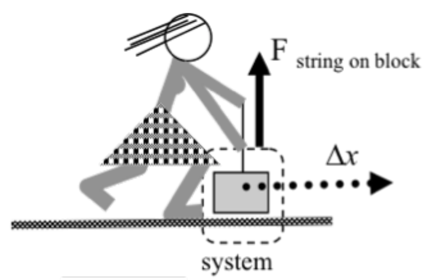
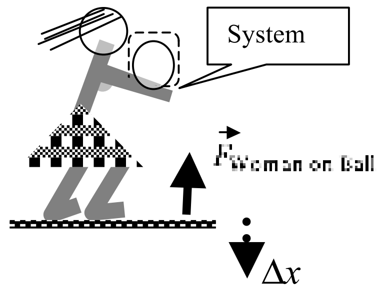
c) Explain what is happening in the picture to the right.



$$W = 0$$

d) Examine the picture and compare it to the mathematical expression below the picture. Do you think this makes sense? Why?



$$W_{\text{done by } F \text{ woman on ball}} = -F_{\text{Woman on Ball}} \times \Delta x$$

e) Explain what is happening in the picture to the left. Pay attention to the arrows representing the force exerted on the ball and the displacement of the ball.

f) Examine the picture and compare it to the mathematical expression below the picture. Do you think this makes sense? Explain. What is the work done by the force that Earth exerts on the ball?

Did You Know?

The unit of measurement for work is the newton • meter. This unit is often referred to as a joule, in honor of the 19th century English physicist James Prescott Joule.

g) Explain how the unit of measurement for work compares to the mathematical equation for work.

Did You Know?

Work done by a **constant** force on an object is equal to the product of the force magnitude and displacement magnitude with a positive sign ($W = F_{\text{W on B}} * \Delta x$) if the force and displacement are in the same direction and the product of the force and displacement with the negative sign ($W = -F_{\text{W on B}} * \Delta x$) if they are in the opposite direction. If the force and displacement of the object are perpendicular to each other, the force does NO work!

Homework

2.5 Observe and explain

Eugenia slowly lifts a 5 kg box by exerting a constant force. She moves the box from the ground up onto the table, which is 1 m high.

a) Draw a force diagram for the box while she is lifting it (consider the box moving at constant speed all the time). What is the amount of force that Eugenia exerts on the box? How do you know?

b) Calculate the work Eugenia has to do in order to lift the box onto the table.

c) Suppose Eugenia exerted a larger force on the box at the beginning. What would she have to do to get the box to stop when it got to the table?

2.6 Reason

Minh is riding the elevator up to the fourth floor of a shopping mall. He moves with a constant velocity from the second floor to the third floor.

a) Sketch the initial and final states, and then identify the system.

b) Make a reasonable approximation for Minh's mass and the distance between the floors in the building.

c) Estimate the work done on Minh by the elevator as he goes from the second to third floor. To calculate the force exerted on Minh, choose him as the system and draw a force diagram.

d) If Earth is not in the system, what work does it do on Minh?

2.7 Regular Problem

Shelly is now riding up the same elevator as Minh in the previous problem. Shelly's 2/3 the mass of Minh and the elevator goes from the second to the sixth floor.

a) Sketch the initial and final states, and then identify the system.

b) Compare the work done by the elevator on Shelly to the work done on Minh.

Reflect:

How does work in physics compare to work in real life?

What is the same? What is different?

Ask your relatives what they think the word "work" means in physics and then try to teach them what you know.

What difficulties did they have? Share them tomorrow in class.

Lesson 3: Just Name It!

3.1 Describe

In all of the activities you did before, the work was done on the system by an external force. This caused different types of changes in the system's ability to do something (for example, to smash chalk); in other words, the system's **energy**. Below, we describe several types of changes. Invent a name for each type of change; i.e. each type of energy gained.

a) The external force caused the block to move higher above Earth's surface.

b) The external force caused the cart to move faster and faster.

c) The external force caused the slingshot to stretch.

d) The external force caused the surfaces of the touching objects to warm.

Did You Know?

These changes are called ***energy changes*** of a particular system. Each type of energy has a formal name:

kinetic energy (K)
gravitational potential energy (U_g) of the system object–Earth
elastic potential energy (U_s)
internal energy (U_{int}) of two touching surfaces

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e) In parts (a) through (d), you came up with names for different types of energy. See if you can match your answers to the traditional terms in the help box above.

f) Describe the change in energy of a system if someone does positive work on it? Negative work?

3.2 Design an experiment Use materials on your desk to show an experiment consistent with each item below. Identify your system for each experiment.

a) Positive work causes an increase in the gravitational potential energy of the system.

b) Positive work causes an increase in the kinetic energy of the system.

c) Positive work causes an increase in the elastic potential energy of the system.

d) Kinetic energy in the system is converted to gravitational potential energy.

e) Kinetic energy in the system is converted to elastic potential energy.

f) Gravitational potential energy in the system is converted to internal energy.

g) Gravitational potential energy in the system is converted to elastic potential energy.

3.3 Relate

Describe one real-life situation that is consistent with the processes described below. Identify your system for each situation.

a) Positive work causes an increase in the gravitational potential energy of the system.

b) Positive work causes an increase in the kinetic energy of the system.

c) Positive work causes an increase in the elastic potential energy of the system.

d) Kinetic energy in the system is converted to gravitational potential energy.

e) Kinetic energy in the system is converted to elastic potential energy.

f) Gravitational potential energy in the system is converted to internal energy.

g) Gravitational potential energy in the system is converted to elastic potential energy.

3.4 Observe and Reason

Lift a box from the floor to a tabletop very, very slowly at a constant velocity. Assume that during this process you do a total of 125 J of work. *(There are no changes in kinetic energy or internal energy of the system.)*

a) Identify the objects included in your system. What is not in your system?

b) Draw a picture of the initial and final states

c) Complete the table below.

Portion of the Process	**Work that has been done so far**	**Gravitational Potential Energy of the Box-Earth system**
Before you start, the box is on the floor.		0 J
You have lifted the box ¼ of the way.		
You have lifted the box ½ of the way.		
You have lifted the box ¾ of the way.		
You have lifted the box all the way to the table.	125 J	

3.5 Reason

Go to the Physics Teaching Technology Resource website and investigate the experiment under Newton's Third Law (forces approach), where Eugenia and David push on each other: http://paer.rutgers.edu/pt3/experiment.php?topicid=3&exptid=37.

The above video depicts a situation where David and Eugenia are both on rollerblades. First, David pushes Eugenia. Then Eugenia pushes David.

a) Choose David as your system.

b) Describe how the energy of the system changes after each process.

c) Now choose Eugenia as your system. Describe how the energy of the system changes after each process.

d) Compare your results from David as your system and Eugenia as your system. What caused the change in energy of each system?

3.6 Observe and Reason

Pull back the spring on a Nerf gun very, very slowly at a constant velocity. Assume that during this process there are no changes in kinetic energy or internal energy of the system. You then point the Nerf gun vertically and release the trigger causing the dart to shoot up. The dart then comes back down and lands on the ground.

a) Identify the objects included in your system. What is not in your system? *Make sure to include all relevant objects.*

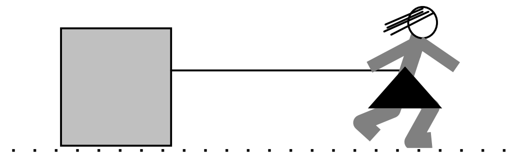
b) Complete the table below. Draw a picture of each portion of the process. What are your assumptions?

Portion of the Process	Picture	Energy of the system
Before you start, the Nerf gun is sitting in your hand 1m above the ground.		
You have pulled the spring back all the way.		
You point the gun vertically and release the trigger.		
The dart flies up 3 m.		
The dart falls down and hits the floor where it stops.		

3.7 Observe and Describe

A system consists of a crate and a rough horizontal surface on which it sits (see the illustration below). The rough surface is made of a special material that **changes color** when it changes temperature.

a) On the picture to the right, identify the initial and final states for objects in the system. Explain why you made this decision.



You do positive work on the system by pulling the crate for about 10 m at a constant velocity. You observe the colors of the surface change (showing the temperature increase).

b) Draw a force diagram that explains why the crate moves at constant velocity although you exert a constant force on it.

c) Describe how the system (block and surface) is different after you do the work than before the crate started moving.

d) If the ground/surface were not there, would the box have "warming potential?" Should we include or exclude the ground as part of our system?

e) Revisit the choice of a system. Do you want to make any changes? Write down your system below.

3.8 Hypothesize

a) Write an **equation** that represents the relationship between **work** (W) done on a system and the **final energy** (U_f).

b) Imagine that “the box sitting on the table” is the now the initial state. How much initial energy does the system Earth-box have?

c) You slowly lift the box to a higher shelf by doing 50 J of work. Will the system Earth-box have more or less energy than the original problem? Explain.

d) How could you add **initial energy** (U_i) to the equation you wrote above to make it a more complete representation of the work-energy relationship?

3.9 Test Your Idea

A older friend of yours in the honors physics class performed an experiment where she presses down on a spring, releases, watches it fly up, and finally falls and is caught. She created this table by calculating the energy involved.

a) Complete the table by describing the energy change that occurred.

