Project-Based Inquiry Science

Building Big Things

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IT's ABOUT TIME®
HERFF JONES EDUCATION DIVISION

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Learning Set 1
What Are Machines and How Are They Used?

Lesson 1.1:
Thinking about Machines

Overview

How would you build a building the size of your school? In this lesson, you will brainstorm what you know and need to know in order to understand how machines help you build big things.

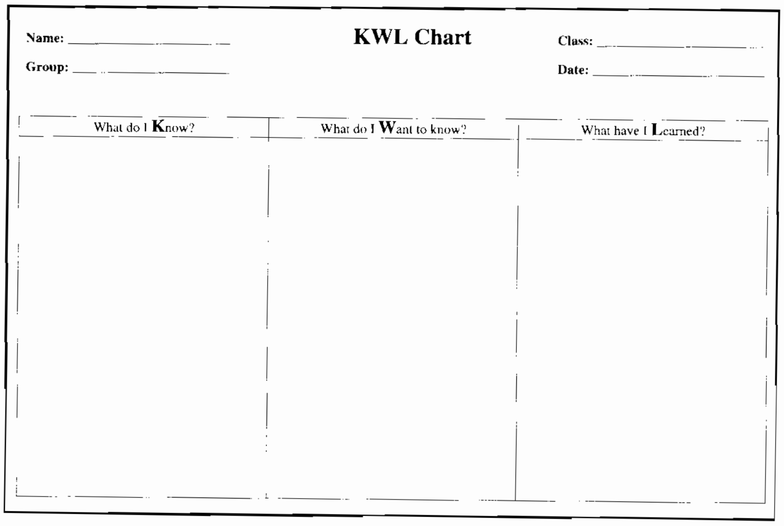
Constructing a KWL Chart

Look at the title for this unit. It is the question:

How do machines help me build big things?

All of your investigations and readings will help you to answer this question. It is called the "driving question" because it "drives" everything you will do.

Before you begin any of the investigations, you are going to share your ideas about this question with your class. You and your classmates will discuss possible answers. You will first work in your small groups. As you do, you will record your ideas on a KWL chart. You will also record other questions you have on the chart. Then, your teacher will record all your ideas on a class chart.


Name: __________ KWL Chart Class: __________

Group: __________ Date: __________

What do I Know?	What do I Want to know?	What have I Learned?

You probably have used a KWL Chart before. What does KWL stands for?

KWL stands for:

What do I Know?

You and your classmates may already have some ideas about machines and big things. Record these items in the "Know" column of the chart.

What do I Want to know?

Someone in your class might say they “know” something that you think could be wrong. Or, you might think you know something, but through discussion, you might realize that you aren’t so sure. Turn these ideas into questions about how machines help you build big things. Those are the questions that belong in the “What do I want to know?” column. You might choose to investigate those questions.

What have I Learned?

You will be learning new information. Hopefully, you will find answers to the questions listed in the “What do I want to know?” section. You can record that information in the “learned” column at the appropriate time.

Learning about Building Big Things

You have talked about how machines are used to build big things. Now, look at a real example of using machines to build something really big, a skyscraper! As you read the following article, think about the kinds of machines that must have been used and the tasks they performed

The World Trade Center Rises Again

On September 11, 2001, a great tragedy took place in New York City. The twin towers of the World Trade Center were attacked and destroyed. A smaller skyscraper, 570 feet and 47 stories high, known as 7 World Trade Center (WTC) stood near the towers. It also collapsed that day. The rebuilding of 7 WTC became very important to the city because the bottom floors of this building contained a huge power station. This plant supplied much of Manhattan’s electricity.

Reconstruction of the building began in 2003. It started with the building of the new power station. However, builders knew they had two big challenges. First, they had to make the plain steel power station below and the glittering glass office building above look like one beautiful building. Second, and most important, they wanted to make it the safest skyscraper in the world.

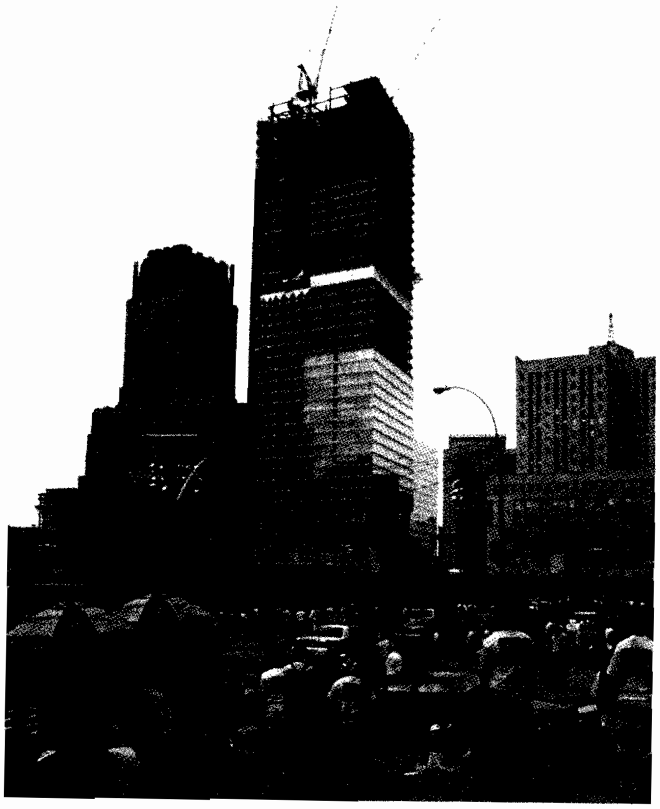
For the first challenge of appearance, builders created a steel curtain wall. They made the wall to match the glass above. Builders installed 15-foot-tall, 5-foot-wide panels of machined and polished triangular steel prism bars. The bars were set in two rows 6.5 inches apart. Each section weighed 1,500 pounds. This bottom wall now contains 130,000 prisms. The prisms reflect lights and colors in different directions. Even more remarkable is that this beautiful wall is also functional. It serves as the ventilator for the three-story high electric transformers that lie beneath and need to breathe.

For the second challenge of safety, 7 WTC was constructed using a method called concrete-core construction. In this type of construction, a steel frame is built first. Then, concrete is poured around the steel framework. One worker called it "a building within a building." More 2-foot thick concrete walls also encase the building's massive central core. The core consists of the emergency stairways, elevators, and sprinklers.

The final result is a skyscraper 750 feet high with 52 floors. It cost $700 million to build. The building used more than 15,000 tons of steel. About 538, 420 square feet of laminated glass were installed around the top 42 floors. Workers believe 7 World Trade Center is the safest skyscraper ever to poke its nose into the New York skyline. The reconstruction of the World Trade Center complex has begun.

Building a Safe Skyscraper Questions

What did you learn from the article? Answer the following questions about the machines used to construct 7 World Trade Center.



1. How were both steel and concrete used to make the building strong and safe?
2. How do you think the bottom wall was altered to make it also serve as a ventilator for the power sub-station?
3. What machines do you think were used to dig out the foundation of the building?

What's the Point?

Think about the kinds of tasks the machines were used to do. They were used to move very heavy objects and lift things very high. The construction workers could not have built 7 WTC without the machines! Machines are very important. They make it possible to do things people could not do by themselves.

Lesson 1.2:
The Construction-Site

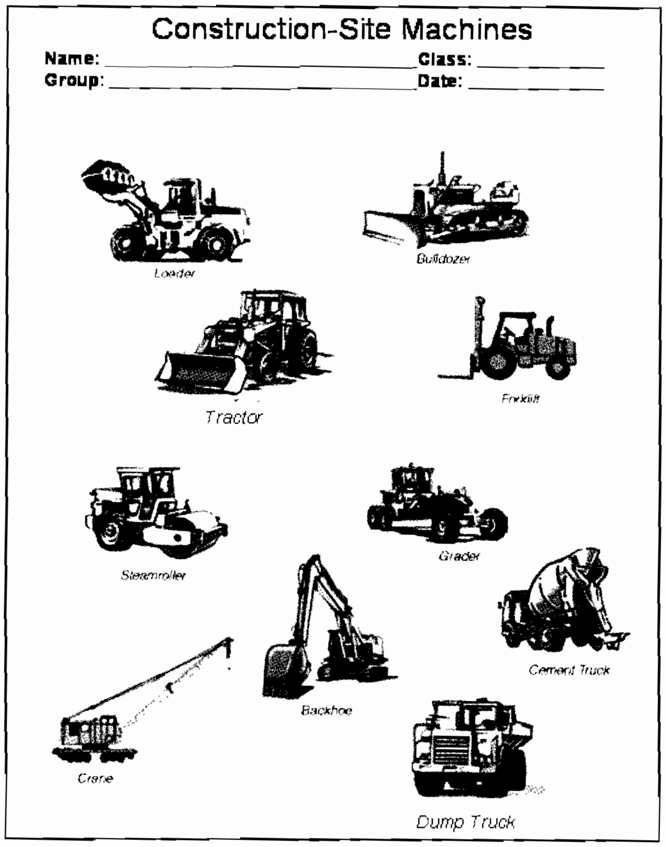
Overview

You have just begun your study of machines in order to answer the driving question, "How do machines help me build big things?" You read an article describing how machines were used to build a tall building. The machines helped the workers do things they could not have done on their own. In this lesson, you will get to see real construction machines in action.

Activity: Construction-Site Visit
Procedure

Your teacher will arrange for you to visit a construction site or show you a video of a construction site.

As you walk around the construction site or watch the video, identify the machines being used, the materials on the site, and the kinds of tasks being done. The Construction-Site Machines sheet shows some of the machines that you might see.



Use your Construction-Site Observations worksheet to record your observations. Also, draw pictures of any equipment or materials that are not shown on the Construction-Site Machines sheet, or that you cannot name.

Construction-Site Observations

Name: ________________ **Class:** ____________________

Group: ________________ **Date:** ____________________

Site name: ____________________________________

Location of site (main cross streets): ____________________

Equipment at the Site

__ Crane
__ Tractor
__ Bulldozer
__ Backhoe
__ Steamroller
__ Fork lift
__ Cement truck
__ Dump truck
__ Other trucks
__ Jackhammer
__ Saw
__ Drill
__ Hammer
__ Ramp
__ Pulley system
__ Wheelbarrow
__ Shovel
__ Other

Drawings

Building Materials

__ Bricks
__ Lumber/Wood
__ Stones
__ Metal (beams, sheets, etc.)
__ Glass
__ Plastic
__ Other Materials

Site Features

_ Dirt Piles
_ Wood
_ Water
_ Large rocks
_ Other features

Construction-Site Observation Questions

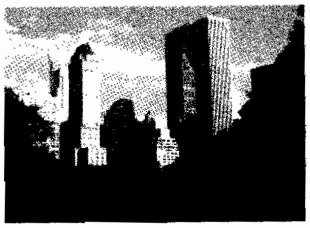
What did you observe? Answer the following questions.

1. What type of building is being constructed?
2. What will the purpose/use of the building be?
3. What was on the site before the construction?
4. Describe the area around the building (trees, rocks, other buildings, etc.)
5. What kinds of tasks did you see the workers doing without machines?
6. What kinds of tasks did you see the workers doing with machines?
7. What else did you observe anything else related to building or machines?

Lesson 1.3:
What Makes Something a Machine?

Overview

The pictures show some large structures in New York City: a high-rise building, a bridge, and a baseball stadium. People need to use machines to build these and other structures in your city. But exactly what is a machine? In this lesson, you will develop a class definition for the term "machine." You will also be introduced to the design challenge that you will work on during Learning Set 3.

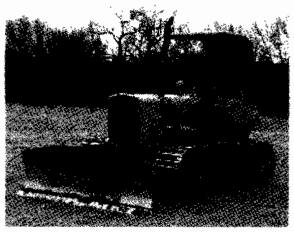


Learning about Types of Machines

Construction Machines

There are all kinds of machines that people use to help them build things. Some of them are big construction machines like tractors and bulldozer's. There are many different types of construction machines. You may have seen examples of these machines during your construction-site visit.

Loader



Bulldozer

Forklift

Handheld Machines

Can a whole building be built with just large construction machines? Of course not! There are smaller machines that people use with their hands. These machines can be called "handheld." Examples of handheld machines include a hammer, a saw, a screwdriver, and a drill. You probably think of these as tools. Tools are really handheld machines. These handheld machines are not as big as the large construction machines. However, they also help people do things and are just as important.

Everyday Machines

There is another group of machines that are not necessarily used to build things. These machines make it easier for you to do everyday things. For example, think about a box tied up with string or ribbon. It can sometimes be difficult to break string or ribbon with your hands. It is much easier to use a pair of scissors. Scissors are a type of everyday machine.

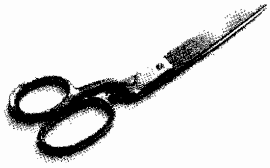
Another useful machine is a ramp, like a ramp on the back of a truck or a semi trailer. It is easier to push or carry a box up a ramp than it is to lift it straight up into the back of the truck. A ramp also helps someone in a wheelchair to get into and out of buildings.

Why Is It Important to Learn about Everyday Machines?

You may have many machines in your house. You probably don't have large construction machines. However, you may have small handheld machines and everyday machines.

There are many types of machines and they can be very different. It is hard at first to see how a construction machine, handheld machine, and everyday machine can be alike. A bulldozer, a shovel, and a pair of scissors have something in common. They all make doing things easier. This is true for all machines. Since everyday machines are smaller and simpler, they are easier to study. Over the next few weeks you will learn about different types of everyday machines, and how they make things easier to do.





Types-of-Machines Questions

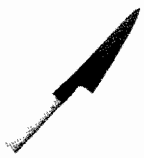
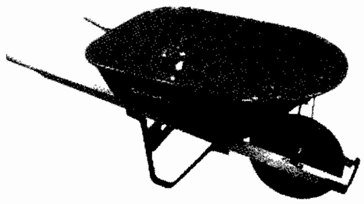
1. Why do you think people use machines to help them build things?
2. What does each of the following machines do to help people build things?

a) loader

b) bulldozer

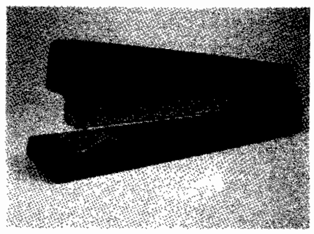
c) forklift

3. List two or more handheld machines and two or more everyday machines that people might have in their houses. You might even walk around your house to see what you can find.
4. All of the objects below are machines. Describe what each machine is used to do.

