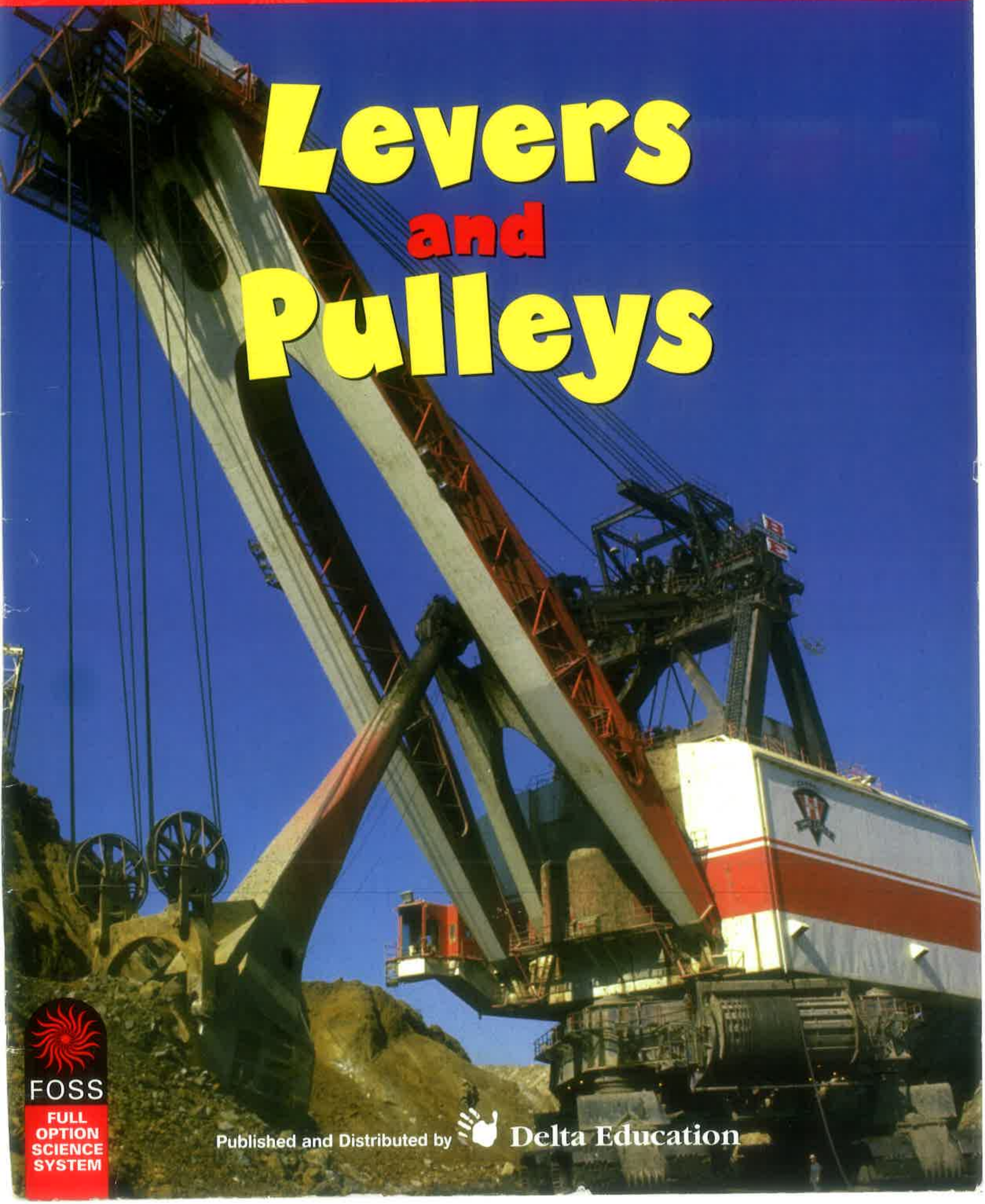
FOSS Science Stories

Levers and Pulleys



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Levers and Pulleys

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TABLE OF CONTENTS

SIMPLE MACHINES

A young girl is lifted by a seesaw. A seesaw is one example of a lever.