Portion of the Process	Initial Energy of the System	Work done to the system	Final Energy of the System	Description of Energy Change During the Process
The spring sits there and then is pushed down	0 J	0.0005 J	0.0005 J	
The spring is released and begins speeding upward.	0.0005J	0 J	0.0005 J	
The spring stops speeding up and hangs at the height of the bounce for a brief instant.	0.0005 J	0 J	0.0005 J	
The spring stops hanging and speeds downward.	0.0005 J	0 J	0.0005 J	
The spring speeds toward the table but is caught just before it hits.	0.0005 J	-0.0005 J	0J	

b) Use the data in the table to evaluate your hypothesis about the relationship between work, initial energy, and final energy. Revise your hypothesis if needed.

c) What can happen to energy in a system? What *cannot* happen to energy in a system? What is the role of work?

d) Scientists use the expression, *"Energy of a system is* ***conserved*** *during a process."* How can they say this if the energy changes?

e) Write an equation for the relationship between initial (U_i) and final energy (U_f) of a system when there is no work done on the system.

Homework

3.10 Describe

Describe a real-life situation in which an external force does the following and state explicitly whether the system's energy increases or decreases:

a) Positive work on a system;

b) Positive work on a system but with a value that is less than in part (a);

c) Negative work on a system;

d) Zero work on the system even though an object in the system moves.

3.11 Reason

You push a small block that started from rest across a table; you do 25 J of work on the block. The system's (which consists of the **block** and the **table**) internal energy increases by 20 J.

a) How much kinetic energy does the system have?

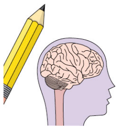
b) Write an mathematical statement for the situation.

3.12 Reason

An object falls from a height of 10 m. The object-Earth system initial began with 200 J of gravitational potential energy. Just before it lands it has no gravitational potential energy but it has 150 J of kinetic energy.

a) How much work is done on the system? How did you solve this problem?

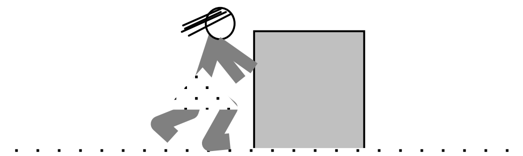
b) What can be doing work on the system?



3.13 Represent and Reason

Madison pushes a square block across **a rough surface**. The block moves at constant velocity. The surfaces of the block and the floor become warmer.

Consider the **block** and the **floor** in the system.



a) Does Madison do work on the system? Does the floor do work on the system? Explain your answer.

Consider **just** the **block** in the system.

b) Does Madison do work on the system? Does the floor do work on the system? Explain your answer.

c) Describe the difference between the two situations described above. Is either of these representations better than the other? Why?

Reflect:

Why is it important to choose a system?

How does your system affect what objects can do work on the system?

How does work done on the system affect the energy of that system?

Lesson 4: Raising the Bar

4.1 Represent and Reason

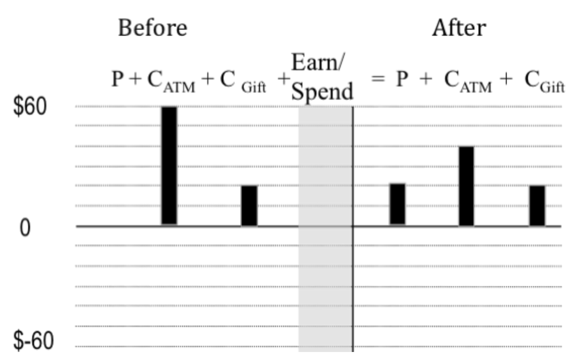
a) Have you ever used charts to represent data? Give an example.

b) Create a chart that shows that you have \$60 in your bank account, no money in you pocket, and \$20 on your gift card.

c) Imagine that you withdraw \$20 from your bank account and put it in your pocket. Create a new chart that represents your new situation.

d) If we place the two charts side-by-side, how does it express a **process**? Explain.

Need Some Help?
We can use a bar chart to represent transformations of a quantity during some process. We do this by placing the **before** bar chart next to the **after** bar chart.



We can also abbreviate the column headings in order to make this easier to read. We just have to make sure to include a key so that we know how to reading the chart. See below.

- **P** represents the amount of money in your pocket
- $\mathbf{C_{ATM}}$ represents the amount of money in your ATM card
- $\mathbf{C_{GIFT}}$ represents the amount of money on a rechargeable Best Buy gift card.
- **Earn/Spend** represents the amount of money that you gain or lose through transaction with other people

For situations with no money in a particular column, place a zero (0) to represent no bar.

---

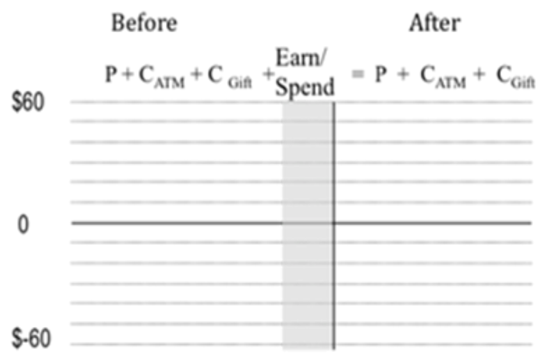
e) What do you notice about the money before and after this process?

Did You Know?
The total amount of money you have remains the same before and after, unless you earn some or spend some -- right? If the total amount of money you have does not change, we say it is **constant**. If it changes in a predictable way due to the expenses, we say that it is **conserved**, as it does not appear from nowhere and disappear to nowhere.

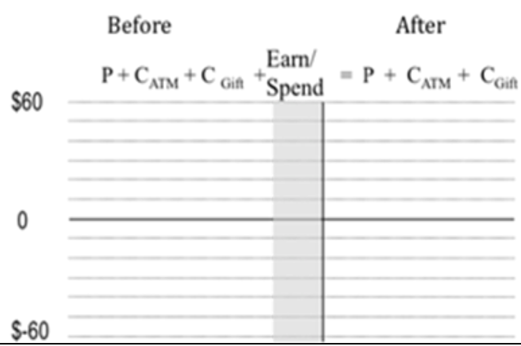
4.2 Represent

<table>
<tr><th>Situation Before and After</th><th>Bar Chart Representation</th></tr>
<tr><td>a) You have $15 in your pocket, $60 in your ATM account, and a gift card with $20 on it. You withdraw $20 cash from the ATM.

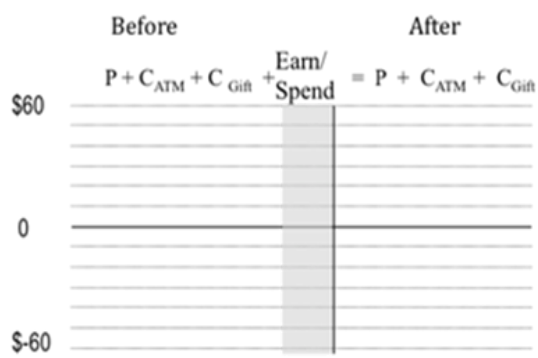
Represent this transaction on the bar chart. Did you earn or spend any money?

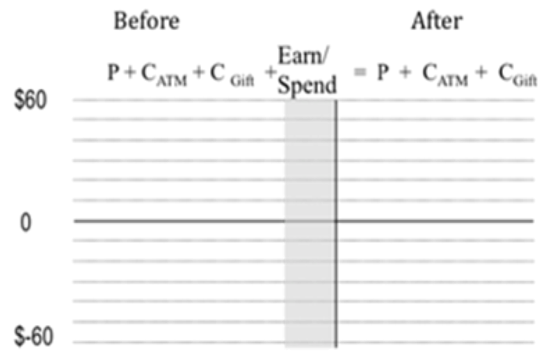
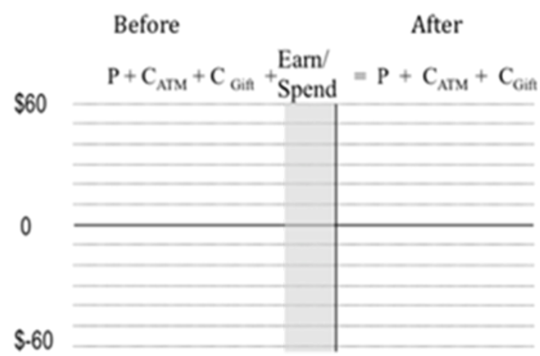
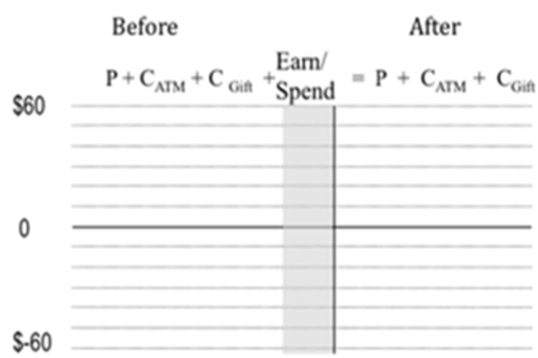
Represent this transaction with a mathematical statement</td><td>
</td></tr>
<tr><td>b) Next, you buy a snow shovel for $10 cash at Jones Hardware.