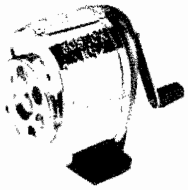




a) ______ b) ______ c) ______





d) ______ e) ______ f) ______



g) ____________

h) ____________

Defining a "Machine"

Have you ever been talking about something with a friend or family member, and all of a sudden realized that you're not talking about the same thing? Being clear about definitions is very important. Scientists need to agree on how to define things so that when they talk to each other, they can be sure they're all talking about the same thing.

Before you can begin to answer the driving question, "How do machines help me build big things?" it is important to define what is meant by the term "machine." Remember all the examples of machines you have seen so far in this unit. Think of the ways they are similar as you write your definition of "machine."

Think-Pair-Share Session

To arrive at a class definition of "machine," you will take part in a Think-Pair-Share session.

Begin by *thinking* about your own definition of "machine." This is the *Think* part of the session. Write your definition in your science log or on your worksheet. Next, *Pair* up with a partner. *Share* your definition with your partner. Write down a definition with which you both agree. Now it's time to Share definition that you and your partner wrote with the class. Your teacher will record and discuss your ideas with the class. Write the definition with which whole class agrees in your log or on your worksheet.

Introducing the Design Challenge: Making Lifting Easier

In this unit, you are trying to answer the driving question, "How do machines help me build big things?" So far, you've seen that machines are actually used to do many different kinds of tasks — push, pull, lift, move, cut, scoop, and more!

One way to learn more about how machines work is to focus on just one kind of task which machines are used to do. Think about why a person might need to use a machine to lift something.

People need to lift heavy things all the time. Around school, you may have to carry many books. After school, you might have a job where you move heavy boxes. At home, you might rearrange furniture in your bedroom. If you got hurt, you might not be able to lift things. Or, some objects might just be too heavy to lift. There are lots of situations in which people need help lifting heavy things.

Later in the unit, you will design and build models of machines that lift heavy things with very little effort. You will use a large can of food or juice to represent an object that might be heavy to lift. To simulate a person who lacks the strength lift something heavy, you will only be allowed to use a single, thin strand of cotton thread to lift the can.

After designing and building your machine, you will demonstrate it for the class and give a presentation.

Here are a few descriptions of times in which people need help lifting heavy things. Keep these in mind throughout the unit. You might be able to think of other situations that you can use in the final presentation of your machine.

Many jobs require lifting and carrying heavy things. How could a machine help in this situation? Some people aren't very strong because of injury, disease, or age. However, there are many times every day that they might need to lift something heavy like bags of groceries. What can they do to lift something that is too heavy for them to lift safely? They could ask someone for help, but what if they need help every day? What they really need is a machine that helps them.

Learning Set 2
How Do I Move Things?

Lesson 2.1
Developing a Definition of Force

Overview

How would you move the materials and dirt to clear off a building site? What does it take to put anything into motion? In this lesson you will observe a class demonstration about pushing and pulling a heavy bucket. You will then develop a class definition of "force."

Activity: Pushing and Pulling a Heavy Bucket

Procedure

Your teacher will conduct a demonstration in which a heavy bucket will be pushed and pulled gently at first. Then the push and pull will be increased slightly. Finally, the push and pull will be very strong.

Observe the changes in the motion of the bucket for the small, medium, and large pushes and pulls. Record your observations in your science log.

Defining Force

You observed a heavy bucket being pushed with different amounts of force. Think about what happened when the bucket was pushed lightly. Think about what happened when the bucket was pushed strongly. Use these observations to come up with a definition of force. Your definition should show the relationship between force and motion.

Think-Pair-Share Session

To arrive at a class definition of "force," you will take part in a Think-Pair-Share session.

Think about your own definition of "force" as it relates to motion, based on the demonstration. Write your definition on your worksheet. *Pair* up with a partner. Share your definition with your partner. Write a definition with which you both agree. Now it's time to *Share* the definition that you and your partner wrote with the class. Your teacher will record and discuss your ideas. Write the definition with which the whole class agrees on your worksheet. You will return to look at your definition again after the next Lesson.

Pushes and Pulls

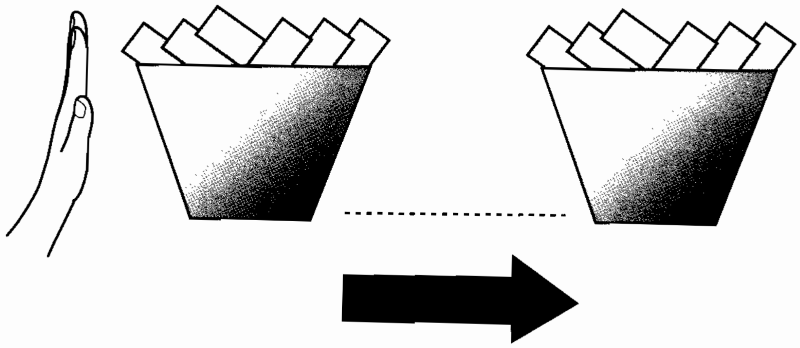
Think about all the things you did in school and at home today. Did you lift things? Did you move things? In school you probably lifted your books or pushed your chair. At home, you probably pulled the door closed.

A **force** is a push or a pull. You apply a force to move or lift something. There are many examples of things that you move in everyday life. Some of these examples include lifting a book to put it on the table, closing a closet door, pushing down on a ball when dribbling a basketball, or lifting a trash bag to take the garbage out. In order to do each of these things, you have to push, pull, or lift something. Or, as scientists would say, to do each of these things you have to apply a force.

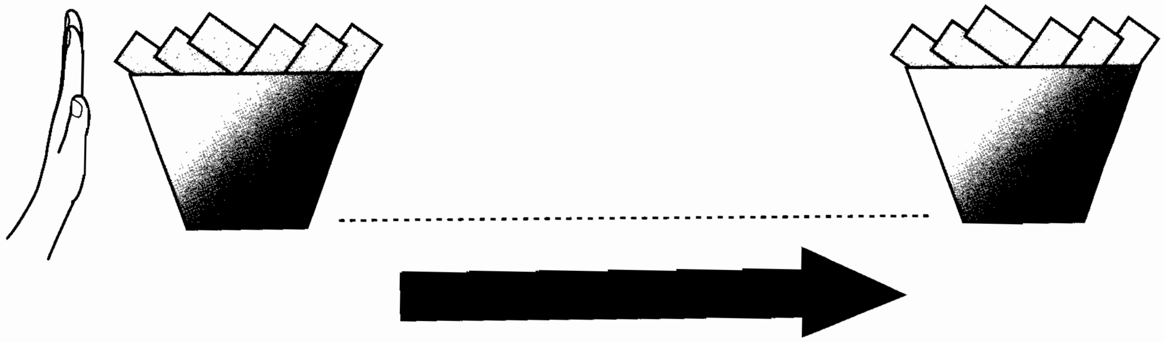
A **force** is a push or a pull.

Think about the demonstrations you did today in class with the heavy bucket. Some of your classmates (or you) pushed the bucket very lightly (or applied a small force). The bucket did not move even though there was a force applied. If students tried to pull or lift the bucket lightly, the same thing happened, it did not move.

Other students pushed a little harder and applied a medium force to the bucket. The heavy bucket moved slowly a short distance when a medium force was applied. The same was true if students pulled or lifted a little harder.



Later, students pushed even harder and applied a large force to the bucket. The heavy bucket moved quickly a larger distance when a large force was applied. The same was true if students pulled or lifted harder.



In these demonstrations, a force was applied to move the heavy bucket. The bucket's motion was affected differently when you applied different amounts of force. With the small force, the motion did not change. The bucket stayed still. With a medium force, it moved a little. With a large force the bucket moved a lot.

You don't just apply forces to get things moving. You also need to apply a force to stop, slow down, change direction, or change speed. For example, while riding your skateboard you press the board to the pavement to brake, slow down, and stop. To turn a corner on your skateboard, you apply a force by pushing on one side of the board's wheels. To speed up on your skateboard, you push off the ground with one foot. Anytime you want to get something moving, stopping, slowing down, changing speed, or changing direction you have to apply a force by pushing or pulling in some way.

Riding a Skateboard	
To slow the skateboard down	Apply a force to the skateboard (drag on pavement)
To speed up skateboard up	Apply a force to the skateboard (push off of pavement)
To change the skateboard's direction	Apply a force to the skateboard (push left or right wheels harder into pavement)

In order to start, stop, change direction or speed of an object, a force must be applied to the object.

Moving objects do not have force o their own. Forces are a result of interactions between two objects. Often, this interaction involves touching. For example, imagine that you are catching a baseball. As the ball is moving through the air, it does not have force. When the ball lands in your glove, the ball applies a force to your glove. You can feel it. Your glove also applies a force to the ball. This force slows the down and makes the ball stop moving. Neither the ball nor the glove had a force by itself. The force acts when the two objects interact, or when the ball hits the glove.

A force is a push or a pull that acts when two objects interact.

Pushes and Pulls Questions

1. Write one example of something you pushed, something you pulled, and something you lifted today. Use different examples from the ones in the reading.
2. Describe why the heavy bucket did not move when a small force was applied. Use the term *force* in your answer.
3. Describe why the heavy bucket moved a little when a medium force was applied. Use the term *force* in your answer.
4. Describe why the heavy bucket moved a lot when a large force was applied. Use the term *force* in your answer.
5. When you were pushing the heavy bucket, what two objects interacted? What object exerted a force on the bucket?

Lesson 2.2:
Force and Motion

Overview

In this lesson you will participate in a set of seven demonstrations. You will be asked to predict the effect of various forces on the motion of a heavy object. Next, you will observe what actually happens. Your class will then develop a "class theory" about force and motion.

Activity: How Do I Move Things?

Procedure

In order to understand the question, "How do I move things?" you are going to do a number of activities applying different forces to a heavy object and observing its motion. You will use a science instrument called a "force probe" to measure the amount of force applied to the object when it is pushed or pulled. As you work on each demonstration, you will first make a prediction about what you think will happen.

Next, you will observe what actually happens. You will also draw a diagram of your observations. Scientists use force arrows to show forces (pushes and pulls) on an object. The direction of the arrow shows the direction of the force. You can show a push to the right with an arrow pointing to the right. The length of the arrow shows the size of the force. If two forces are the same size, you can draw arrows that are the same length to show these forces. Use force arrows when you draw your diagrams You can see an example of force arrows in the last lesson. The force arrows in those diagrams show the direction of the force applied to the heavy bucket.

Finally, you will try to explain what you observed. Your explanations should include any change in motion of the object and the force that the probe was measuring. As you make your predictions, observations, and explanations you will write these on your Force and Motion: Predict-Observe-Explain (POE) worksheets.

Force and Motion		Name: ______	Class: ______
Predict-Observe-Explain (POE)		Group: ______	Date: ______
1. Brick at rest	2. Pushing with equal forces	3. Pulling with equal forces	4. Suspended brick
P:	P:	P:	P:
O:	O:	O:	O:
E:	E:	E:	E:

Sharing Your Explanations and Theories

Share your explanations with your group members and with the class.

Work with your small groups to write a theory that summarizes the demonstrations. The theory should relate force to motion. Share your theory with the class. As a class, discuss the similarities and differences among the different theories. Develop a class theory about forces and motion.

Balanced Forces

Balanced Forces in the Classroom

Have you ever tried to move something and just were not able to? You pushed or pulled with all your strength, and it did not budge. You may have thought that you were not strong enough, or that the object was too heavy. In science language, there were *balanced forces* acting on the object.

Balanced forces mean that the force you apply is opposed by another force that is (a) equal in size and (b) acting in the opposite direction. The other force could be friction, or gravity, or something else pushing or pulling on the object. When balanced forces are acting on an object, there is no change in motion. You will be learning about friction and gravity forces over the next few days.

Remember when you pushed lightly on the heavy bucket? It was at rest (standing still). Its motion did not change. It stayed at rest. The forces on the bucket were balanced. You pushed in one direction, but different force, called friction pushed in the opposite direction. The two forces were equal in size and opposite in direction.

Balanced forces are equal in size and opposite in direction.

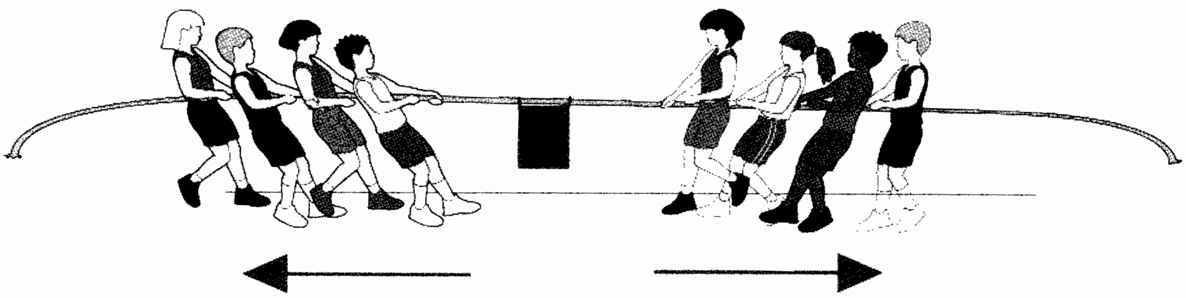
Think about another example from class to help you understand the idea of balanced forces. In class, you applied balanced forces to a heavy object. You pushed on the object with the same amount of force from opposite sides. The force probes measured the amount of force that you applied on each side and you saw that they were the same. You also pulled on the object with the same amount of force in opposite directions. The force probes showed that the forces were equal. In both cases, you observed that the motion of the object did not change. It stayed at rest and did not move.

Another Example of Balanced Forces

Another example of balanced forces is the game tug-of-war. The same number of people hold onto each end of a rope. A flag is tied to the center of the rope. Each team pulls on the rope and tries to move the flag to their side.