Imagine being strong enough to lift your teacher into the air. Picture doing it with just the strength you already possess. If you think it's impossible, it's not! If you've ever played on a seesaw with someone bigger than you, you've already seen how you can lift someone heavier into the air! You probably found that the closer your friend sat to the center support bar, the easier it became to raise him or her. Even though your friend may have been heavier than you, you could lift him or her because you had the help of a *simple machine*. A seesaw may not seem like a machine to you, but it is. A seesaw is a *lever*, and a lever is a simple machine.

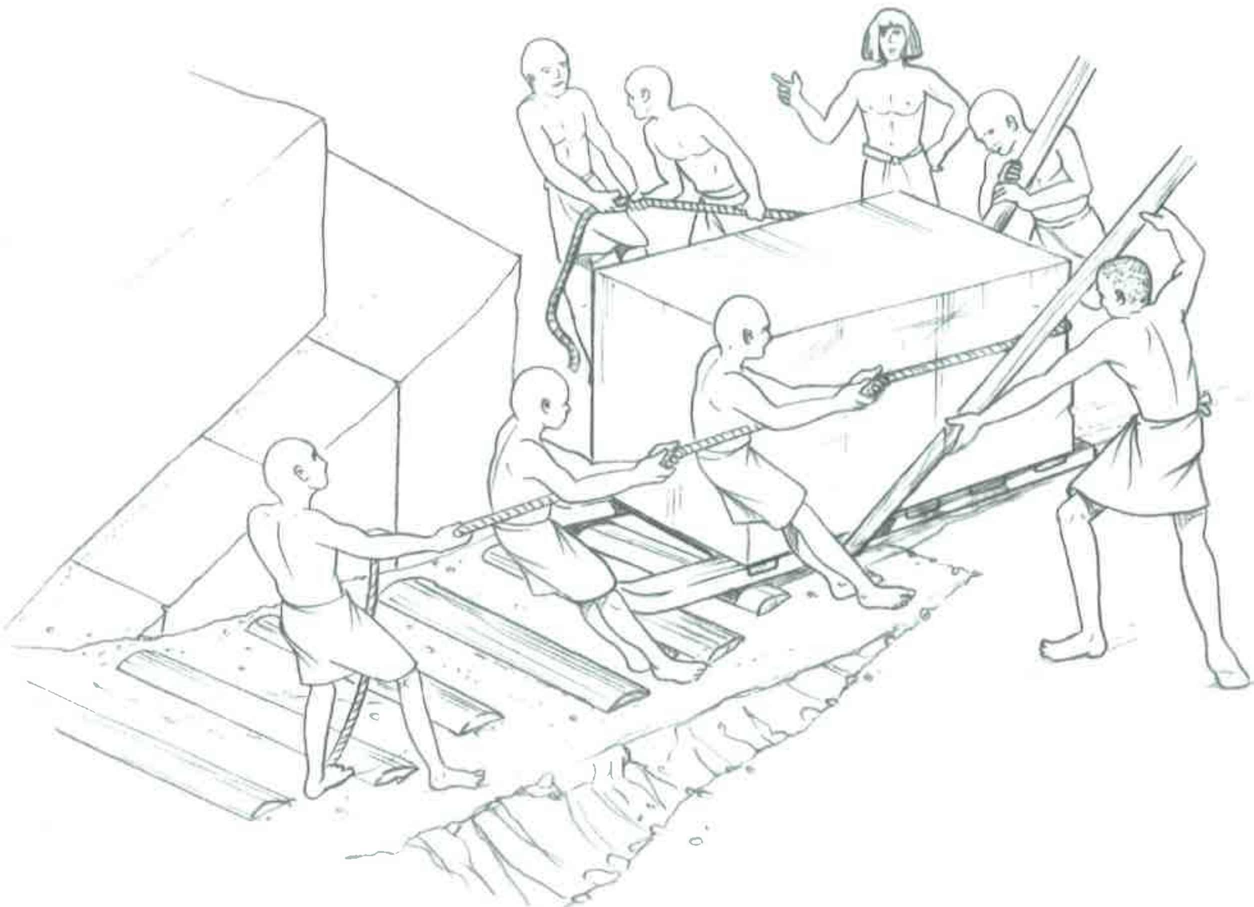
Machines are devices for doing work. We use machines to help us every day. We can build houses and furniture using power tools or clean our clothes in washing machines. We can drive cars or fly in planes. Those kinds of machines are *complex*. Complex machines are often powered by motors. Motors have many parts, and some of those parts are simple machines.