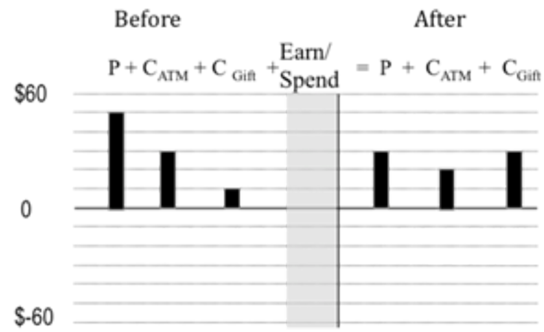
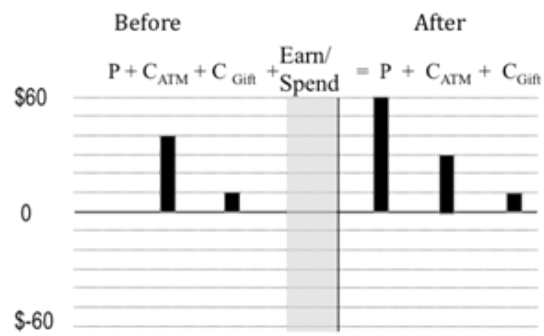
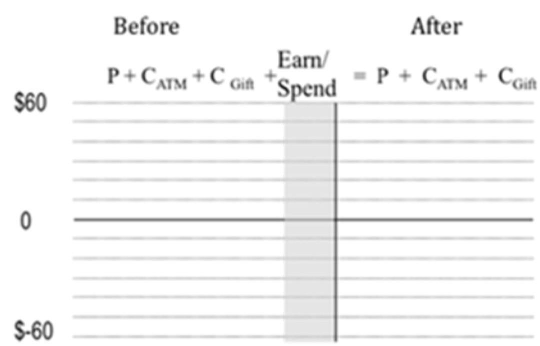
Represent this transaction on the bar chart. Did you earn or spend any money?

Represent this transaction with a mathematical statement</td><td>
</td></tr>
<tr><td>c) After returning from the hardware store, you spend three hours shoveling snow for an old lady who gives you $20 cash.

Represent this transaction on the bar chart. Did you earn or spend any money?

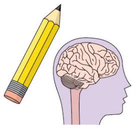
Represent this transaction with a mathematical statement</td><td>
</td></tr>
</table>

Situation Before and After	Bar Chart Representation
d) When you are finished shoveling, you spend $**20 cash** to put gas in your car so you can drive to the Best Buy. Represent this transaction on the bar chart. Did you earn or spend any money? Represent this transaction with a mathematical statement	
e) At Best Buy, you purchase a "Cher's Greatest Hits" DVD Box Set for $40. You empty out your gift card and use your ATM card to pay for the rest. Represent this transaction on the bar chart. Did you earn or spend any money? Represent this transaction with a mathematical statement	
f) What happens next? Continue the story and make a graph to match.	

Situation Before and After	Bar Chart Representation
g) Does this graph show something that could happen? If not, explain why not. If so, describe a situation it could match.	
h) Draw the missing bar. Write a mathematical statement to match the chart. Describe a story that could match.	
i) Make a chart to match this mathematical statement: $20 + $0 + $0 + $40 = $20 + $40 + $0 Describe a story that could match.	

a) Which of the above follow the principle that money is *constant*? *Conserved*?

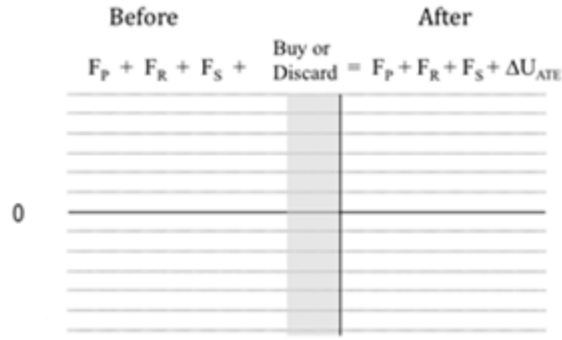
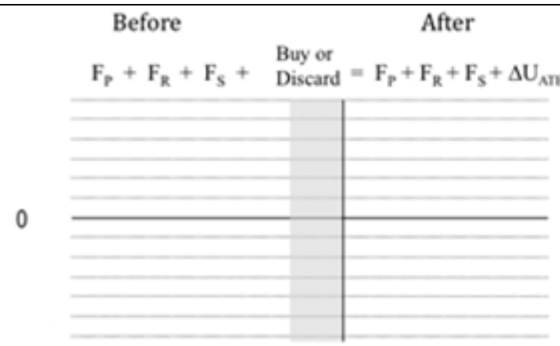
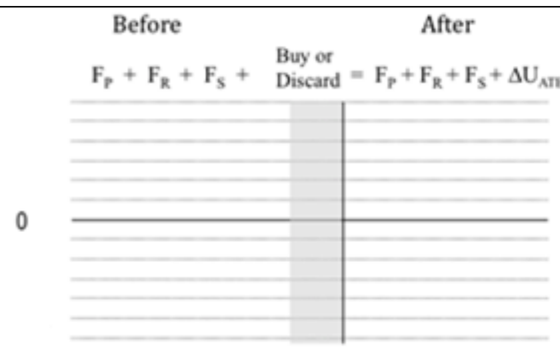
b) Draw a comparison between money transfers and energy transfer. What similarities do you see?



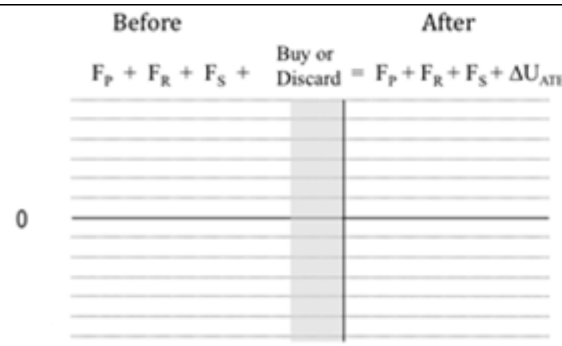
4.3 Represent and Reason

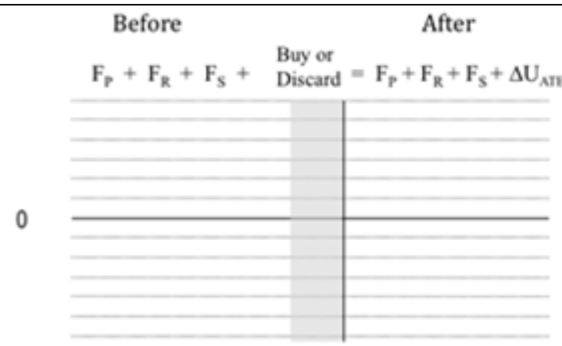
This time the exercise concerns the food in your house, and we are going to make bar charts with estimated quantities instead of exact numbers. Make sure the total mass of food remains the same unless you buy some or throw some out.

- $\mathbf{F_P}$ represents the amount of food in your pantry
- $\mathbf{F_R}$ represents the amount of food in the refrigerator
- $\mathbf{F_S}$ represents the amount of food on the stove
- $\mathbf{\Delta U_{ATE}}$ represents the amount of food "U" ate

Situation Before and After	Bar Chart Representation
a) You have some food in your pantry and some food in your refrigerator already. You return from a shopping trip with a few bags of groceries. You put some away in the pantry and some away in the fridge. Choose units and estimate quantities. In this problem, is ΔF_R positive, negative, or zero?	
b) The situation starts from where we left off in the previous question. You take some ingredients from the pantry and some from the refrigerator and make a meal on the stove. Fill in the chart and write a mathematical representation below	
c) Next, you eat half of the food you cooked, and store the rest in the refrigerator. Which is larger, ΔF_R or ΔU_{ate}?	

<table>
<tr>
<td>d) You wake up in the middle of the night and eat half the leftovers that are in your fridge.

Make a chart to match and write a mathematical representation.</td>
<td>
</td>
</tr>
<tr>
<td>e) The next day you come home with a big sack of White Castles. You eat the sack of White Castles and throw out your leftovers from the day before.

Choose units and estimate quantities. Write a mathematical representation below.</td>
<td>
</td>
</tr>
<tr>
<td>f) Make a story to match the chart. Write a mathematical representation.</td>
<td>
</td>
</tr>
</table>

Why do we show ΔU_{ate} on the "after" side but not on the "before" side?

4.4 Represent and Reason

While working on the following problem, Alan decided that he could represent work-energy processes with a bar chart similar to the ones we used for money.

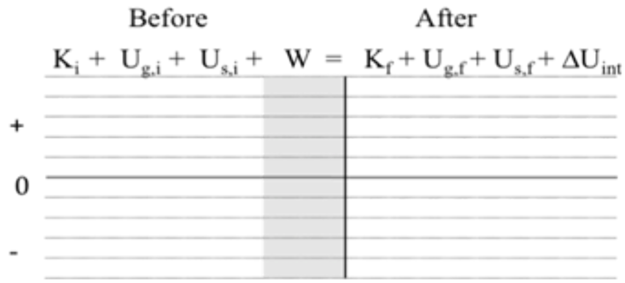
<u>Problem</u>: Jessica stands in an elevator on the first floor. The elevator doors close and the elevator delivers Jessica to the fourth floor. Jessica and Earth are in the system. Identify all the changes that occur.

a) Identify the system of interest

b) Draw pictures of the initial and final states. (Make sure to include a description.)

c) Review the problem and create your own work-energy bar chart.
(“Need Some Help?” is on the next page)

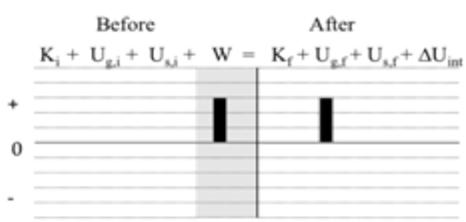
Need Some Help?
Work-energy bar charts provide a concrete way to represent work-energy processes. In a work-energy bar chart, a bar represents each type of energy initially in the system, as well as the final energies of the system. If external objects do work on the system (positive or negative), then there is a bar to represent work.