Imagine that you are playing tug-of-war with your friends. Your team starts by pulling really hard, with all of your strength. But the other team is also pulling with an equal amount of force and in the opposite direction. The motion of the flag in the middle of the rope will not change. It will not move. The flag does not move because the force that your team is pulling with is equal to the force applied by the other team, but in the opposite direction. The forces on the rope are balanced. When the forces are balanced, the motion of the flag in the center of the rope does not change.

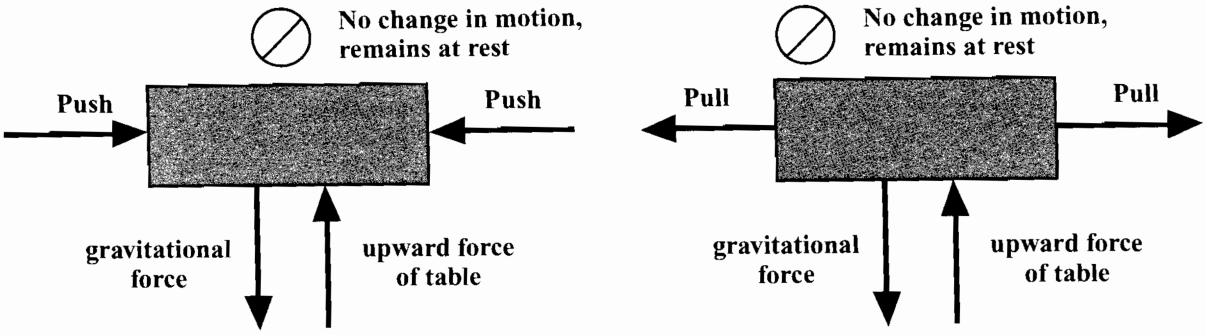
To win the tug-of-war game, one team must pull harder than the other. You will read more about this later when you learn about unbalanced forces.



When balanced forces are acting on an object, there is no change in motion. In other words, an object that is not moving will continue not to move, and an object that is moving at a constant speed will continue to move at a constant speed, when the forces applied to it are balanced.

Force Diagrams

You drew diagrams for each situation. They probably looked something like the following:



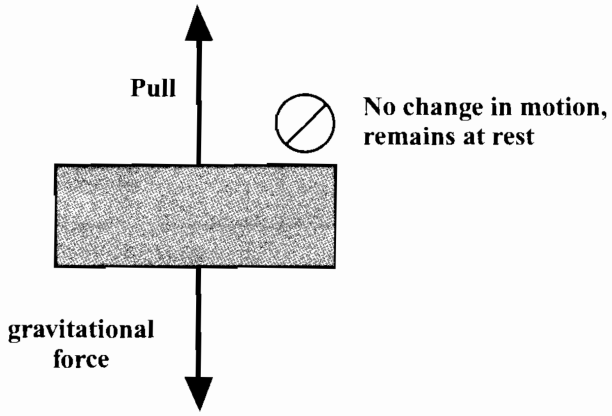
Force diagrams of balanced forces acting on an object

In these diagrams, the arrows represent the direction and size of the forces that you applied on the object. The arrows pointing towards the object represent pushing. The arrows pointing away from the object represent pulling. The arrows are the same size because you pushed or pulled on the object with the same amount of force. The arrows point in opposite directions because you pushed or pulled in opposite directions. Did the motion of the object change? No, the object did not move. It did not move because the forces that you applied to it were balanced. Go back and look at your POEs. How can balanced forces help you to explain some of the demonstrations?

Gravitational Force

It may seem strange to you that a table exerts an upward force on an object, because you don't see the table actually doing anything. Remember that a force acts when two objects interact. The object is sitting on the table. The object pushes down on the table and the table pushes back up on the object.

In class you also did a demonstration where you held an object in the air. You felt yourself applying a force to the object to hold on to it so that it didn't drop. You may have felt like you were just "holding" the object. However, you were applying a "pulling force." Even though you applied a pulling force to the object, the motion of the object did not change. The object did not move. You have seen that if the object does not move, then the forces acting on the object must be balanced. What is the force opposite to the force applied by your hand? The force that kept the brick from moving was the downward **gravitational force**.



Gravitational force is the force that pulls everything towards the Earth. When an object is suspended in the air, the force holding it up must balance the gravitational force pulling it down. To hold a bag of groceries you must pull up with a force equal to the downward gravitational force.

Gravitational force is the force that pulls everything towards the Earth

Friction

Think back to the heavy bucket demonstration that you did in class a few days ago. If you pushed on the bucket with a very small force, the bucket did not move. If the bucket did not move, there must have been a force to balance the small force that you applied. But there was nothing else pushing on the bucket. Or was there?

There is a force called **friction** between the bucket and the floor that is holding the bucket in place. Friction is a force that resists motion when two objects touch. In the case of the bucket and the floor, friction is the force holding the bucket in one place. The force of friction balances out the small force that you apply to the bucket. This is why the bucket did not move when you applied a small force.

When the bucket is just sitting on the floor, the friction force does not act. Friction acts to resist motion. When you push on the bucket, friction acts to keep the bucket from moving.

Friction is a force that resists motion when two objects touch.

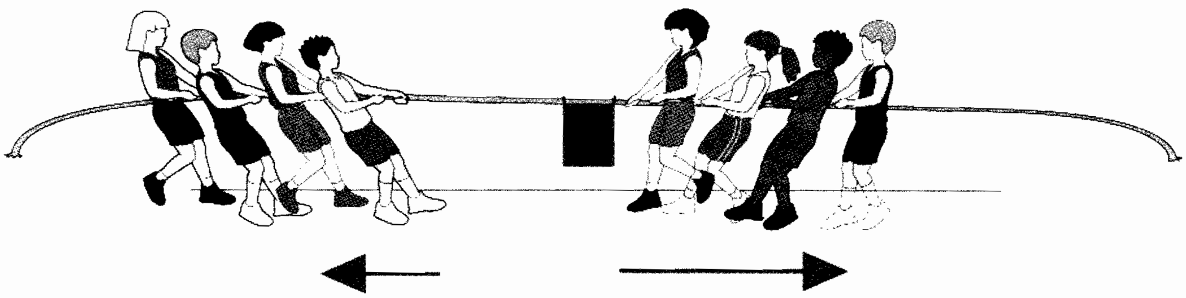
Unbalanced forces are forces that act on the same object,
in opposite directions, and are not equal in size.

By applying an unbalanced force you can start an object moving, make a moving object stop, or change the direction of the motion.

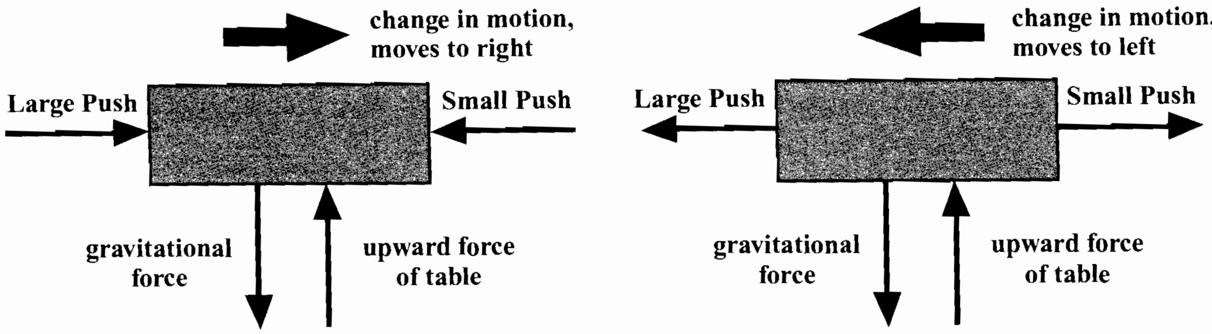
Changes in motion include, starting to move,
stopping, and changing direction.

Think back to the game of tug-of-war. At the start of the game, both teams pull really hard on opposite ends of the rope. The two teams pull with balanced forces, and the flag in the middle of the rope does not move.

But after a little while, the other team begins to get tired and pulls with less force. Your team becomes excited and pulls with even more force. Your team pulls and pulls. Soon the other team is falling towards you and the flag moves to your side of the center mark. Your team wins! What happened during the game? The flag in the middle of the rope moved towards your side because there were unbalanced forces acting on the rope. The force that your team applied was greater than the force applied by the other team. When the forces became unbalanced, the flag started to move in the direction of the greater force. That direction was towards your team, so you won!



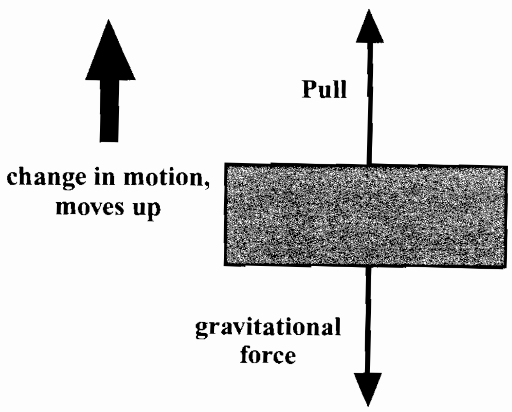
In class you pushed an object more on one side than on the other side. The force probes measured the different amounts of force that you applied to the object. The object moved across the table in the direction of the greater force. You also pulled on the object with different amounts of force, and the object moved in the direction of the greater pulling force. You drew diagrams for each situation. Your diagrams probably looked something like the following.



Force diagrams of unbalanced forces acting on an objects

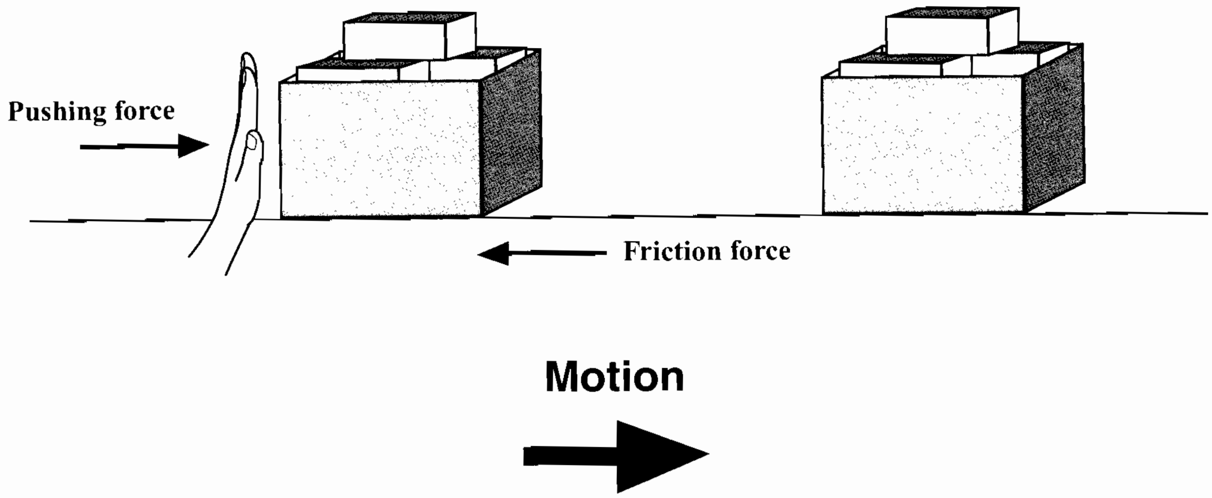
In these diagrams, the thin arrows represent the direction of the forces that you applied on the brick. The thin arrows are different sizes because you pushed and pulled on the object (the brick) with different amounts of force. What happened to the object this time? The object moved across the table. The thicker arrow shows the direction of the motion. It moved because you pushed on it with unbalanced forces.

You also need to apply unbalanced forces to lift something. Think about the demonstration in class when you lifted the heavy object. What did you do to lift the object? You applied an unbalanced force that was greater than the gravitational force pulling down. When you lifted with a greater force than the gravitational force pulling down, there was an unbalanced force acting on the object. The object's motion changed in the direction of the greater force, and the object moved up.



Pulling the object upwards

The same thing also happens when you are trying to slide something heavy across the floor. One of the reasons it is so difficult is that there is a friction force acting against your pushing. This friction force balances out the force you apply. If you want to push the box across the floor, what do you have to do? You have to push with a greater force than the force of friction acting against you. When you do this, there is an unbalanced force acting on the box. The box begins sliding in the direction of the greater force (the direction that you pushed it).



Pushing against friction with unbalanced forces

Balanced Force Questions

1. A strong man pulls a desk to the right. A small child pulls the desk to the left.

a) Draw a picture of this situation. Include force arrows and show the direction of motion.

b) Why do you think it will move this way?

2. When an apple falls from a tree, what force is pulling it down? Are there balanced or unbalanced forces acting on the apple when it falls? How do you know?

3. Give an example of something that you have moved. Describe the forces acting on the object and explain why the object moved. Use the words friction or gravitational force in your description.

Lesson 2.3:
The Heavy Object-Lift Challenge

Overview

In this unit, you are trying to answer the driving question, "How do machines help me build big things?" As a start, you explored many different types of machines. You learned that machines help people to do many different kinds of tasks, including moving heavy objects. To understand how objects move, you then studied forces and motion. You learned that moving an object from rest (standing still) requires an unbalanced force.

To help you better understand how machines work, you will apply what you have learned to build a machine. In this lesson you will be introduced to the challenge that you will begin working on in the next Learning Set.