Sometimes we may want to lift, push, or pull objects, or we may need to break or cut them. Some of these jobs require a lot of *force*. When we use simple machines, we gain a *mechanical advantage* by increasing the amount of force we can bring to bear on an object.

When we talk about how simple machines operate, we use the word *effort* to describe the amount of force we apply to the machine. Simple machines help us in two ways. We can apply less effort over a greater distance, or we can apply more effort over a shorter distance. Simple machines provide a gain in effort or a gain in distance. In addition, some simple machines change the direction of effort. Effort is measured in *newtons*. The newton is the metric unit of force.

There are six simple machines. They are the *lever*, the *wheel and axle*, the *pulley*, the *inclined plane*, the *wedge*, and the *screw*. The lever is a beam that pivots at a fixed point. The wheel and axle is a wheel or bar (such as a crank) that rotates around an axis. The pulley is a grooved wheel that turns on an axle and holds a cord or rope. The inclined plane is a tilted flat surface or ramp. The wedge is two inclined planes back to back. The screw is an inclined plane spiraled around an axis.

These six machines have been used for thousands of years. The wedge, inclined plane, and lever are the oldest known machines. Stone Age people used wedges to split wood and shape flint. Early farmers used wedges as plows to till soil. Using wedges in the form of chisels, ancient Egyptians cut massive stones to build the pyramids. They dragged the stones up inclined planes and moved them into position with levers. The



The ancient Egyptians moved heavy weights using levers and inclined planes.

Egyptians used the lever in other ways, too. The *equal-arm balance* is a kind of scale that they used some 7,000 years ago.

The Romans moved building stones with cranes that were operated with pulleys. The effort needed to do the work was provided by slaves walking inside a wheel-shaped treadmill. Monument builders also used pulleys to construct monuments and temples. A pulley in use appears in Syrian artwork dating from the 8th century B.C.E. In the 3rd century B.C.E., the Greek mathematician Archimedes used the screw to lift water from a lower level to a higher level. In the 1st century B.C.E., a Roman engineer named Vituvius made the water wheel practical. This wheel-and-axle machine ground grain into flour.

Simple machines still help us today, both as parts of complex machines and alone. A broom is a lever. A doorknob is a wheel and axle. Pulleys operate many windows and garage doors. Some driveways are inclined planes. Some doorstops are wedges. A thermos cap is a screw. Sometimes one simple machine is combined with others. An example is the hand-held can opener. Each of its handles is a lever, and the turning knob is a wheel and axle. The blade cuts using the principle of the wedge. Look around and see if you can find other simple machines that are used alone or in combinations.

QUESTIONS TO EXPLORE

- **How could you lift your teacher into the air? Could you do it with one hand?**
- **What are some of the simple machines we use every day?**
- **Why do people use simple machines?**

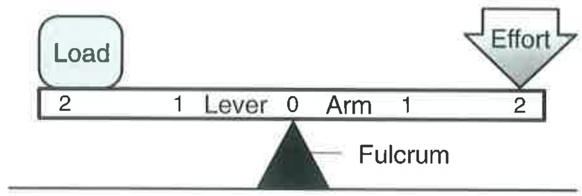
Archimedes

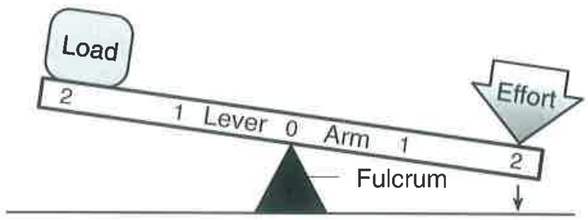
Archimedes was a Greek inventor and mathematician who lived from 287 to 212 B.C.E. He was one of the first to study the way levers work. He realized that the longer he made the arm of the lever, the greater the load he could move. He is thought to have said that with a place to stand and a long enough lever, he could move the Earth.