We don't know the exact amount of energy or work usually but we can still make estimates based on the situation. The column for the work bar is shaded to indicate that it is not a type of energy but is instead a process involving an interaction between a system object and an object outside the system.

4.5 Explain
Alan solved problem 4.4. Use his solution and your response in the previous activity(4.4) to answer the questions that follow, below.

Alan's solution: The system includes Jessica, who might be moving so we may need to consider kinetic energy. The system also includes Earth, so we will have to consider gravitational potential energy, too. But because Jessica's initial and final velocity is zero, the kinetic energy does not change. I put the initial energies of the system on the left side of the bar chart and the final energies on the right side. However, I had no energy on the left but some on the right, which can't be possible. Then I remembered the elevator that pulled Jessica up. The elevator is not in my system, so it must do positive work on Jessica. I put the work done in the column labeled *W* for work.



System	Initial State	Final State
Jessica Earth	Jessica is not movi standing in the elev on the first floor.	Jessica is not movi standing in the elev on the fourth floor.

a) How does your answer compare with Alan's?

b) Does Alan's bar chart help him understand the problem? Explain your answer.

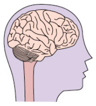
c) What do the lengths of the bars represent in Alan's Work-Energy bar chart?

d) How do you think Alan decided to make the lengths of the bars in his bar chart? Explain.

Use the rubric below to assess your work-energy bar chart. How did you do? Describe your difficulties.

Rubric to self-assess your work-energy bar charts

Absent	An attempt	Needs some improvement	Acceptable
No work-energy bar chart is constructed.	Work-energy bar chart is constructed but is missing or contains extra energy bars; the initial and final states described do not match the initial and final states on the chart. The initial quantities plus the work do not equal the final quantities.	Work-energy bar chart lacks a key feature such as labels, the zero energy is not indicated, or quantities are not drawn to scale.	The chart is labeled clearly so that one can understand the initial and final states of the system. The relative lengths of the bars are correct. And the zero energy is indicated.



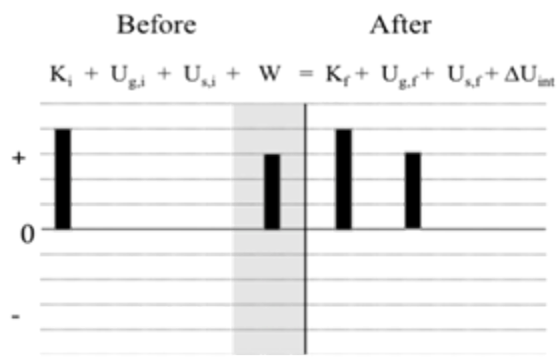
4.6 Reason

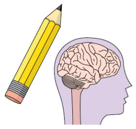
a) Look back at the bar charts from the previous activity. If the elevator only went to the ½ as high, which of the bars would change and by how much?

b) How would the work-energy bar chart look if we chose a final state when Jessica was still moving?

c) How can we convert Alan's bar charts into a mathematical statement?

d) Describe a situation with Jessica that could be represented by this energy bar chart.



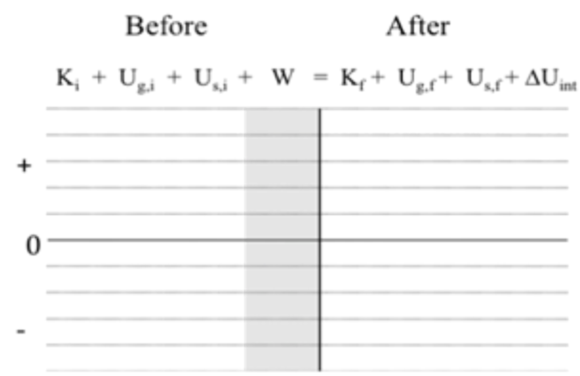


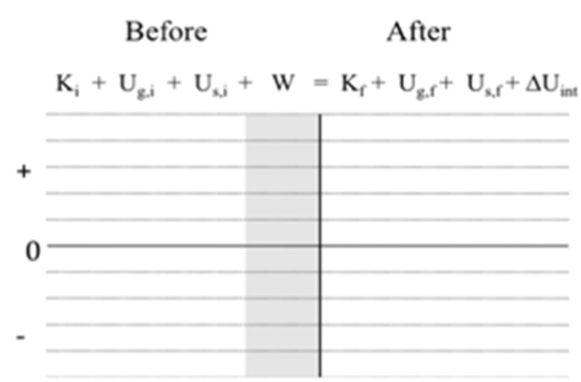
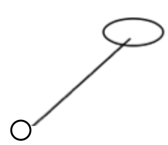
4.7 Represent and reason

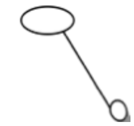
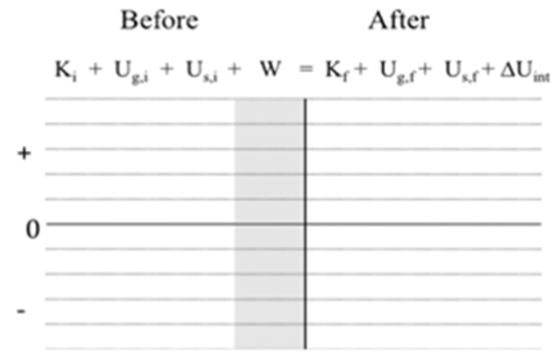
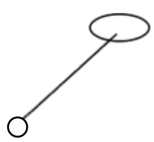
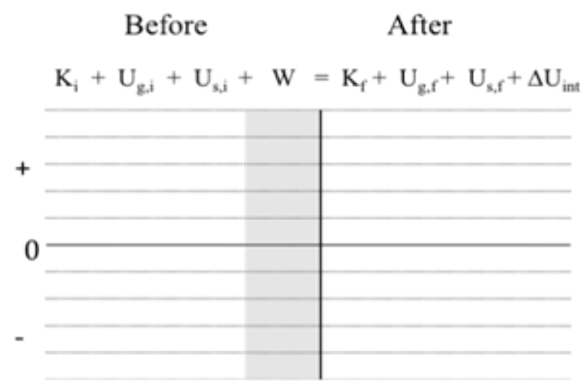
You are investigating the energy of a pendulum "bob" that swings back and forth. (a "bob" is a weight that hangs on the end of a string).

Use the materials in front of you to make observations of the bob at different points along its path. Make sure you observe the bob swinging for a while before you fill out the table.

a) Complete the tables below to describe all the energy transformations. Be sure to identify the system in each step. See the first row for help.

Initial State	Final State	Construct the Work-Energy Bar Chart
The bob has no velocity and is at the highest point of the swing. $U_{g,\,i} = 10$ J	The bob is at the bottom of the swing and is going really fast. $K_f = 10$ J	
		
System: **Bob, Earth, and surrounding air.**		**Equation:** $U_{g,\,i} = K_f$ **10 J = 10J**

Initial State	Final State	Construct the Work-Energy Bar Chart
The bob is at the bottom of the swing moving really fast. K_i=10 J	The bob gets to the top of the swing and slows down.	
		
System: **Bob, Earth, and surrounding air.**		**Equation:**

<table>
<tr><td>The bob has no velocity and is at the highest point of the swing
</td><td>The bob is at the bottom of the swing and is going really fast backwards.
</td><td>
</td></tr>
<tr><td colspan="2">System:</td><td>Equation:</td></tr>
<tr><td>The bob has come to a stop at the top of the swing's motion and begins to swing forward.
</td><td>After a few swings the bob eventually comes to a stop at the center of the swing.
</td><td>
</td></tr>
<tr><td colspan="2">System:</td><td>Equation:</td></tr>
</table>