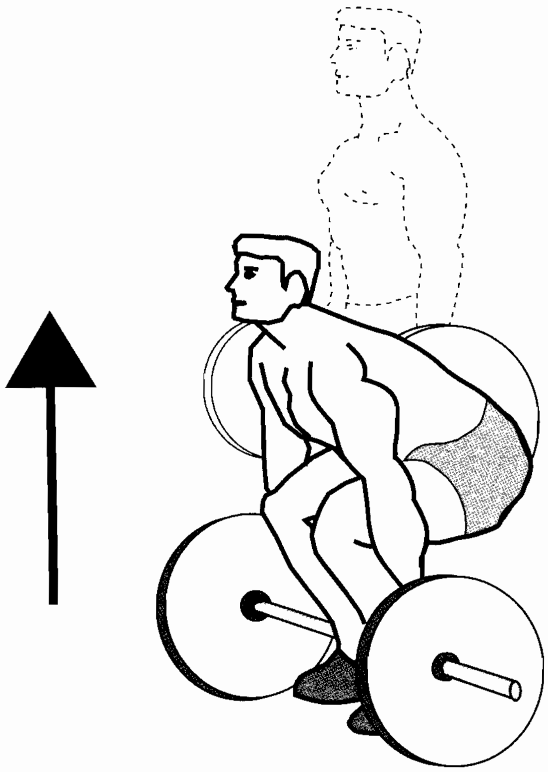
The Design Challenge

Imagine that Henry is at the top of a very steep ledge. He wants to use some rope to lift up a large crate of food. The crate is 10 m (meters) below him. Henry, however, is not strong enough to raise the heavy crate directly. Also, his rope is too weak to lift the crate without breaking.

Henry has some building materials in his truck. He would like to use them to build a machine that he can connect to his rope and raise the crate. He needs your help to design this machine.

You will build a scaled-down model of a machine to help Henry. (Scaled-down means smaller than the actual size.) You will build a machine that will *raise a heavy object 10 cm (centimeters)*. Henry's rope is weak, so to model this, you will use a *single strand of cotton thread.*

Activity: Dead Lift



You have been asked to build a machine that will lift a heavy object with as little strength as possible. What if you don't need a machine? What if the thread you are asked to use can lift the object by itself? Before you begin designing your machine, you need to find out whether you can lift the object with the thread alone.

In the Olympics, one activity that weightlifters do is called the dead lift. The rules of dead lifting are simple. You must raise a barbell off of the floor up to your knees until your legs and back are straight. In this activity, you will dead lift an object using thread.

Procedure

Analyzing the Situation

Analyze the situation by answering the following questions in your science log.

To lift the block, you will apply an upward force with the thread. What other force acts on the block? Draw a picture and label the forces on the block.

To lift the block, you will change its motion from rest to moving upward. Will the forces on the block be balanced or unbalanced?

To lift the block, which force must be larger? Make sure your diagram shows this.

Preparing the Object for the Dead Lift

Before you lift the block with the thread, you must attach the thread to the block. To attach the thread, follow these steps:

1. Tie a knot with a small loop at one end of the thread (the loop should have the diameter of a penny).
2. Wrap the cord around the hook on the object and pass the free end of the cord through the loop. This will make a lasso that is fitted around the hook.
3. Tighten the lasso around the object's hook by hand.

Now you can proceed with the activity.

Data Collection

Tie a single strand of thread to the block and see if you can lift the block straight up. What happens?

You now know that the single thread is too weak, but you need to know how much stronger it would need to be to lift the object. Investigate to find out how many strands of thread are needed to lift the object. Knowing this will tell you how much help the machine you design and build must provide so that you can lift the block with the small force that the can provides. Use a table like the one below to record your data.

Hint: Tie each strand to the hook separately. Don't double the thread or make a U-shape through the loop because your results will not be accurate. One strategy would be to start with lots of threads. Then use fewer and fewer threads until you break them when lifting the block.

Number of Strands of Thread	Able to Lift Block? (Yes or No)

Design Requirements

You now have a set of requirements to guide the design of your machine. The chart below shows how these requirements compare to the real requirements for Henry's machine.

If it took three strands of thread to lift the object, the machine you build must apply a force three times greater than the force of the thread. How many strands of thread did you need to lift the block? Use this information to fill in the last row of the table below.

Henry's Machine	Your Model Machine
1. Must lift a *crate of food.*	1. Must lift a *heavy object.*
2. Must lift the barrel *10 m.*	2. Must lift the object *10 cm.*
3. Must use a *weak rope.*	3. Must use a *single strand of thread.*
4. Must apply a force greater than the gravitational force on the barrel.	4. Must apply a force greater than the gravitational force on the block (______ times greater than the force of the thread)

Why Do You Need to Know about Forces?

Think back to the construction site or construction video that you observed at the beginning of the unit. You and your classmates discussed what each of the different types of machines might be used for. Machines are used to build big things because they can apply a larger force that you can apply by yourself. Large objects, such as heavy metal beams, large piles of bricks, and big piles of dirt are difficult to move around. This is because there are large gravitational and friction forces acting on them. It is not possible for people to move such heavy objects by themselves. A machine is able to apply a larger force than a person can. This is why it is able to move larger objects. The machine can apply a force greater than the gravitational or friction force. Since the applied force is greater, there are unbalanced forces acting on the object and the object's motion changes. It changes from rest to moving. This is why people use machines to help them build big things.

Machines can be designed to move specific objects. For example, a bulldozer is designed to push dirt from one place to another, so it applies an unbalanced force along the ground. A backhoe is designed to dig holes, so it applies unbalanced forces both down to scoop up the dirt and then up to lift it out of the hole. Smaller machines are designed the same way. A hammer, for instance, is designed to push a nail through wood so it applies a large unbalanced force to the head of the nail. A pair of scissors applies an unbalanced force to a very small point on a piece of paper, which allows the scissors to cut a clean, straight edge.

Check for Understanding

1. Select two machines in your house. (Remember that machines help people do physical tasks. They do not just make life easier. A microwave is not a machine.) Describe where the unbalanced forces are when you use each machine.

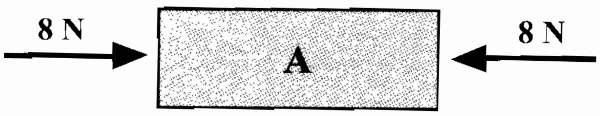
   In each of the following situations, a brick used for building is initially at rest (not moving) and then various forces are applied to it. In each case:

a) Describe the forces acting on the brick (are they pushes or pulls?).

b) State whether the forces are balanced or unbalanced.

c) Describe the resulting change in motion of the brick.

2.



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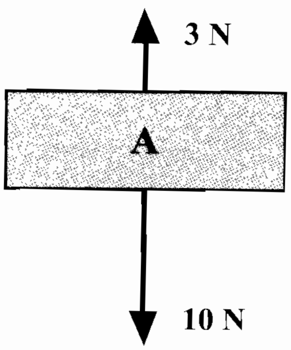


Here's some more practice applying the ideas you've learned about balanced and unbalanced forces.

In each case:
a) Draw the force arrows representing the forces described.

b) Draw a motion arrow or a no motion sign ⊘ to show if the brick's motion will change or not.

4. Balanced forces are pulling on a brick.
5. A brick is pushed to the right.
6. A brick is lifted off a table.
7. A brick is held in the air.

Learning Set 3
How Do Machines Move Things I Can't?

Lesson 3.1:
The Inclined Plane

Overview

If you can understand how simple machines work, you can apply this knowledge in your machine design. In this lesson, you will investigate one of the simple machines — the inclined plane.

You will record the force needed to lift an object directly. Then you will compare it to the force needed to slide the object up inclined planes of varying steepness. You will also compare the distances through which the force is applied in each case.

Activity: Investigating the Inclined Plane

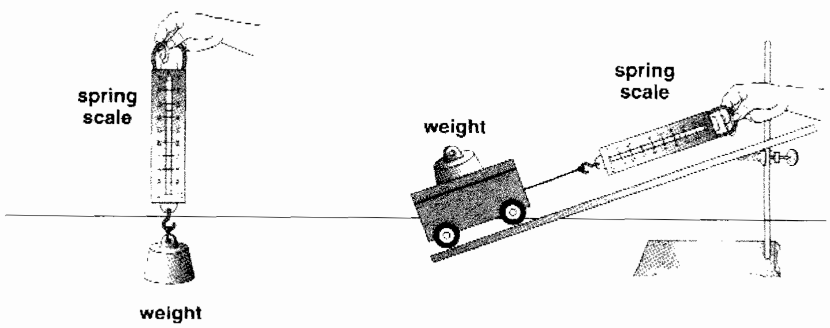
An inclined plane is a simple machine. It can make lifting something much easier. In this investigation, you will learn how the inclined plane works. You might want to use an inclined plane when you work on the design challenge and build a machine to lift a heavy object.

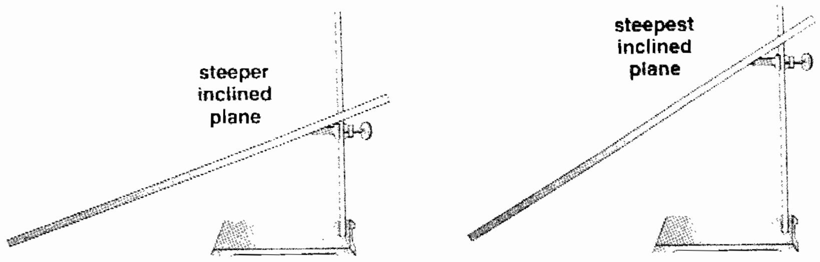
In this investigation, you will answer the question:

How do inclined planes of varying steepness help you lift an object?

Hypothesis: Write a sentence describing a) how you think the inclined plane will help and b) how you think the steepness of the inclined plane will affect the results.

Set-up: The diagram below shows the four set-ups for this investigation. You will be lifting the block straight up and you will be pulling the block up to the same height using inclined planes of varying steepness. You will compare the force and distance in these situations.





Materials: List the materials you will need to do this investigation.

Procedure

Part 1: Lifting the object

1. Prepare the first setup as shown in the diagram. Set up a ruler that allows you to easily measure when you have lifted the object 20 cm.
2. Lift the object 20 cm with the spring scale. Measure the amount of force in newtons (N) that you apply. Record this measurement in your data table.
3. Lift the block again to 20 cm, and measure the distance in centimeters (cm) that the person's hand moves while lifting the block. Record this measurement in your data table.

Repeat this procedure three times to get three sets of measurements.

Part 2: Using an inclined plane to lift the object

1. Prepare the second setup as shown in the diagram.
2. Set the object on the bottom of the ramp with the wheels on the ramp. Pull the object up the ramp with the spring scale until it reaches a vertical height off the table of 20 cm. Measure the amount of force (in newtons) you apply. Record this measurement in your data table.
3. Pull the object up the ramp again to the same spot. Measure the distance (in centimeters) that the person's hand moves while pulling the object. Record this measurement in your data table

Repeat this procedure three times to get three sets of measurements. Make sure you pull the object at the same angle each time!

Part 3: Using a steeper inclined plane to lift the object

1. Prepare the third setup by moving the ramp so that it is steeper. (See the diagram above.)

2. Set the object on the bottom of the ramp with the wheels on the ramp. Pull the object up the ramp with the spring scale until it reaches a vertical height off the table of 20 cm. Measure the amount of force (in newtons) you apply. Record this measurement in your data table.

3. Pull the object up the ramp again to the same spot. Measure the distance (in centimeters) that the person's hand moves while pulling the object. Record this measurement in your data table

Repeat this procedure three times to get three sets of measurements. Make sure you pull the object at the same angle each time!

Part 4: Using an even steeper inclined plane to lift the object

1. Prepare the fourth setup by moving the ramp so that it is even steeper. (See the diagram above.)

2. Set the object on the bottom of the ramp with the wheels on the ramp. Pull the object up the ramp with the spring scale until it reaches a vertical height off the table of 20 cm. Measure the amount of force (in newtons) you apply. Record this measurement in your data table.

3. Pull the object up the ramp again to the same spot. Measure the distance (in centimeters) that the person's hand moves while pulling the block. Record this measurement in your data table

Repeat this procedure three times to get three sets of measurements. Make sure you pull the block at the same angle each time!

Data: Use tables similar to the following to record your data.

Without Inclined Plane

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

With Inclined Plane

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

With Steeper Inclined Plane

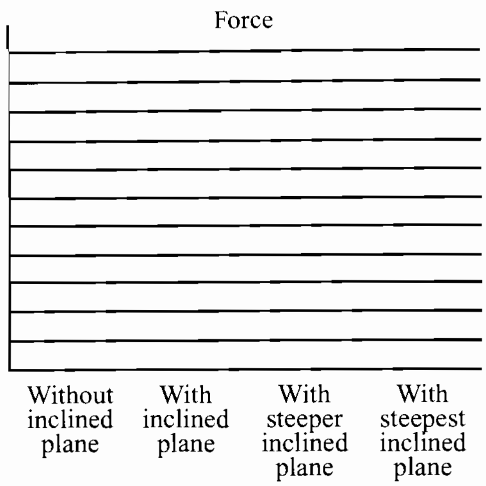
	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

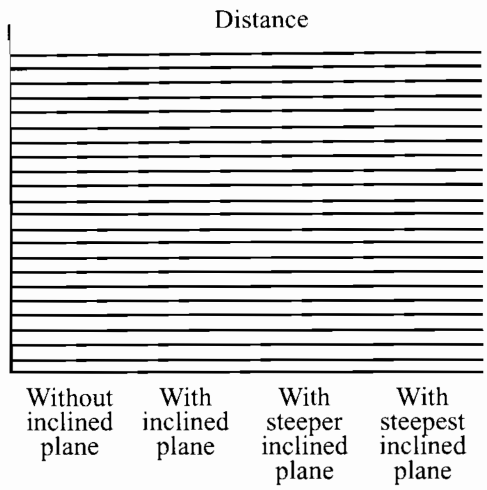
With Steepest Inclined Plane

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

Graphs:

Using the averages from your data, graph the results for force and distance. Be sure to label the vertical axis on each graph with the appropriate units.





Results: What do your data tell you?

Conclusion: What can you conclude about inclined planes in general?

Evidence: What does your graph show to support your conclusion?

Was your hypothesis supported? Was it complete?

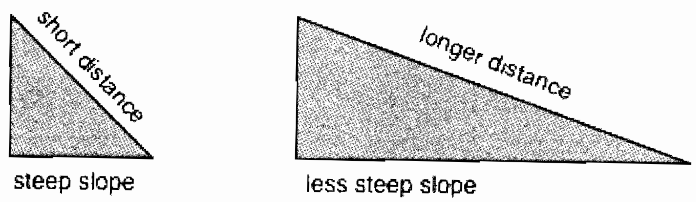
Rule of Thumb: What is your group's Rule of Thumb, or recommendation, for using an inclined plane to lift an object? Your Rule of Thumb should discuss what the inclined plane might look like and how it makes lifting a heavy object easier.