CLASS-1 LEVERS

The *lever* is one of the simplest machines and also one of the most common. The lever is a rigid beam that can pivot at a fixed point. We call the beam the *lever arm*, and the fixed point is the *fulcrum*. The object to be moved or the resistance to be overcome is the *load*. The amount of force exerted to move or overcome the load is the *effort*.

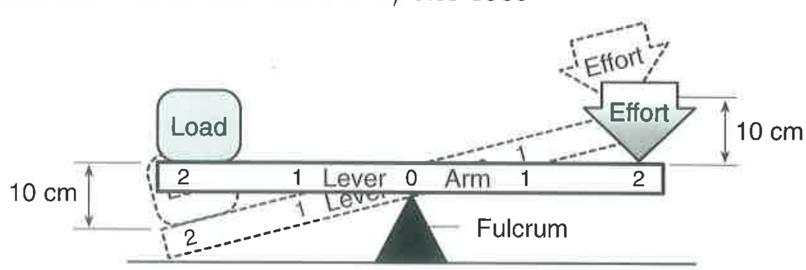
The lever can be set up in different ways. A *class-1 lever* has the fulcrum located somewhere between the effort and the load. With this kind of lever, the direction of force is changed. Effort applied downward moves the load up. Effort applied upward moves the load down.

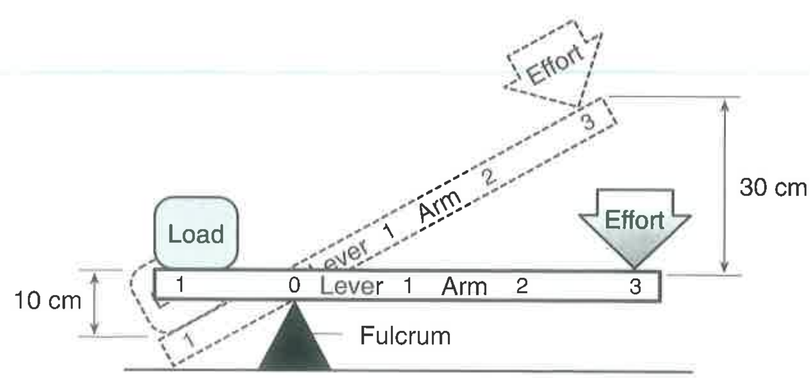




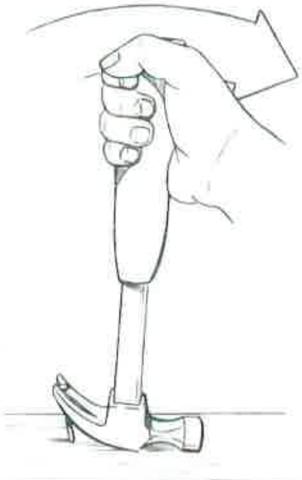
If the distance from the fulcrum to the load is equal to the distance from the fulcrum to the effort, there is no mechanical advantage. You exert effort for the same distance the load moves. The force of the effort is equal to the force of the load.

If the load is moved closer to the fulcrum, you gain a mechanical advantage. It now takes less effort to lift the load. In fact, the closer the load moves to the fulcrum, the less effort it takes to lift the load. But there is a cost. As the load moves closer to the fulcrum, the effort must move a greater distance, and the load is lifted a shorter distance. You trade reduced effort for increased distance.