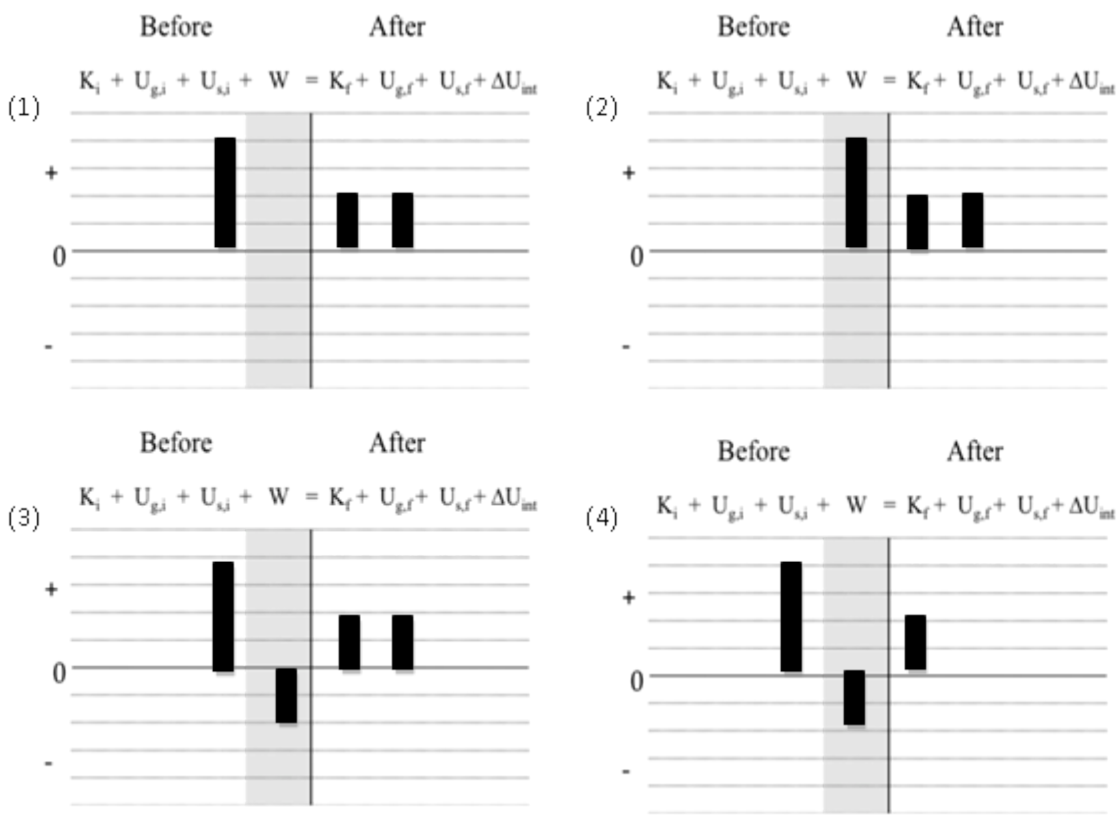
a) Describe how the system's energy has changed in each step the bob swung back-and-forth.

b) How has the <u>*total energy*</u> of the system changed?

c) If the rope from the pendulum is not in the system, how is it accounted for in the bar charts? (Hint: think of the direction of the force that the rope exerts and the direction of the bob's displacement at the chosen locations.)

4.8 Reason

Adventurous Theo was testing out a stunt cannon. He compressed the spring inside the cannon and placed himself in the barrel. He then released the spring and was pushed up. Which of the following charts (#1-4) accurately represents the situation where Theo and the cannon are the system?



a) Which graph accurately represents the situation where Theo and Earth are the system?

b) In which graph(s) is energy constant?

c) In which graph(s) is energy conserved?

Homework

4.9 Observe and Reason

Use the PhET simulation Energy Skate Park to answer the questions below.

Go to the website: http://phet.colorado.edu/ and search for “Energy Skate Park.”
Click on the first Simulation and then click Run Now!

a) Identify your system.

b) Draw an energy bar chart for the system as the skater goes from the top of the ramp down to the bottom. Then draw a bar chart for the process as he continues from the bottom of the track up the other side. Make sure your charts are consistent with your chosen system.

c) Based on your observations, when does the system have the highest kinetic energy?

d) When does the system have the highest gravitational potential energy?

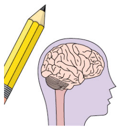
e) Is the skater your system? If so, is he able to have gravitational potential energy and kinetic energy by himself?

f) Click on the Bar Graph tab on the right side of the simulation. Compare your bar charts with the ones provided. How are they similar? How do they differ?

g) What do you notice about the "Total" column on their Bar Graph? What does this represent?

h) On the Bar Graph provided, what could "Thermal" stand for? What kind of energy would that look like on our bar charts?

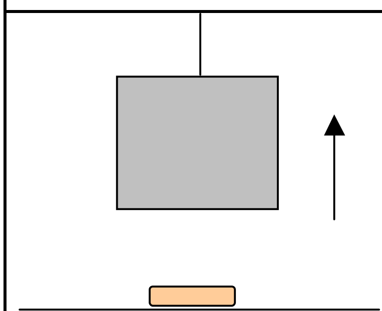
i) Click "Track Friction>>" and change the coefficient of friction between the skater and the track. How does that change the bar chart? Use your knowledge of energy transfer to explain what you observe.



4.10 Represent and Reason

For each of the three situations we discussed in the first lesson (the chalk-smashing problems in previous Lessons 1.4 , 1.5, and 1.7), answer questions (a-e) for each situation below.

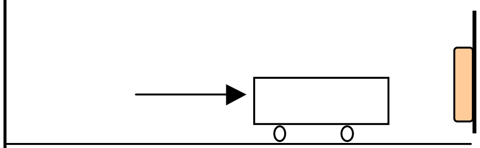
a) Identify the system
b) Describe the initial and final states
c) Make energy bar charts
d) Create a representative mathematical statement (use numbers to represent the amount of energy of the system).
e) Discuss all of the processes form the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved? What is the difference?

1.4 The block is lifted above the chalk.	a) Identify the system
	b) Describe the initial and final states

c) Make energy bar charts :

d) Create a representative mathematical statement (use numbers to represent the amount of energy of the system).

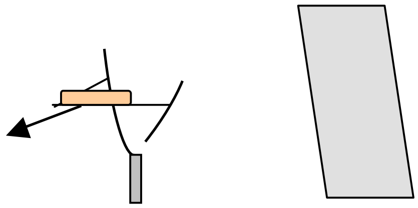
e) Discuss all of the processes form the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved?

1.5 The cart is pushed towards the chalk.	a) Identify the system
	b) Describe the initial and final states

c) Make energy bar charts :

d) Create a representative mathematical statement (use numbers to represent the amount of energy of the system).

e) Discuss all of the processes form the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved?

1.7 The slingshot is pulled back to shoot the chalk.	a) Identify the system
	b) Describe the initial and final states

c) Make energy bar charts :

d) Create a representative mathematical statement (use numbers to represent the amount of energy of the system).

e) Discuss all of the processes form the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved?

4.11 Reason

In this lesson you have investigated the ideas of constant and conserved quantities.

a) Based on your observations, when is energy constant?

b) Based on your observations, when is energy conserved?

c) What role does work play in the bar charts? Does it affect whether the energy is constant or conserved?

4.12 Reason and Represent

Heather decides to practice her skiing down a tall mountain, but wants to know how much kinetic energy she will have at different points in her trip. The system skier-Earth has 4×10^5 J of gravitational potential energy before she starts moving down the ski slope. Create work-energy bar charts to help you solve these problems, and answer questions (a-e), below.

a) How much kinetic energy does the system have when the skier is $\frac{1}{4}$ the way down?	
b) How much kinetic energy does the system have when the skier is $\frac{1}{2}$ the way down?	
c) How much kinetic energy does the system have when the skier is $\frac{2}{3}$ the way down?	
d) How much kinetic energy does the system have when the skier is $\frac{3}{4}$ the way down?	
e) What assumptions do you have to make to solve this problem?	

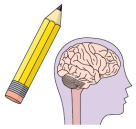
4.13 Represent and Reason

You push a small block across a table; you do 25 J of work on the block. The system's (which consists of the block and the table) internal energy increases by 20 J.

a) Create a work-energy bar chart.

b) How much kinetic energy does the system have?

c) Discuss the processes from the point of energy conservation. Is the energy constant? Is the energy conserved? What is the difference?



4.14 Represent and Reason
An object falls from a height of 10 m. While it is falling, the gravitational potential energy of the system object-Earth decreases by 200 J and its kinetic energy increases by 150 J.

a) Create a work-energy bar chart.

b) How much work is done on the system? What can be doing this work?

c) Discuss the processes from the point of energy conservation. Is the energy constant? Is the energy conserved? What is the difference?

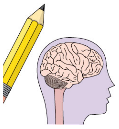
Reflect:

What is the purpose of work-energy bar charts?

Find a family member or a friend and teach her/him about the bar charts.

What difficulties did they have? Prepare to share your experience in class.

Lesson 5: Is That Real?



5.1 Represent and Reason

Open the following video file using the link below:
http://www.youtube.com/watch?v=TK27aknWVI4.

Watch the video of the elephant and then answer the following question. Feel free to revisit the video if needed.

a) Write about all the different things you see in the video that relate to energy.

Choose two different situations from the video that you can analyze and then share with the class.

b) Describe or draw your initial and final states

c) Include your choice of a system

d) Create three different representations (i.e. picture, bar chart, force/motion diagrams, number statement, graphs, etc) to demonstrate the changes that occurred during the process.

e) Is the elephant situation realistic in terms of the physics and energy?

5.2 Represent and Reason

Using a computer go to the PhET website:
http://phet.colorado.edu/simulations/sims.php?sim=Energy_Skate_Park and download the Energy Skate Park simulation. Once the download is complete, run the program and begin the activity.

Create a skate park by taking pieces from the top left corner and connecting them together. You can click on the track to bend it. Otherwise just click on the "track" tab from the top and choose from the premade tracks.

a) Draw a picture of your track.

Place the skateboarder on the track and observe the motion. You can investigate further by changing the skate or you can scroll down and adjust the friction. Choose two different situations from the simulation that you can analyze and then share with the class.

b) Describe or draw your chosen initial and final states

c) Include your choice of a system

d) Create three different representations (i.e. picture, bar chart, force/motion diagrams, number statement, graphs, etc) to demonstrate the changes that occurred during the process.

e) Is the skateboarding situation realistic in terms of the physics and energy?