Simple Machines: Part 1

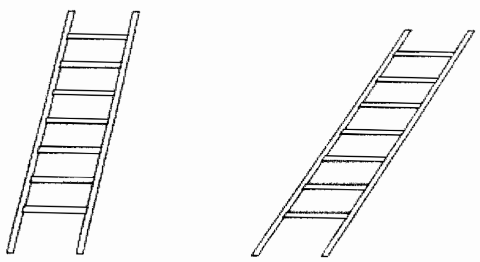
In class, you investigated one type of simple machine — the inclined plane. There are actually six types of simple machines. You will learn about three of them in this reading. Some simple machines make things easier by changing the direction of the applied force. For example, you might apply a pulling force and the machine converts it into a lifting force. Some simple machines (like the inclined plane) make things easier by changing the amount of force needed. You used less force lifting a heavy object with the inclined plane than lifting it directly. This almost sounds like magic. However, you saw in your investigation there is a trade-off (an exchange of one thing in return for another). The trade-off for the inclined plane was that the force had to be applied over a greater distance. You will learn more about this trade-off principle as you study other simple machines.

The Inclined Plane

The inclined plane is a simple machine that helps by requiring less force. The trade-off is that although it requires less force to lift something, the force must be applied over a greater distance. How much an inclined plane helps depends on its slope. Look at the two inclined planes in the diagram. As you discovered in your investigation, it would take much more force to push something up the first one than the second. As the distance is increased (and the slope is decreased), it requires less force.



A ladder is an example of an inclined plane. It makes it easier to climb up to a certain height. It is easier to climb if the ladder is not so steep.



Many people think that the stones used to build the pyramids in Giza, Egypt were lifted into place with the help of enormous ramps.

The Wedge

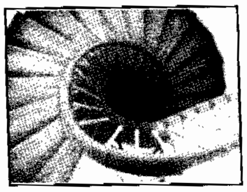
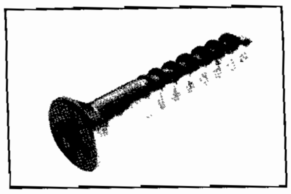
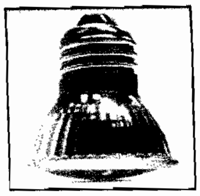
The wedge is another type of simple machine. It is simply a variation on the inclined plane. The wedge is made of two inclined planes put together to make an edge. The wedge makes things easier in two ways. Similar to the inclined plane, it reduces the amount of force needed to move something. It also changes the direction of the applied force. A wood splitter is an example of a wedge. Force applied to the flat part of a wood splitter is changed to push out to the sides, acting to push apart the wood on either side of the wedge. This is why wedges are used to cut things. A knife is another example of a wedge. When you use a knife to cut an apple, the force you push down on is transformed sideways to push apart the pieces of the apple.

The Screw

The screw is another kind of simple machine. Actually, a screw is made up of an inclined plane wrapped around a cylinder. Think of the common screw. The thread that wraps around the screw is the inclined plane. The screw makes things easier by changing a small force in a turning direction into a larger force in a downward direction. The trade-off with using a screw is that you have to apply the force through a greater distance.

If you look at a screw, you will see that the threads on some screws are wide apart. On others, they are close together. The wider apart the threads are, the "steeper" the inclined plane. It is easier to put in a screw with narrow threads than one with wide threads. However, you will have to make many more turns of the narrow-thread screw.

Other examples of screws used in daily life include a spiral staircase and threads on twist-on bottle caps.

There are three more types of simple machines – the lever, the pulley, and the wheel and axle. You will learn about these later.

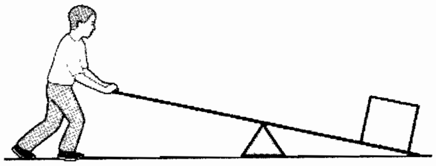
Simple Machines: Part 1 Questions

1. List two examples of inclined planes and explain what they are used to do.
2. List two examples of wedges and explain what they are used to do.
3. List two examples of screws and explain what they are used to do.

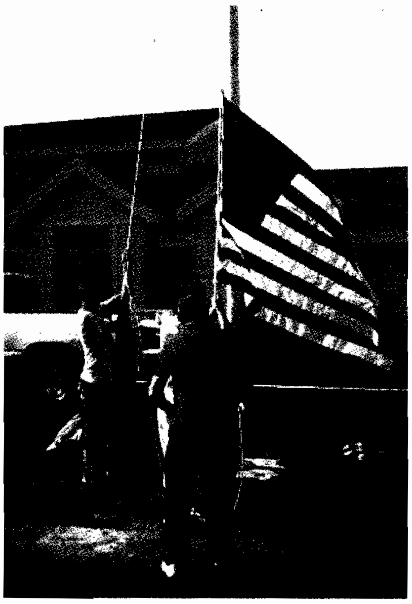
Lesson 3.2
The Lever and the Pulley

Overview

Have you ever used the end a claw hammer to remove a nail? If so, you have used the simple machine called the lever.



A lever can make lifting something much easier. In this lesson, half of your class will investigate the lever.



Have you seen someone pull a flag up a flagpole? If so, you have probably seen the simple machine called the pulley in action. One half of your class will investigate the pulley.

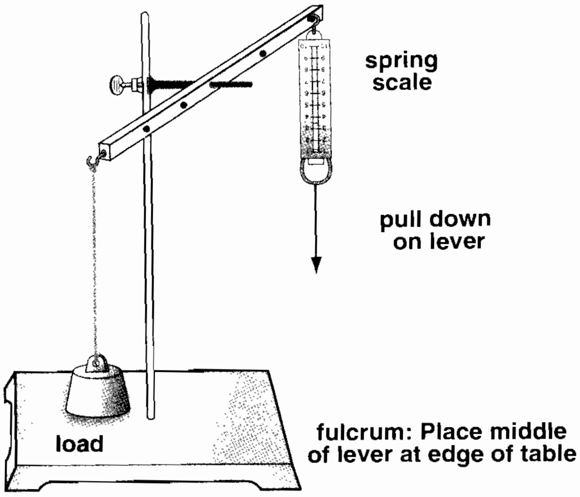
Activity: Investigating the Lever

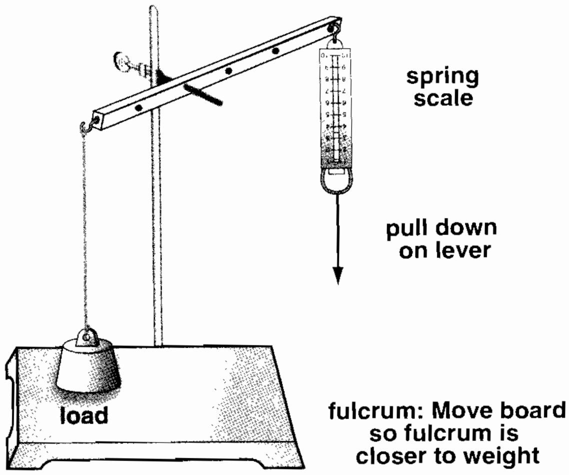
In this investigation, you will answer the question:

How do different levers help you lift an object?

Hypothesis: Write a sentence describing how you think the lever will help and how you think the location of the fulcrum will affect the results. (The fulcrum is the support about which a lever turns.)

Setup: The diagram below shows the setup for this investigation. You will be lifting the object straight up and you will be lifting it to the same height using various levers. The first lever will have the fulcrum located in the center of the board. For the next two setups, you will move the fulcrum closer and closer to the block. You will compare the force and distance in these situations.





Materials: List the materials you will need to do this investigation.

Procedure

Part 1: Lifting the object

1. Prepare the first setup by tying a string around the object.
2. Lift the object to a height of 10 cm with the spring scale, and measure the amount of force (in newtons) you apply. Record this measurement in your data table.
3. Lift the object again. Measure the distance (in centimeters) that the person's hand moves while lifting the object. Record this measurement in your data table.

Repeat this procedure three times to get three sets of measurements.

Part 2: Using the lever to lift the object

1. Attach the clamp to the ring stand near the top. Use the other half of the clamp to attach the bolt. The bolt will be the fulcrum of your lever.
2. Slide the wooden lever onto the bolt, so that the bolt goes through the middle

of the lever. Secure the lever by screwing on the wing nut (not too tight).

3. Hook the object to one end of the lever. The arm of the lever should be horizontal. (See the diagram above.) Hold a ruler up or attach it to the ring stand so that you can easily measure 10 cm above where the object is now hanging.
4. Lift the object by pulling straight down on the lever with the spring scale, and measure the amount of force (in newtons) you apply. Record this measurement in your data table.
5. Lift the object again, and measure the distance (in centimeters) that the person's hand moves while pulling down on the lever.

Repeat this procedure three times to get three sets of measurements.

Part 3: Using the lever to lift the object (fulcrum closer to the object)

1. Move the fulcrum (where the lever is attached to the bolt) to one of the holes closer to the object.
2. Hook the object to one end of the lever. The arm of the lever should be horizontal. (See the diagram above.) Hold a ruler up or attach it to the ring stand so that you can easily measure 10 cm above where the object is now hanging.
3. Lift the object by pulling straight down on the lever with the spring scale, and measure the amount of force (in newtons) you apply. Record this measurement in your data table.
4. Lift the object again, and measure the distance (in centimeters) that the person's hand moves while pulling down on the lever.

Repeat this procedure three times to get three sets of measurements.

Part 3: Using the lever to lift the object (fulcrum even closer to the object)

1. Move the fulcrum even closer to the object.
2. Hook the object to one end of the lever. The arm of the lever should be horizontal. (See the diagram above.) Hold a ruler up or attach it to the ring stand so that you can easily measure 10 cm above where the object is now hanging.
3. Lift the object by pulling straight down on the lever with the spring scale, and measure the amount of force (in newtons) you apply. Record this measurement in your data table.

4. Lift the object again, and measure the distance (in centimeters) that the person's hand moves while pulling down on the lever.

Repeat this procedure three times to get three sets of measurements.

Data: Use tables similar to the following to record your data.

Without Lever

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

With Lever (fulcrum at center)

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

With Lever (fulcrum closer to the object)

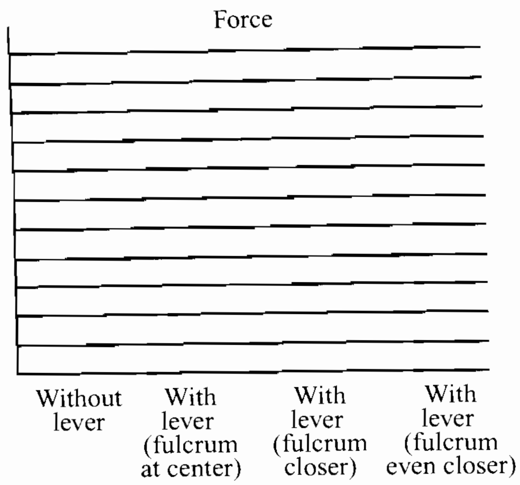
	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

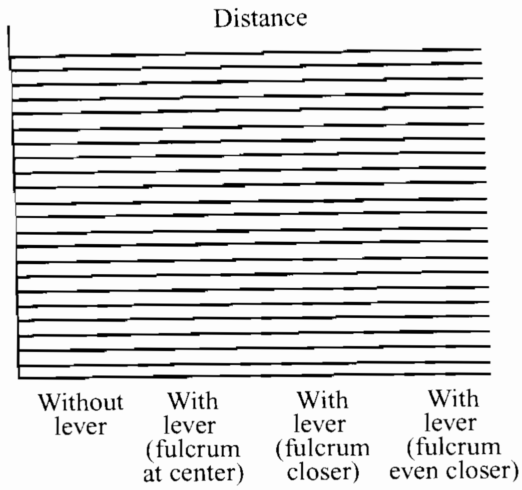
With Lever (fulcrum even closer to the object)

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

Graphs:

Using the averages from your data, graph the results for the force and distance below. Be sure to label the vertical axis on each graph with the appropriate units.





Results: What do your data tell you?

Conclusion: What can you conclude about levers in general?

Evidence: What does your graph show to support your conclusion?

Was your hypothesis supported? Was it complete?

Rule of Thumb: What is your group's Rule of Thumb, or recommendation, for using a lever to lift the can? Your Rule of Thumb should discuss what the lever might look like and how it makes lifting the can easier.

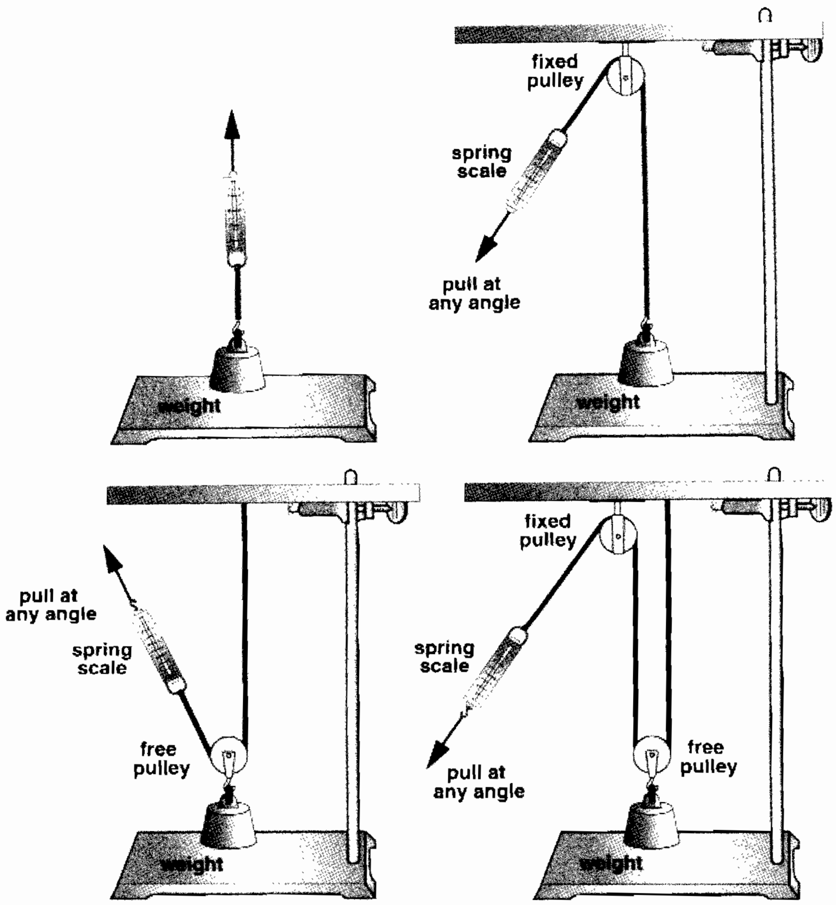
Activity: Investigating the Pulley

A pulley is another example of a simple machine. It can make lifting something much easier. In this investigation, you will learn how pulleys work. You will also answer the following question:

How do different arrangements of pulleys help you lift an object?