5.3 Represent and Reason

Get a pullback/wind-up toy car from your teacher. Investigate your toy car by observing it under several different conditions (off a ramp, different surfaces, etc.)

a) Discuss briefly the different investigations that you conducted using your toy car.

Choose two different situations from your investigation that you can analyze and then share with the class.

b) Describe or draw your initial and final states

c) Include your choice of a system

d) Create three different representations (i.e. picture, bar chart, force/motion diagrams, integer statement, graphs, etc) to demonstrate the changes that occurred during the process.

e) Is the toy car situation realistic in terms of the physics and energy?

5.4 Reason

a) Did any of the situations in 5.3 seem the unrealistic? Did any of this seem simplified? Explain.

b) Were any of these situations more difficult to analyze? Explain.

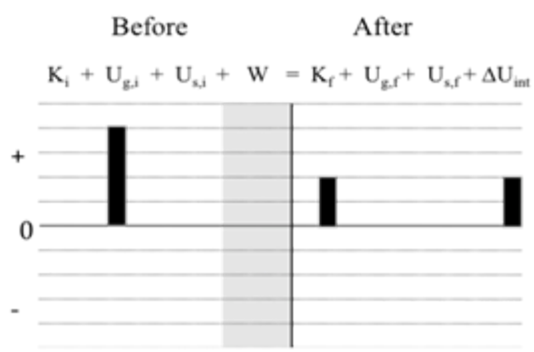
c) How might physics help you know whether to believe what you're seeing?

Homework

5.5 Describe and Represent

Relate what you just learned about physics to real life. Create a mathematical statement and describe a real-life process that is consistent with each given work-energy bar chart. Complete the table below.

- Discuss all of the processes from the point of view of energy conservation.
- In what processes is the energy constant? In what processes is the energy conserved? What is the difference?

<table>
<tr><th>Bar chart for a process.</th><th>Describe a possible consistent process.</th><th>Provide a mathematical statement.</th></tr>
<tr><td>
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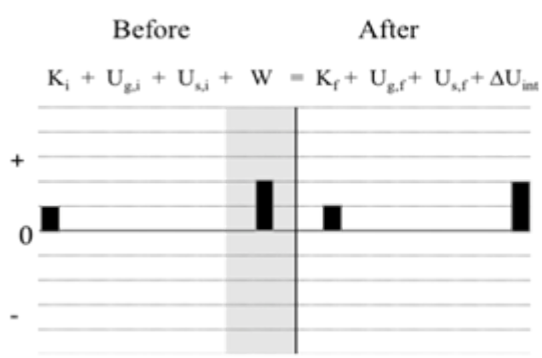
<tr><td>
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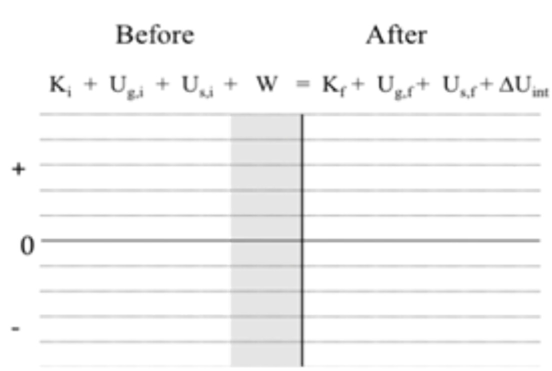
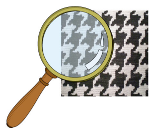
<tr><td>
</td><td></td><td>$40\text{ J} + (-25\text{ J}) = 15\text{ J}$</td></tr>
</table>

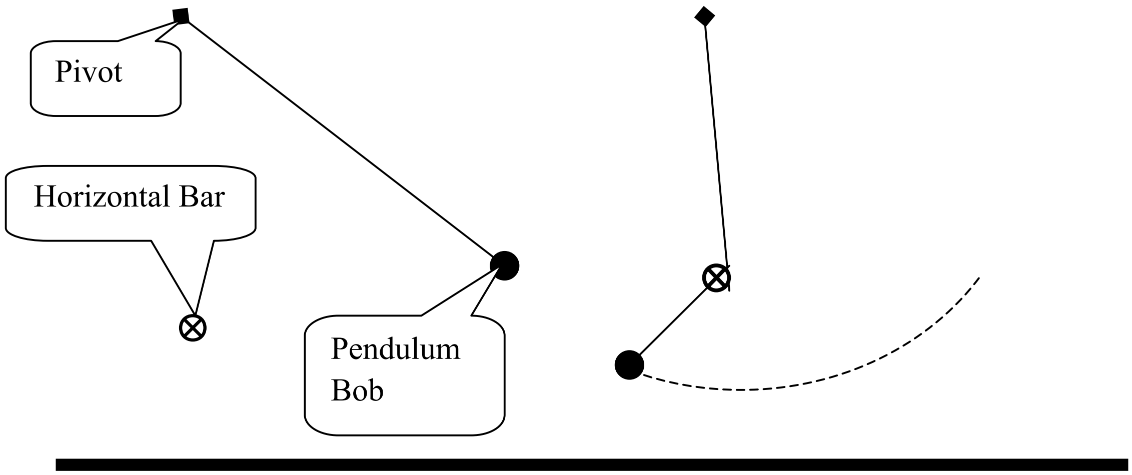
Reflect: What did you learn during this lesson? If you were to write a letter to your past self about how physics is represented in the real world, what would you say?

Lesson 6: Galileo's Pendulum



6.1 Observe and Find a Pattern

Design an experiment to investigate the factors that determine how high a pendulum will swing when there is bar in its way. You will have a pendulum bob, ring stand, and a bar whose height can be adjusted using clamps. If you have a video camera you can use this to help you record and analyze the data.



a) Design the observational experiment and write the procedures below.

b) What variables are you measuring? Which are independent and which are dependent?

c) Perform your experiment and record your results in a table.

d) Analyze each trial in terms of energy. What system did you choose for analysis? What is the initial and final state of the system in each trial?

6.2 Hypothesize

a) What changes occur to the pendulum's motion during the experiment?

b) What aspects of motion do not change?

c) What patterns do you see in the data?

d) What features of its behavior can be explained using the concept of energy?

e) Formulate a hypothesis that can be used to predict the height of a swinging pendulum when a bar is in the way.

6.3 Test Your Idea

Design a testing experiment for the hypothesis you develop.

a) State clearly the hypothesis you will test in the experiment.

b) Decide what quantities you will measure and what quantities you will calculate.

c) Decide what objects are in your system and whether any external objects do work on it.

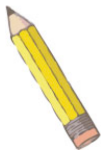
d) When you are done, make a prediction and perform the experiment.

e) How close is your outcome to your prediction? What judgment can you make about your hypothesis?

Revise and retest if necessary.

An alternative version of the experiment can be found at the PAER website: http://paer.rutgers.edu/pt3/experiment.php?topicid=4&exptid=203

Homework



6.4 Write a Report

Reflect on the experiment (Galileo's pendulum) that you performed in class. Write a lab report for this investigation. The report should describe what you did and what you found so other scientists can repeat your experiment and obtain the same results.

Use the rubric below to help you write the report.

Ability	Absent	An attempt	Needs some improvement	Acceptable
Is able to formulate the question to be investigated.	No mention is made of the question to be investigated.	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 and 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.	It clearly describes what happens in the experiment, both verbally and by means of a labeled picture.
Is able to construct a mathematical (if applicable) relationship that represents a trend in 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).

6.5 Evaluate

Tomorrow in class you need to review the lab report of your classmate using the rubric above. Write a short report describing your review without giving any scores. Think of the strong sides of the report. Think of what could be improved. If your classmate has any difficulties, suggest activities or lessons that they may want to revisit. 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.

Reflection: How is a testing experiment different from an observational experiment? Can you explain it to someone who has never taken physics? Give two examples of each from the modules with you worked so far.

Lesson 7: Simple Machines I

7.1 Design an Experiment

Design an experiment to determine the amount of work it takes to move a cart from the bottom to the top of an incline. The goal of this experiment is to find patterns relating work and energy.

You have the following materials: two inclined planes that go to the same height but have different slopes, force probe or spring scale, a cart, meter sticks, and a scale to measure mass.

Describe the experiment you will perform, draw a picture.

a) Determine what the system of interest is and the initial and final states.

b) Decide what quantities you will have to **measure** to find the work it takes to move the cart up the incline.

c) Perform the **experiment** and record your data in a table.

d) Decide if you can make any assumptions that will help to simplify the problem.

Here's an Idea!

You may notice that when the cart is pulled really fast up the incline, the force measured by the spring scale was hard to read. Try pulling the cart fast and then slow and steady. Which way makes it easier to take the force measurement? Why are the measurements different (Hint: Think of whether the cart is accelerating)?

e) Draw a work-energy bar chart that represents the process. Think of what is included in your system. Choose initial and final states.

7.2 Observe and find a Pattern

a) Repeat the same steps for a second set of trials; this time pull the cart straight up the side of the incline, starting from the ground and finishing at the top. Record data, and draw a work-energy bar chart that represents this situation.

b) Look for patterns in the data you collected.

c) How does the work-energy bar chart for each set of trials differ? How do the heights of the bars compare between the diagrams?

d) How does the amount of work it takes to move the cart to the top differ in each set of trials (assume that the cart moves very slowly)?

e) Was one method of getting the cart to the top "easier" than the other? Describe how.

f) What was the gravitational potential energy of the system when the cart was at the top of each of the inclines?

Ability	Absent	An attempt	Needs some improvement	Acceptable
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 and independent and dependent variables are identified and the choice is explained.
Is able to use available equipment to make the 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.	It 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 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).

7.3 Hypothesize

a) In this experiment you determined the work needed to lift the cart straight up so it covers the distance Δy in the vertical direction. Look back to your bar charts from the experiment. What type of energy increases as a result of doing work on the system?

b) Write an equation for the work-energy relationship in this problem.

c) How did we mathematically define work in the beginning of the unit? What is the force that is doing the work? What is the magnitude of the force that you need to exert on the cart to lift it up very slowly? To answer this question, draw a force diagram for the cart and decide which force on the diagram is doing the work.

d) How can we combine the two expressions above in terms of gravitational potential energy change?

e) How can we write the expression for the gravitational potential energy of the system that involves an object of mass *m* at the height *x (displacement!)* above the surface of Earth?

7.4 Test Your Idea

a) Given the dimensions of another group's ramp, predict the amount of energy the system cart-Earth would have when the cart is at rest at the top of the ramp. Perform the experiment and record your results. How did the outcome and your prediction compare?

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 incorporate assumptions.	A prediction is made that follows from the hypothesis and incorporates assumptions.

b) Revise your hypothesis if necessary.

7.5 Reason

You, Brianna, and Doug just finished bowling and are ready to put the bowling balls away. Doug uses a ramp to roll the ball to the top shelf while Brianna says it is easier to just lift the heavy ball straight up.

a) What are the pros and cons of both methods?

b) If both bowling balls have the same mass, does Doug do less work than Brianna to get the ball to the top shelf assuming that they both lift the balls very slowly. Why is this assumption important?

Did You Know?

Simple Machine: A simple machine is a device in which only one external force does work on a system.

Mechanical Advantage: A simple machine or a compound machine (two or more simple machine combined to make one device) work in such a way so a smaller force (but exerted over a greater distance) performs the same amount of work as would be performed without the machine. ***No machine can give you an advantage in work.*** You win in force but lose in distance! **By definition, the mechanical advantage of an inclined plan is the ratio of length/height - MA=L/H.**

---

c) How does Doug's ramp work like a simple machine?

d) Doug says his method gives him a better mechanical advantage for moving the bowling balls to the top shelf. Brianna disagrees. Which method do you think is better? Explain.

Write and Reflect

Write an article for a scientific journal describing what you learned about simple machines. Use the rubrics to make your article similar to the articles scientists write.

Lesson 8: Simple Machines: Applications

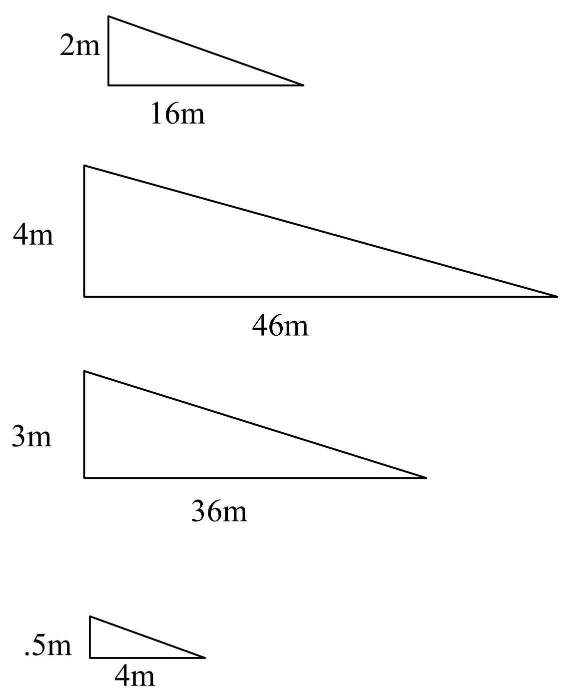
8.1 Represent and Explain

You are a member of a team hired by an architectural firm to design a wheelchair accessible entrance to a building. The Americans with Disabilities Act requires the steepness of wheelchair ramps to be less than a 1:12 ratio of vertical change to horizontal change.

a) Explain why the Americans with Disabilities Act is concerned with the steepness of accessibility ramps.

b) Draw three ramps that meet their requirement. Label the relevant dimensions and explain how you chose them.

c) Decide which of the following ramps meet the recommendation. *(Some are represented by a picture and some are represented by a ratio.)*



(v) 1:10

(vi) 3:42

(vii) 2:28

d) Calculate the smallest amount of work that is required to push a 20 kg object up each of the ramps (v–vii).

Need some help?
Remember from our dynamics unit that we can draw force diagrams to solve this problem. Then we can begin to ask ourselves, "*What objects are exerting a force on a box that you're pushing up a ramp? What is the magnitude of this force? How can we determine this?*"

8.2 Reason
A notice came in the mail that revealed the staircase height, 2.5 meters. Now that we have this piece of information we can begin working on building the ramp. If the staircase is 2.5 meters high,

a) How long does a ramp need to be to fit the regulations?

b) The company controller says this is too long. The controller argues that regardless of the length of the ramp, a person pushing the chair must do the same amount of work to get a wheelchair to the top. He suggests that we can save money by using less construction material by making the ramp as short and steep as possible. He wants to make a ramp with a length of 4.0 m.

c) Give two reasons why it is important not to make the ramp any steeper.

8.3 Explain

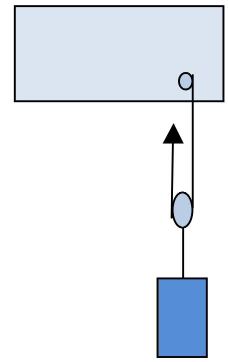
One of your classmates is having trouble understanding the difference between the amount of **effort** it takes to lift or move something (the amount of force you exert on an object or system) and the amount of **work** required to lift or move something. He says, "If it is easier to do, it must be less work."

a) Describe how you would help your classmate to understand this idea better.

b) Use examples like the ramps from the previous problem.

Lesson 9: Simple Machines II

9.1 Test an Idea



In the previous lab, we found that using an inclined plane does not reduce the amount of work you have to do to lift an object.
Your friend Cadence says, *"I have a simple machine that allows me to lift an object by doing less work than if I lifted the same object without the machine."* She claims her machine reduces the amount of work that is needed to lift an object. Her simple machine is called a movable pulley. She drew a schematic of this machine for you. (diagram at right).

a) Design an experiment to test her idea. You have the following equipment: Single moveable pulley, block, and spring scale

b) Describe your experiment; include all the details about what you will measure and how you will measure it: **variables!** What are your independent and dependent variables?

c) Is it possible to reduce the amount of work needed to lift an object to a certain height? Explain.

d) Make a prediction for the outcome based on Cadence's hypothesis.

Use the rubrics below to help you answer the questions in an informal lab report.

Scientific Ability	Absent	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 incorporate assumptions.	A prediction is made that follows from the hypothesis and incorporates assumptions.
Is able to make a reasonable judgment about the hypothesis.	No judgment is made about the hypothesis.	A judgment is made but is not consistent with the outcome of the experiment.	A judgment is made and is consistent with the outcome of the experiment but assumptions are not taken into account.	A reasonable judgment is made and assumptions are taken into account.

a) Perform the experiment and describe the outcome of the experiment

9.2 Evaluate

a) Describe your data and highlight any important patterns you noticed.

b) What judgment can you make about Cadence's hypothesis? Explain.

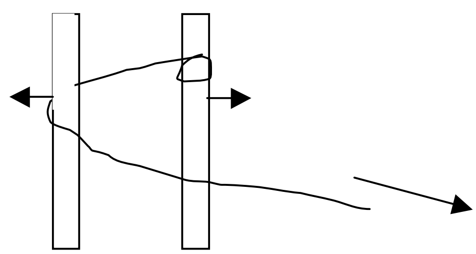
c) Write a revised hypothesis.

d) Does Cadence's idea represent a mechanical advantage? Explain why it is easier to pull the block up using Cadence's pulley.

e) Compare this device to the inclined plane. What is different and what is the same? Think about the purpose of both devices.

Need some help?
Remember that a mechanical advantage is when a simple machine allows you to exert a smaller force (exerted over a greater distance) on a system in order to do the same amount of work on a system as would be performed without the machine.

9.3 Compare
You will be performing an experiment involving two meter sticks, some rope, and two of your classmates. Two of you will be holding the meter sticks parallel to one another, one meter stick per person. The third will tie the end of a rope around the first meter stick and then loop it around the second meter stick. The goal of this experiment is to see whether the "pulley" arrangement of the rope can act like a simple machine.



The two people holding the meter sticks try to pull them apart. The person holding the rope tries to pull the meter sticks together.

a) Design and perform an experiment that will allow you to find a pattern in the number of times you wrap the rope around the meter sticks and the force exerted by the people pulling the sticks apart and the person pulling the sticks together.

b) Draw a picture of the experiment and describe what you did.

c) Record the data you collected and decide what the best way to represent it is.

d) Describe the pattern you found in words and mathematically.

e) Use your knowledge of mechanical advantage to relate the force exerted on the rope to the process of wrapping it around the meter sticks multiple times. Compare your pattern to the definition of mechanical advantage. Use any necessary representations to help with your explanation. Are the two relationships consistent? How do you know?

Homework

9.4 Evaluate

Using your textbook, the Internet, or encyclopedias, find more examples of simple machines. Compare them to the machines we worked with in class (movable pulley and the inclined plane).