Hypothesis: Write a sentence describing how you think the pulley will help and how you think different arrangements of pulleys will affect the results.

Setup: The diagram below shows the setup for this investigation. You will be lifting the object straight up and you will be lifting the object using a variety of pulley arrangements. The first pulley arrangement is a fixed pulley. The second is a free pulley. The third combines a fixed and a free pulley. You will compare the force and distance in these situations.



Materials: List the materials you will need to do this investigation.

Procedure

Part 1: Lifting the object

1. Prepare the first setup by tying a string around the object.
2. Lift the object to a height of 20 cm using the spring scale, and measure the amount of force (in newtons) you apply. Record this measurement in your data table.
3. Lift the object again to a height of 20 cm, and measure the distance (in centimeters) that the person's hand moves while lifting the block. Record this measurement in your data table.

Repeat this procedure three times to get three sets of measurements.

Part 2: Using a fixed pulley to lift the object

1. Set up the fixed pulley. (See diagram above.) Attach the pulley to the top of the ring stand and tie one end of the string to the object. Thread the string through the pulley so that as you pull down on the free end, the object moves up. Set the ruler near the object to use as a reference height. Attach the spring scale to the free end of the string.
2. Lift the object to a height of 20 cm by pulling on the string with the spring scale. You can pull at any angle. Measure the amount of force (in newtons) you apply. Record this measurement in your data table.
3. Lift the block again to 20 cm, and measure the distance (in centimeters) that the person's hand moves. Record this measurement in your data table.

Repeat this procedure three times to get three sets of measurements.

Part 3: Using a free pulley to lift the object

1. Set up the free pulley. (See the diagram above.) Tie a piece of string to the ring stand. Thread the free end of the string through the pulley. Tie the object to the pulley so that as you pull up on the string the pulley (with the object attached) moves up. Set a ruler near the object to use as a reference height. Attach the spring scale to the free end of the string.
2. Lift the object to a height of 20 cm by pulling on the string with the spring scale. You can pull at any angle. Measure the amount of force (in newtons) you apply. Record this measurement in your data table.
3. Lift the block again to 20 cm, and measure the distance (in centimeters) that the person's hand moves. Record this measurement in your data table.

Repeat this procedure three times to get three sets of measurements.

Part 4: Using a fixed and a free pulley to lift the object

1. Set up the fixed and free pulleys. (See the diagram above.) Use the free pulley setup from Part 3. Instead of pulling on the free end of the string, attach a second pulley to the ring stand (like the fixed pulley Part 1) and thread the free end of the string through this pulley. Set a ruler near the object to use as a reference height. Attach the spring scale to the free end of the string.
2. Lift the object to a height of 20 cm by pulling on the string with the spring scale. You can pull at any angle. Measure the amount of force (in newtons) you

apply. Record this measurement in your data table.

3. Lift the object again to 20 cm, and measure the distance (in centimeters) that the person's hand moves. Record this measurement in your data table.

Repeat this procedure three times to get three sets of measurements.

Data: Use tables similar to the following to record your data.

Without Pulley

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

With Fixed Pulley

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

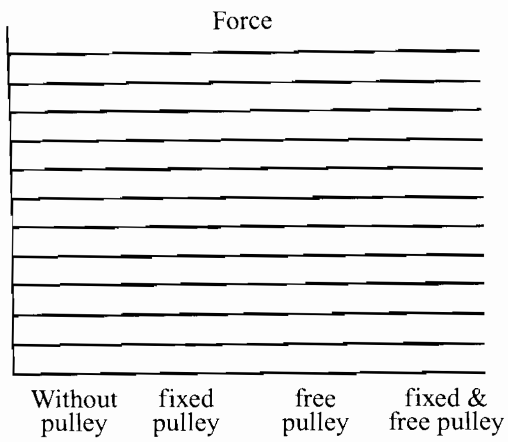
With Free Pulley

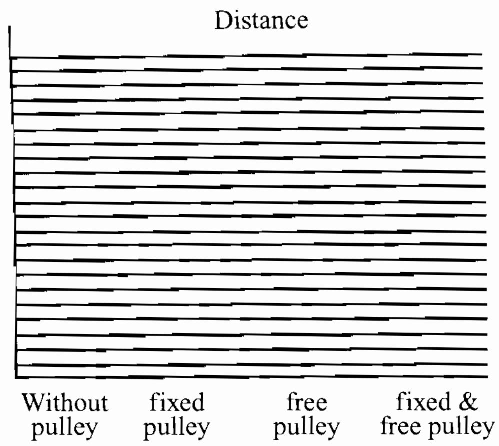
	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

With Fixed and Free Pulleys

	Force (N)	Distance (cm)
Trial 1		
Trial 2		
Trial 3		
Total		
Average		

Graphs: Using the averages from your data, graph the results for the force and distance below. Be sure to label the vertical axis on each graph with the appropriate units.





Results: What do your data tell you?

Conclusions: What can you conclude about levers in general?

Evidence: What does your graph show to support your conclusion?

Was your hypothesis supported? Was it complete?

Rule of Thumb: What is your group's Rule of Thumb, or recommendation, for using a lever to lift the object? Your Rule of Thumb should discuss what the lever might look like and how it makes lifting the object easier.

Lesson 3.3
Sharing Data

Overview

In the last lesson, you learned how either a lever or a pulley can be used to make it easier to lift things. Both reduce the force required and change the direction of the force to make it easier to apply.

You will now share your results in a Poster Session. You will also read more about how a lever and a pulley work. You might want to use a lever or a pulley when you work on the design challenge and build a machine to lift a heavy object.

Preparing for a Poster Session

When you are finished with your investigation, you will share your results with the class during a Poster Session. During a Poster Session, your group will make an Investigation Poster. The poster will include the procedure you followed, the data you obtained, and the meaning of your results. An Investigation Poster is one way to help you present and explain this information. In this presentation, you'll be showing the results of your investigation to your classmates. They'll want to understand:

What question you were trying to answer in your investigation

The procedure you used and why you thought it would answer the question

The materials you used

Your results and what they mean

It is very important to report the procedure you're using when you conduct an investigation. Each group might conduct their investigations differently. It will be important to compare results from these different tests. This is what scientists also do with the results of their investigations.

Make an Investigation Poster that you can hang on the wall for others to see. The poster should include six kinds of information:

The question you were trying to answer in your investigation

Your prediction for the outcome of the investigation

The procedure and whether this was a fair test

Your data and a data analysis that shows a trend, if there is one

Your interpretation of the results and a conclusion that answers your question

A Rule of Thumb for using your simple machine to lift a heavy object

If you think your test wasn't as fair as you had planned, you might want to report on how you would change your procedure if you had a chance to do it again.

Your teacher might provide you with some additional details that you will need for your poster presentation.

Learning from a Poster Session

After each group has created their Investigation Poster, groups will present their poster. When listening to the presentations, it will be important to ask questions to make sure you understand results. Ask questions to satisfy yourself that the results and conclusions others have drawn are true. It's important to believe the results that other groups report.

A number of groups will be presenting on the same machine. Make sure the various groups are all seeing the same effects of changing the machine. Look for differences on how groups completed the investigation. Make sure that their data seems consistent with other groups. Be sure to point out any errors in procedure, variable control, or interpretation of data.

As other groups present their work, look for answers to these questions:

- What was the group trying to find out?
- What variables did they control as they did their procedure?
- Is their data scattered or is it fairly consistent?
- Did they measure the force needed to lift the object in a consistent way?
- Did their procedure cause them to conduct a poor, uncontrolled investigation?
- What did they learn and what is their Rule of Thumb?
- What conclusions do their results suggest?

End-of-Lesson Questions

Look at the following questions. Make sure you answer all of them.

What was the variable you were testing during your investigation? Explain how you were able to change the variable you were testing to determine its effect.

List all of the variables you controlled (did not change) during your investigation.

How many trials did you perform? Explain why you performed that number of trials.

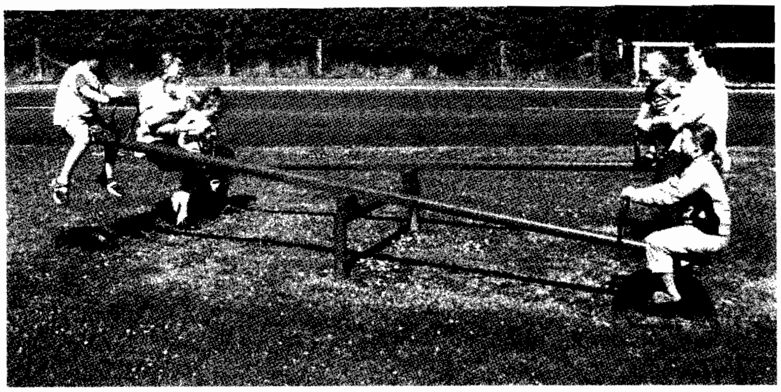
How consistent was your set of data? Why is consistency in repeated trials of testing important during an investigation?

Was the data set you collected useful in determining the effect the variable had on lifting the object? Explain why, or why not.

Simple Machines: Part 2

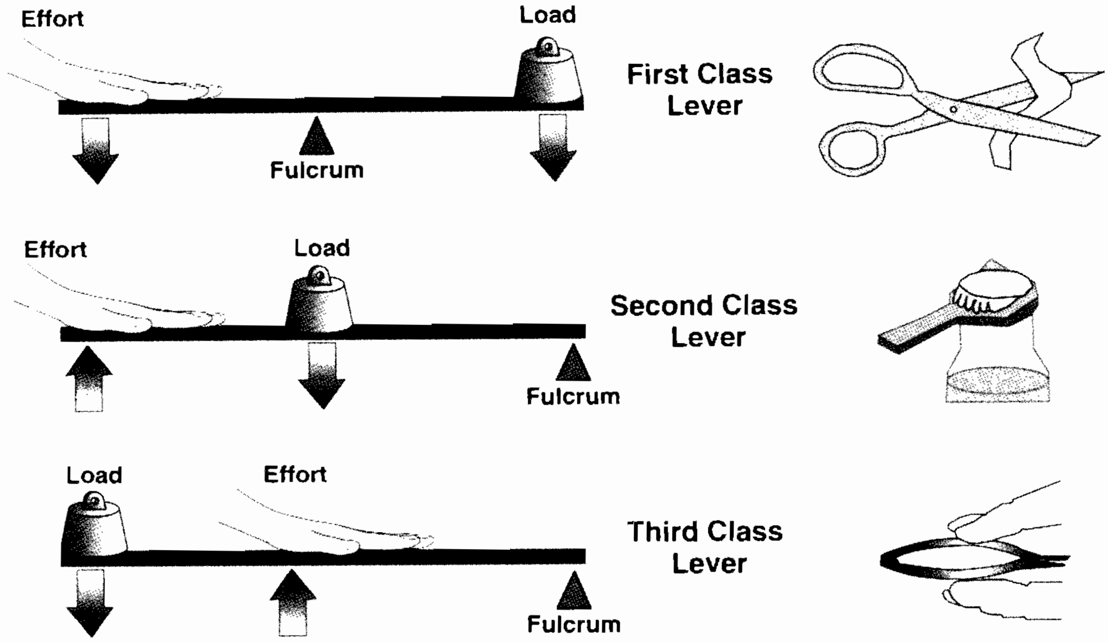
There are six types of simple machines. You learned about the inclined plane, the screw, and the wedge in the last reading section. In class, you investigated two other types of simple machines — the lever and the pulley. You saw that the lever not only allowed you to use less force to lift an object, it also let you push down instead of lifting up. In this reading, you will learn more about the lever and pulley as well as one other type of simple machine — the wheel and axle.

The Lever

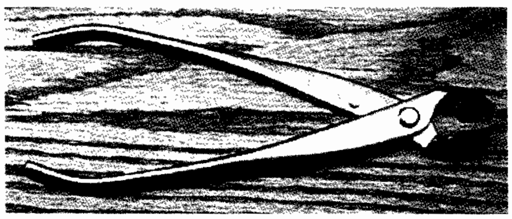


As a young child, you may have played on a see-saw (teeter-totter) at the playground. On a see-saw, your weight pushing down lifts your friend up. A see-saw is an example of a lever. By changing its use slightly, a see-saw can be used to lift heavy things. In the investigation you did in class, you used a lever to lift an object with less force than it took to lift it directly.

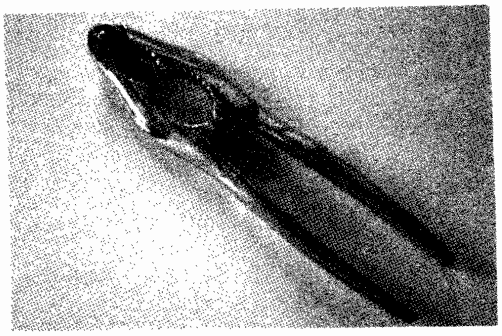
The lever is a type of simple machine. All levers have some type of pivot point called a fulcrum. The lever rotates (turns) around the fulcrum. Levers work in different ways depending on where the fulcrum is and where the force is applied. The applied force is sometimes called the effort. The object being moved is called the load. There are three classes of levers. Notice where the fulcrum is in each class of lever.