9.5 Pose a Problem

Create one problem dealing with a simple machine and calculating work-energy.

Solve the problem with as many representations as you can.

Tomorrow in class you will exchange this with a classmate. You will answer your partner's question and then discuss the answers.

Reflect: What is the purpose of simple machines? Find a family member or a friend and teach her/him about simple machines. What difficulties did they have? Look for examples of simple machines in your home. Prepare to share your experience in class.

Lesson 10: Power Up

10.1 Reason

Read the description of power below. Using the information (specifically the units), create a qualitative definition for the term, Power.

Power has units of joules per second (J/s). Joules per second are often called watts (W), named after the 18th century Scottish engineer James Watt.

10.2 Develop a relation

Your friend Heather brings in two motors to class. She wants to install one of them in her lawnmower but wants to make sure that she picks the best motor. Your job is to determine a rating system for the motors to determine which one will cut her grass most efficiently.

You set the motors on top of a table and attach a string and 10.0 kg bob to each of them. You see that Motor 1 pulls the bob from the floor to the top of the table in 0.032 seconds. You see that Motor 2 pulls the bob from 5 cm above the floor to the top of the table in 0.020 seconds.

a) Estimate the height of the table. Devise a physical quantity that can describe the motor's ability to pull the bob up. What is it equal for the first motor? Second motor? Are the numbers reasonable? How d you know?

b) Read the definition for power below. How did your definition compare?

Did You Know?

The physical quantity of **Power (P)** describes how much work is done on a system per time interval or the energy that is transferred into or out of a system each time interval.

$$P = \frac{W}{\Delta t} = \frac{\Delta U}{\Delta t}$$

The units of power are joules/second = watt

10.3 Regular Problem

Corrine is training for the annual javelin throwing contest. Determine how much power she exerts while lifting the following objects. Draw a picture of the initial and final states.

a) a 1.5-kg javelin 1.0 m in 1.0 s

b) a 1.5-kg javelin 1.0 m in 0.5 s

c) a 1.0-kg javelin 2.0 m in 1.0 s

d) a 2.0-kg javelin 1.0 m in 1.0 s

10.4 Explain

The luminosity of the Sun is the amount of power the Sun emits in the form of electromagnetic radiation. The Sun's luminosity is 3.8×10^{26} (W). If you were able to collect all of the Sun's energy, estimate how long you have to collect it in order to light all of Earth's light bulbs. Explain how you came to this conclusion.

Homework

10.5 Regular problem

Tahreen, a 52 kg hiker, climbs to the summit of Mount Mitchell in western North Carolina. During one 2.0 hr period, her vertical elevation increases 540 m.

a) Draw a picture of the process, identify the initial and final states of the process and specify the reference level you are using.

b) Determine the change in gravitational potential energy of the system Tahreen-Earth. Where did this energy come from?

c) Determine the power generated to increase the gravitational potential energy of the system.

10.6 Regular problem

You have developed superpowers overnight. You can now stretch your arms to reach ridiculous heights. You decide to become a hero and on your way home from school, you do the following heroic acts.
Determine how much power you exert while lifting the following objects. Draw a picture of the initial and final states.

a) You rescue a 0.05-kg bird from the sidewalk and place it back in its nest, 5.2 m up in a tree, in 1.0 s.

b) You lift a 6-kg bag of Oreos 3.0 m up to your tree house in 6.0 s for your slumber party with your friends (you have been saving up for all the Oreos).

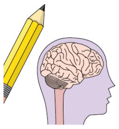
c) You lift a 10.4-kg bag of rice 2.6 m to the top of the pantry for your mom in 2.3 s.

d) Your 70-kg sister twisted her ankle so you lift her from the foyer to the second floor 4.0 m straight up in 10.0 s.

Reflection: How did you learn about power? Give three examples from your day today where the concept of power helps explain what happened.

Ask your relatives or friends what they think the word power means in physics. Then teach them what you know. What difficulties did they have? Prepare to share with your classmates in class.

Lesson 11: Review



11.1 Represent and Reason

Dylan sleds down a hill and then travels for some distance on the snow until he stops. Represent the following processes with bar charts, first including Earth in the system and second not including Earth in the system. Identify all of the objects included in your system.

a) Initial state: Dylan and sled on top of a mountain; final state: Dylan and sled are moving down at 2/5 of the mountain's height;

b) Initial state: Dylan and sled are moving through 2/5 of the mountain's height; final state: Dylan and sled moving fast at the bottom of the mountain;

c) Initial state: Dylan and sled moving fast at the bottom of the mountain; final state: Dylan and sled stop after traveling for some time on a horizontal surface.

d) Discuss all of the processes from the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved? What is the difference?

11.2 Regular Problem

You lift a heavy suitcase from the floor to the top shelf of the closet expending power of 200 W in 3 seconds. If the suitcase's mass is 30 kg, what is the force that you exerted on the suitcase? Is this problem realistic?

Discuss the process from the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved? What is the difference?

11.3 Equation Jeopardy

Examine the following mathematical statements and describe the problems that these statements might help solve. After you come up with the problem, draw a bar chart and solve your problem.

a) $250\text{ J}+(-F \times 5\text{ m}) = 50\text{ J}$

b) $0\text{ J} + 700\text{ J} = 700\text{ J}$

c) $210\text{ J} + 820\text{ J} = 0\text{ J} + 1030\text{ J}$

Discuss all of the processes from the point of energy conservation. In what processes is the energy constant? In what processes is the energy conserved? What is the difference?

11.10 Represent and Reason

Fill in the table that follows.

Experiment: Describe the system and process.	**Draw a sketch showing the initial and final states. Circle the object(s) in the system.**	**Construct a work-energy bar chart and mathematically relate the quantities to each other.**
A motor pulls a roller coaster up the first hill of the track via a chain. *Initial state:* The roller coaster is at rest at the bottom of the hill. *Final state:* The roller coaster is moving at a moderate speed at the top of the hill. *System:* Includes the roller coaster, chain, and Earth but excludes the motor that pulls the chain up the hill.		

11.11 Represent and Reason

Repeat the previous activity with a different system.

Experiment: Describe the system and process.	**Draw a sketch showing the initial and final states. Circle the object(s) in the system.**	**Construct a quantitative work-energy bar chart and mathematically relate the quantities to each other.**
System: Includes the roller coaster and the chain but excludes Earth and the motor that pulls the chain up the hill.		

11.4 Evaluate

Your friend Mark says that simple machines were invented to reduce the amount of work people do to move and lift things. Do you agree or disagree with him? Use experimental evidence and logical arguments to convince Mark of your point of view or to support his claim.

11.5 Reason

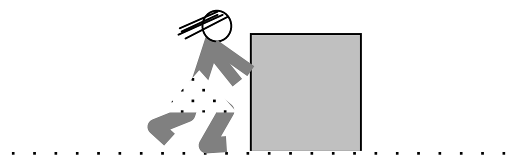
Describe how you can use energy bar charts and other ideas learned in this module to determine the kinetic energy of a 2-kg rock that falls 15 m. What assumptions are you making? If the assumptions are not valid, will the amount of kinetic energy be more or less? What did you include in the system for the analysis?

11.6 Represent and Reason

Draw sketches of 3 processes in which the energy of a system changes as external work is done on the system. Then give your sketches to your friend who will draw bar charts to represent the processes. You, in turn will draw bar charts for her/his processes. After both are done, exchange your bar charts. Did you friend represent your ideas correctly? Did you?

11.7 Regular Problem

Madison pushes a square block across a rough surface. The block moves with constant velocity. The surfaces of the block and the floor become warmer.



Draw a motion diagram and a force diagram for the block.

a) Consider the block and the floor in the system.

Does Madison do work on the system? Explain your answer.	
Does the floor do work on the system? Explain your answer.	
Draw a work-energy bar chart.	

b) Consider **just** the block in the system.

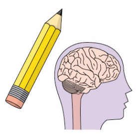
Does Madison do work on the system? Explain your answer.	

Does the floor do work on the system? Explain your answer.	
Draw a work-energy bar chart.	

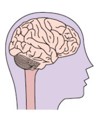
c) Describe the difference between the two situations described above. Is either of these representations better than the other?

d) Explain what would happen if you chose the floor to be in the system and then tried to consider the work of the floor on the box in your solution.

11.9 Regular Problem



Katie pushes a shopping cart down a 10 m aisle by exerting a constant force of 12 N. The cart moves with a constant velocity of 1 m/s. Draw a motion and a force diagram for the cart. Create a work-energy bar chart that is consistent with the situation. Notice that the speed of the cart is constant although Katie is exerting a constant force on it.



11.10 Reason

a) You first slowly lift a heavy medicine ball and place it on the table. Represent the process with a bar chart. What is your system? What are the initial a final states?

b) Next the ball falls off the table. Represent the process with the bar chart for the following initial and final states: initial – the ball just started falling; final – the ball is almost reaching the floor but does not touch it.

c) The ball stops after hitting the floor. Represent the process with the bar chart for the following initial and final states: initial – the ball is almost reaching the floor but does not touch it; final – the ball is at rest on the floor.

d) What happened to your work at the end? The ball is at rest. Did we find the violation of energy conservation?

Congratulations! You completed the energy module! What was difficult about it? What was easy? If you could write a note to your past self explaining how energy is important in your life, what would you say?