First-class levers work like see-saws to change the direction of the applied force. When you push down, the other end of the lever pushes up. Scissors, bolt cutters, and tree trimmers are examples of this kind of lever. When you push down on the top handle of scissors, the bottom blade moves up. As you lift up on the bottom handle of the scissors, the top blade moves down. If the fulcrum of a first-class lever is moved closer to the object being moved (called the load), the amount of force you need to apply to move the load is less. However, the pushing end of the lever moves through a greater distance than what the load moved through. With bolt or branch cutters, you place the object to be cut as close to the pivot point (fulcrum) as possible. This reduces the amount of force you have to apply, but you have to move the handles much more.



Second-class levers have the fulcrum at the end and the load in the middle. A bottle opener is a good example. As you lift on the end of the bottle opener, it lifts the cap off the bottle. This is something you certainly could not do without the help of a simple machine! A nutcracker is another example of a second-class lever. You apply a force at the end of the handles to crack a nut between them.

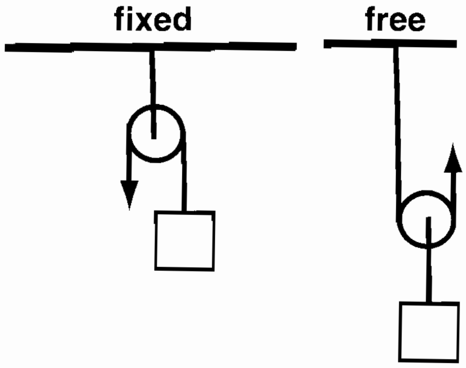


Third-class levers have the fulcrum at one end and the load at the other end. The force is applied in the middle. Tweezers are a good example of a third-class lever. You squeeze the tweezers in the middle and they exert a force at the end. A broom is another example of a third-class lever. The fulcrum is at the top of the broom, you apply a force in the middle, and the broom moves dirt at the bottom. For the tweezers and the broom, the amount of force you apply is greater than the force needed to do the task. However, the distance you must apply the force is much less. It is easier in these cases to apply more force through a short distance than to apply less force through a long distance.

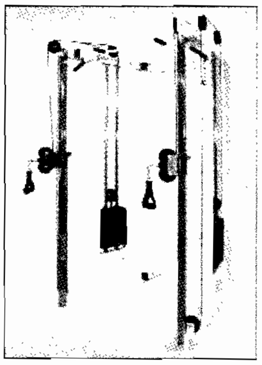
The Pulley

The pulley is another type of simple machine. As you saw in your investigation, there are two basic types of pulleys, the fixed pulley and the free pulley. Fixed pulleys are attached to something solid, like a wall or ceiling. When you use a fixed pulley, it only changes the direction of the applied force. For example, it can change a pulling force into a lifting force. Fixed pulleys do not reduce the amount of force you need to apply.

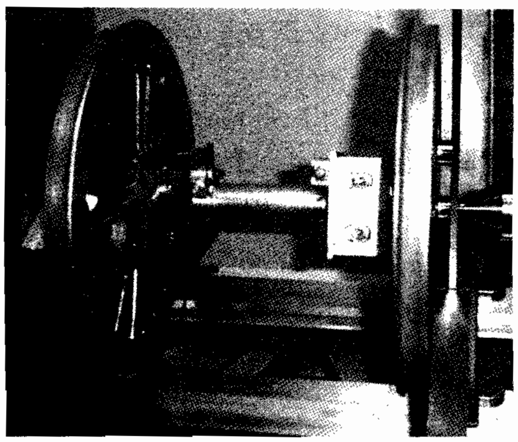
A free pulley is a pulley that is attached to the load and moves along the string with the load when pulled. A free pulley reduces the amount of force needed to move the object, but does not change the direction of the force. There are advantages to using both kinds of pulleys.



When several pulleys of both types are used together in a pulley system, you receive the benefits of each type working for you. In a pulley system, you have to pull on more rope than if you were just lifting the load. The system, however, changes the pulling force to a lifting force and reduces the amount of force needed to lift the load. You may have seen a pulley being used on a sailboat to lift the sails or on a weightlifting machine at the gym.



Wheel and Axle



The final type of simple machine is the wheel and axle. The wheel and axle works by transforming a small force applied in a turning direction into a larger turning force applied at the center of the wheel. For example, think of a steering wheel. The force that a driver applies to the outside edge of the steering wheel is much smaller than the force needed to turn the direction of the axle which turns the car wheels. However, the edge of the steering wheel must move through a much longer arc than the axle moves to make the same turn. Another example of a wheel and axle is the crank that opens a car window in a car that does not have power windows.

Each one of the six simple machines works on basically the same principle. There is a trade-off between the amount of force you apply and the distance along which you have to apply that force. This trade-off is called mechanical advantage.

Simple Machines: Part 2 Questions

1. List two examples of levers. Explain what they are used to do and draw a picture showing the fulcrum, load, and applied force.
2. List two examples of pulleys and explain what they are used to do.
3. List two examples of a wheel and axle and explain what they are used to do.

Mechanical Advantage

In the Predict-Observe-Explain investigations, you learned that to move something, you have to apply an unbalanced force. If the object is really heavy, like a big bucket of blocks or a heavy iron beam, you have to apply a large force to move it. You have to apply a large force because there are large resisting forces acting on it, such as friction or gravity.

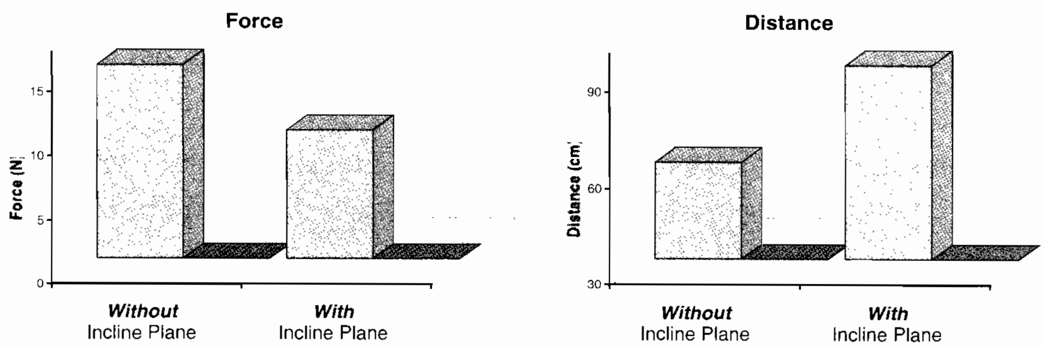
Machines can help you move heavy objects by acting as force transformers. Machines act as force transformers by changing the amount or direction of the applied force. However, there is always a trade-off when you use a machine. A trade-off means that in order to get something you want, you have to give up something. For example, imagine that you and your friends collect and trade baseball or football cards. One of your friends has the card of a star player that you want very much. To trade for that card though, you have to give him one of your favorite cards. In the trade, you got the card you wanted, but you also had to give up a card.

When you use a machine, the same thing happens. If you want to apply less force to move something, you have to apply the force through a greater distance. You gain the ability to use less force, but you have to trade applying the force through a greater distance to get it. This trade-off for machines is called the mechanical advantage of the machine.

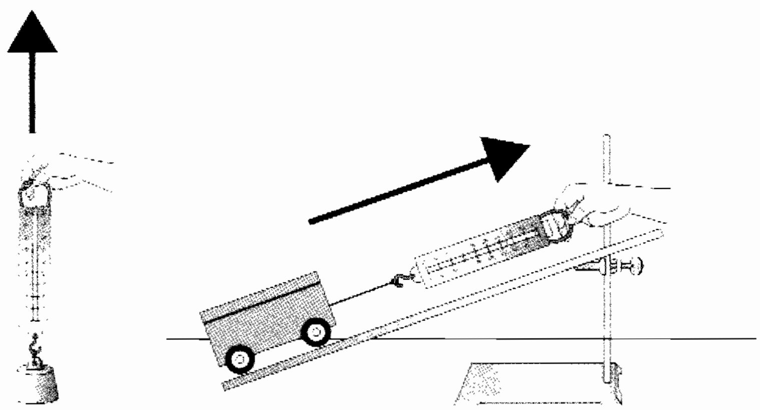
Machines can transform a small applied force into a large force. The trade-off is that the smaller force needs to be applied over a longer distance to do the same task. For example, instead of pushing really hard and applying a big force to lift a heavy box off the floor, you can use a machine to help you lift that box with a much smaller force. The trade-off is that you have to apply the smaller force through a longer distance. The machine transforms the small force you apply through a larger distance into a larger force through a smaller distance to lift the box. This larger force results in unbalanced forces acting on the heavy box, and the box's motion changes. The box moves from its resting position.

Machines can also transform a large applied force into a small force. You may wonder why anyone would want to apply a large force instead of a small force. The advantage is in the trade-off of distance. For example, think about raking leaves in the fall. When you use a rake, you move the top of the handle with quick, sharp strokes. The amount of force you apply is greater than the amount of force needed to move the leaves, but the distance your hand moves is much less than the distance the leaves move. In this case, because the leaves are so light, it is easier for you to apply more force through a short distance than less force through a greater distance to gather up the leaves.

As you can see, the force-distance trade-off is the mechanical advantage of machines. There is an advantage to using the machine instead of doing the task yourself. The advantage is either you have to apply less force through a longer distance, or you have to apply a greater force through a shorter distance.



The mechanical advantage of a machine can be seen most clearly in graphs that show the relationship between force and distance. The graphs shown above are similar to the graphs that you created in class when you investigated the simple machines. These two graphs show the results of an investigation where Jessica tried to move a block from the floor to the top of a table that was 60 cm high. She first lifted it straight up; then she used an inclined plane to help her. In the first graph, Jessica compares the amount of force she applied to move the block. Without an inclined plane, she applied 15 N of force to move the block. When she used an inclined plane, she only needed to apply 10 N of force. This is the advantage of using the inclined plane: Jessica needed less force to move the block. What was the trade-off? When Jessica moved the block without the inclined plane, she needed to apply the force through a distance of 60 cm. However, when she used the inclined plane to move the block, she needed to apply the force through 90 cm. The trade-off for using the inclined plane was that Jessica needed to apply the force through a longer distance.



How would Jessica write a conclusion for this investigation? Her conclusion would need to describe what the data show. In general, Jessica found that she needed to apply less force to move the block when she used an inclined plane than when she lifted it straight up. She also needed to apply the force through a longer distance when she used an inclined plane. Jessica might write a conclusion like the following:

"When I used an inclined plane to move the block, I applied less force but I applied the force through a greater distance than when I lifted the block straight up."

What evidence does Jessica have that this conclusion is correct? She can use the data from her investigation as evidence to support her conclusion. What is the evidence to support the claim that when she used the inclined plane, she *applied less force*? In her investigation, Jessica found that when using the inclined plane she needed to apply 10 N and when lifting straight up she needed to apply 15 N of force. A force of 10 N is less than 15 N, so this evidence supports her claim.

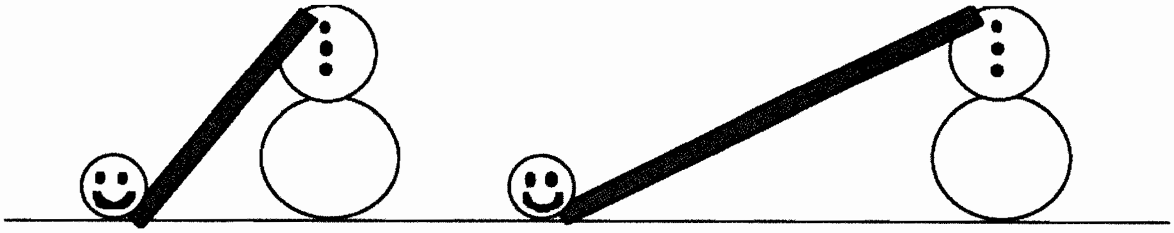
Now look at the second part of her conclusion. Jessica claims that when she used the inclined plane, she needed to *apply the force through a greater distance* than when she lifted the block directly? What is the evidence to support this claim? In her data, Jessica recorded that when she used an inclined plane, her hand moved 90 cm. When lifting straight up, her hand moved only 60 cm. A distance of 90 cm is greater than 60 cm, so this evidence supports her claim that the distance was greater using the inclined plane.

Mechanical Advantage Questions

1. Give an example of something you might trade in everyday life. In this trade, what do you get? What do you give up?
2. Write a few sentences that describe what mechanical advantage means to you.
3. It is winter and you have a "snow day" —school is cancelled. You and your friends are building a snowman. You roll a huge snowball for the bottom, and another big snowball for the middle. As you and your friends try to add the head, you realize that the snowball is too heavy and the body of the snowman is too tall for you to lift the head to the top. You ask your friends, "Now what do we do?" Your best friend remembers something about machines he learned in science class that could save the day. What do you think he remembered?

4. One of your friends suggests using an inclined plane to lift the final snowball onto the snowman. You have two boards to choose from — one is long and one is short. To help decide which will be best to use, label the following in the diagram below:
   a) long ramp
   b) short ramp
   c) larger applied force
   d) smaller applied force
   e) longer distance

f) shorter distance



5. How are force and distance related in the use of an inclined plane?

Learning Set 4
How Can I Make Machines Work For Me?

Lesson 4.1
Complex Machines

Overview

During this unit you have learned that unbalanced forces are needed in order to move things. You've also learned about mechanical advantage and how inclined planes, levers, and pulleys can help you lift things.

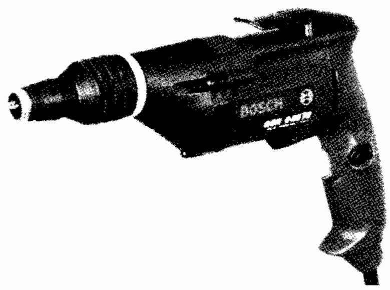
Simple machines cannot always provide enough mechanical advantage to perform a given task. In fact, very few of the machines you use everyday are simple machines. They are actually made up of at least two simple machines. Machines that have two or more simple machines working together are called **complex machines**.

A **complex machine** is two or more simple machines working together.

In this lesson, you will look at a number of examples of complex machines are reviewed. You will name the simple machines that make up the complex machine. Finally, you will return to your machine design.

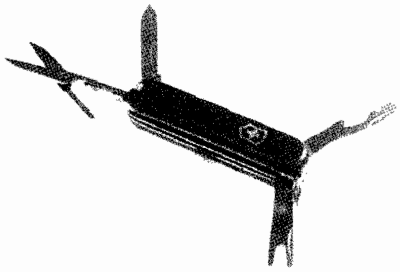
Complex Machines

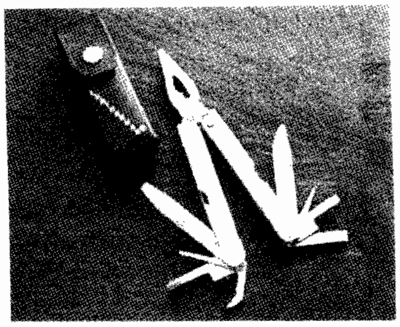
Think about some of the construction machines you saw earlier in the unit. The arm of a backhoe is actually a lever and a wedge. A drill is actually a screw and a wheel and axle. In each of these examples, the simple machines work together.



Some machines like a pocketknife or a Leatherman® tool look like complex machines. They are made of many different simple machines but the simple machines are used separately — they do not work together! Therefore the pocketknife and the tool like the one shown in the photograph are not complex machines.

Simple machines working *together* make something a complex machine.





Let's take a closer look at an example. A shovel is a pretty easy machine to use. It doesn't have any wheels or knobs or moving parts. It seems pretty simple. However, a shovel is a complex machine that is made of two simple machines working together.

The first of these simple machines is a lever. The handle of a shovel acts as a lever to lift the dirt out of the ground. When you push down on the top of the handle, the bottom of the lever lifts the dirt up. The fulcrum is located at the point where the shovel pivots in the dirt. In this way, the handle changes the direction of the applied force. In addition, you apply less force to the shovel than you would if you were lifting the dirt without the shovel. But your hands move down a larger distance than the dirt moves up, so you are applying the force though a greater distance. The mechanical advantage of using the handle of a shovel is that you need to apply less force and the handle changes the direction of the force. The trade-off is that you need to apply the force through a greater distance.

Would a shovel be a good machine if it only had the handle? Of course not! In order for a shovel to help you dig up dirt, it also needs a second simple machine. The second simple machine on a shovel is a wedge. The bottom of the shovel scoop is shaped into a wedge. The wedge helps to push the scoop into the ground so it goes under the dirt that you want to lift up. When you apply a force to the scoop with your foot, this pushes down on the top of the wedge. The wedge then changes the direction of the force from a downward direction to a sideways direction. The force pushing sideways pushes the dirt out of the way so the scoop can go into the dirt that you want to lift. The mechanical advantage of using the wedge on the bottom of the scoop is that it changes the direction of the force that you apply.

In a shovel, the lever and the wedge work together to make it easier to lift and move dirt. When you use a shovel, you gain the mechanical advantage of both simple machines. You need to apply less force than lifting the dirt yourself, and the force you apply is transformed from a down direction to a sideways direction to push the dirt. The mechanical advantage of using this complex machine is greater than using either simple machine alone. The lever and the wedge work together in a shovel to both reduce the amount of applied force and change the direction of the applied force. Together, this makes it easier to dig than using just your hands. Other complex machines work in the same way. Every complex machine has two or more simple machines working together in order to help you do something. By looking at what each simple machine does, you can figure out how they work together to make the complex machine work.

Complex-Machine Questions

1. Name one complex machines that you use everyday.
2. How can you tell if a machine is a complex machine?
3. List the simple machines that make up the complex machine you named in Question 1.
4. What is the mechanical advantage of each simple machine?
5. What is the mechanical advantage of the complex machine? How do the simple machines work together?

Heavy Object-Lift Challenge: Design 1

In your investigations you have learned a lot about how inclined planes, levers, and pulleys work. The mechanical advantage of these simple machines is what makes things easier.

The Design Challenge

Recall the design challenge. Imagine that Henry is at the top of a very steep ledge. He wants to use some rope that he has to lift up a large crate of food that is 10 m below him. His rope, however, is not strong enough to raise the heavy barrel directly, and his rope is also too short. The crate is also too heavy for Henry to lift without help.

Henry has some building materials in his truck. He would like to use them to build a machine that he will connect to his rope and raise the barrel. He needs your help to design this machine.

You will build a scaled-down model of a machine to help Henry. You will build a machine that will *raise a block 10 cm*. Henry's rope is weak, so to model this, you will use a *single strand of cotton thread* somewhere in your machine.

Criteria and Constraints

Before you get started, make sure that you understand what your challenge is. In order to understand what you are designing toward, you must understand two parts of the design task: the criteria and the constraints.

The **criteria** are things that must be satisfied in order for the machine to work. In other words, you need to know the job the machine must do. You must also know how the machine must do that job. Your teacher will lead you in a discussion of these criteria and your class will list them.

The constraints are factors that will limit how you can solve a problem. For this challenge one of the constraints is that you can only use the materials with which you are provided. Think about the other limits that have been placed upon you for this challenge. Your teacher will lead you in a discussion of these constraints and your class will list them, also.

Your Design

Draw a picture of your proposed design. Be sure to identify the following:

- the type of simple machine to be used
- the location of the applied force
- the location of the object to be lifted
- the location of the cotton thread that will be used
- a description of the mechanical advantage of the machine (e.g., the force-distance trade-off).

If you are combining more than one simple machine into a complex machine, show how the two simple machines will be connected to work together.

Materials

List the materials you will need to build your machine.

Sharing Information

When you are planning a design, the opinions of others can be very helpful. They can help you figure out how well your design meets the criteria of the challenge. Design students have a way to give each other feedback during the design process. Different teams set up their drawings. Then, each team takes turns presenting its design to others. All the designers move from one presentation station to another. At each station, they learn about the product or design. They ask questions, and offer suggestions to the team whose product or design is being studied.

This is a way that different teams can learn from each other. A team may have had problems with one part of its design. That team may now have good advice for those who haven't yet faced that problem.

Your teacher will give you time to organize your presentations. Then, your teacher will lead you through this sharing session.

Revisiting Your Design: Iteration

You may have thought that you could easily design and build a machine to lift a heavy object using just a string. You have even done investigations that would help you with your final design. However, you can begin to see that your early designs need to be improved. In design, improving upon your first design is important. That does not mean that early designs are not important. They help you to build a better machine.

Use the notes from your sharing session to revise your machine so that it is ready to build. Draw a picture of your revised design. Be sure to identify the type of simple machine to be used. If you are combining more than one simple machine into a complex machine, show how the two simple machines will be connected to work together. Also indicate the location of the applied force, the block, and strand of thread, and explain the mechanical advantage of the machine (the force-distance trade-off).

Be sure to add any new materials you will need in addition to your first equipment list.

Lesson 4.2
Build and Test Machines

Overview

In this lesson you will build and test your machines for the design challenge. Before testing the machine with the single strand of cotton thread, you will measure the force and distance needed to lift the object with and without the machine. From this data, you will be able to describe the mechanical advantage of their machine. After testing your machine with the thread, you will record the results, describe the strengths and weaknesses of your design, and share your designs and results with the class. From class discussions, you will be able to make recommendations for how to improve your design. You will be given an opportunity to modify your design and test it one last time.

Heavy Object-Lift Challenge: Design 2

Now that you have designed your machine, you must test it. The goal of this test is not only to see if it works, but also to determine what did and did not go well. This information will help you to improve your design.

Planning Your Test

How will you test your machine? Describe what you will measure. (Remember, you need to describe the mechanical advantage and trade-off of your machine.)

Results

What happened in your test? Describe your results and record any measurements.

Analysis

What did you learn? Are there any problems with your design? How could you make it better?

Sharing Results

Preparing Your Machine for a Gallery Walk

A **gallery walk** is a step in the middle of a design sequence. It gives each group a chance to share what they have tried and learned. It also provides an opportunity to learn from others.

Prior to this step, you will have worked in groups to find a solution to the challenge. You will have built the first version of a design. You will also have tested it and gathered data about how your design worked. At this point the opinions of others can be very helpful. They can help you evaluate how well the design meets the criteria. The gallery walk shows a variety of solutions. It presents what works or does not work. Remember, you can learn a lot for "failed" attempts.

Before you present your design to the rest of the class, first look at what might be important to share, discuss, and consider during your presentations. In science this year, you will often present your ideas and things you design to each other. The gallery walk works best when everyone is communicating well. The groups who are presenting must explain the important aspects of their design or product. The other groups must pay attention and think of important questions to ask.

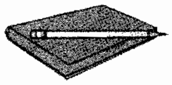
Participating in a Gallery Walk

When you take part in a gallery walk, it is important to look at each design carefully. You should ask questions about the design. When your group is presenting, explain your design. You need to justify the decisions you made. You also need to support your design choice with evidence. The evidence can come from tests of the design. It can also come from similar cases that you know about.

Be prepared to ask (and answer) questions, such as:

- Can you show us how this is constructed?
- How well does it work?
- How does the design meet the criteria?
- How did the challenge constraints affect the design?
- Describe the mechanical advantage of each simple machine you used. If you built a complex machine, be sure to explain how the simple machines work together. What are the trade-offs for your machine?
- Describe how the block is being moved in terms of balanced and unbalanced forces.
- State the results of your machine test. Did it work? How much force was required to lift the block?
- If your machine did not work, it's okay. However, you must explain why it did not work and make some suggestions of how you might improve the design.
- What other ideas or designs do you want to test?

Fill out a Gallery-Walk Notes sheet as you listen to everyone's presentation.



Name: ____________ Class: ____________

Group: ____________ Date: ____________

Gallery-Walk Notes

Design Iteration (Version): ____

Design or Group	How Well It Works	What I Learned and Useful Ideas: Design Ideas	Construction Ideas	Science Ideas

Plans for Our Next Iteration (Version)

Lesson 4.3:
Final Group Presentations

Overview

In this lesson, you will have an opportunity to apply all the knowledge you have learned and the feedback you received from others to your final design. The groups in your class will then make their final presentations. The rest of the class will evaluate each presentation using a scorecard.

Heavy Object-Lift Challenge: Design 3

It is time to finalize your machine design. This is the last version of the machine that you will get to test. You will present this machine and your results to the class. Use the results of your first test to improve your design.

Your Final Design

Draw a picture of your final design. Be sure to identify the type of simple machine or machines to be used. Also indicate the location of the applied force, can, and strand of thread, and explain the mechanical advantage of the machine (and each simple machine if your design is a complex machine).

Materials

List the materials you will need to build your machine.

Now that you have built your final machine design, you must test it. The goal of this test is not only to see if it works, but also to determine what did and did not go well. You will need to report this information in your final presentation.

Testing Your Machine

How will you test your machine? What you will measure. (Remember, you need to describe the mechanical advantage and trade-off of your machine.)

Results

What happened in your test? Describe your results and record any measurements.

Analysis

What did you learn? Are there any problems with your design? How could you make it better?

Machine-Presentation Guidelines

Your group will be presenting your machine design to the rest of the class. You want to make an interesting and informative presentation. As you prepare your final presentation, use the following guidelines to help you:

- State the names of the group members.
- Briefly describe the Heavy Object-Lift Challenge. (There may be visitors in the class who are not familiar with the task
- Include a picture of your final machine design which includes
  - a name for your machine
  - the kind(s) of simple machine(s) being used
  - the location of the applied force
  - the location of the can being lifted
  - the location of the cotton thread being used to lift the can
- Describe the mechanical advantage of each simple machine you used. If you built a complex machine, be sure to explain how the simple machines work together. What are the trade-offs for your machine?
- Describe how the object is being moved in terms of balanced and unbalanced forces.
- State the results of your machine test. Did it work?

Your machine was designed to help Henry lift a can of food to the top of a cliff. In what other situations might your machine be useful?

Finally, be sure to answer the driving question of the unit: How do machines help me build big things? Use what you have learned in the unit to briefly answer the question.

Don't forget that your classmates will be evaluating your presentation. They will be looking for the following things as your group presents:

- Is the presentation clear and organized?
- Is there collaboration in the group? Did everyone contribute to the presentation?

Evaluating Group Presentations

Name: ____________________ **Date:** ____________________

Group Name:						Group Name:					
	High				Low		High				Low
Description of can-lift challenge	5	4	3	2	1	Description of can-lift challenge	5	4	3	2	1
Identify all simple machines	5	4	3	2	1	Identify all simple machines	5	4	3	2	1
Mechanical advantage	5	4	3	2	1	Mechanical advantage	5	4	3	2	1
Balanced/unbalanced forces	5	4	3	2	1	Balanced/unbalanced forces	5	4	3	2	1
Machine test results	5	4	3	2	1	Machine test results	5	4	3	2	1
Other situations to use machine	5	4	3	2	1	Other situations to use machine	5	4	3	2	1
Answer driving question	5	4	3	2	1	Answer driving question	5	4	3	2	1
Clear presentation	5	4	3	2	1	Clear presentation	5	4	3	2	1
Organization	5	4	3	2	1	Organization	5	4	3	2	1
Group collaboration	5	4	3	2	1	Group collaboration	5	4	3	2	1
Positive comment:						Positive comment:					

Group Name:						Group Name:					
	High				Low		High				Low
Description of can-lift challenge	5	4	3	2	1	Description of can-lift challenge	5	4	3	2	1
Identify all simple machines	5	4	3	2	1	Identify all simple machines	5	4	3	2	1
Mechanical advantage	5	4	3	2	1	Mechanical advantage	5	4	3	2	1
Balanced/unbalanced forces	5	4	3	2	1	Balanced/unbalanced forces	5	4	3	2	1
Machine test results	5	4	3	2	1	Machine test results	5	4	3	2	1
Other situations to use machine	5	4	3	2	1	Other situations to use machine	5	4	3	2	1
Answer driving question	5	4	3	2	1	Answer driving question	5	4	3	2	1
Clear presentation	5	4	3	2	1	Clear presentation	5	4	3	2	1
Organization	5	4	3	2	1	Organization	5	4	3	2	1
Group collaboration	5	4	3	2	1	Group collaboration	5	4	3	2	1
Positive comment:						Positive comment:					