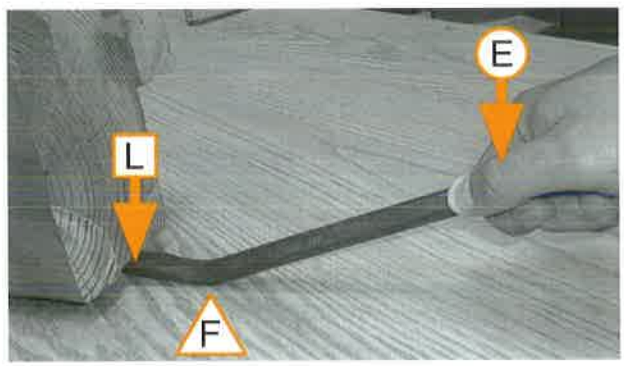
Think how difficult it would be to pull a nail out of wood with muscle power alone. The job becomes simple with a claw



A claw hammer acts as a class-1 lever when used to pull a nail.

hammer. The claw hammer is a class-1 lever. The handle and the claw of the hammer work as the lever arm. In this case, the lever arm is not straight, but curved. The fulcrum is the top of the hammer head. It rests against the wood. The nail is the load (in this case, a resistance to be overcome). Although you push the handle for a greater distance than the claw moves, you don't need as much effort to pull the nail. Imagine two claw hammers, one with a long handle and one with a short handle. Which hammer would pull the nail with less effort?

Other class-1 levers include the crowbar and the tack puller. Can you see where the load and the fulcrum are and determine where the effort is applied?

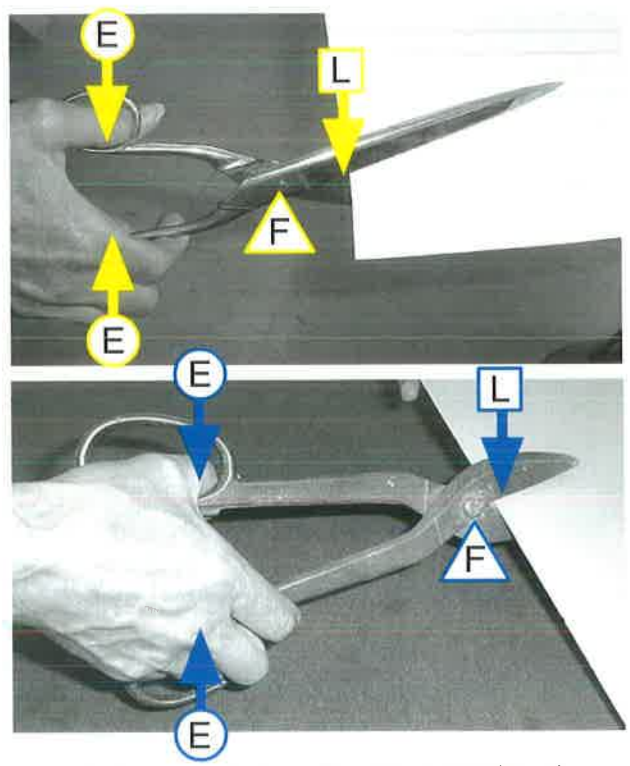


A crowbar is another example of a class-1 lever.

Class-1 levers can be joined. Two levers working together form a *double lever*. The fulcrum is the place where the levers cross. Examples of double class-1 levers are scissors and tin snips, which are shears for cutting metal. The levers work together to apply pressure. The load is a material's resistance to the cutting blades.

Double class-1 levers offer an advantage of either distance or effort. When you cut through paper with long-bladed scissors, you gain distance. The short, looped handles are moved a small distance while the blades cut through a long distance.

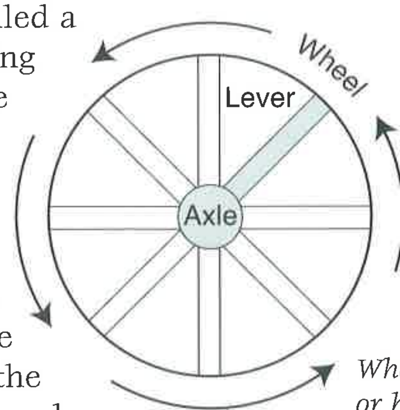
Using tin snips, you gain effort. The long handles move a greater distance than the short blades do. That gives you enough power to cut through metal. Pliers and bolt cutters are double levers, too. What kinds of advantages do they offer?



Scissors and tin snips are examples of double class-1 levers.

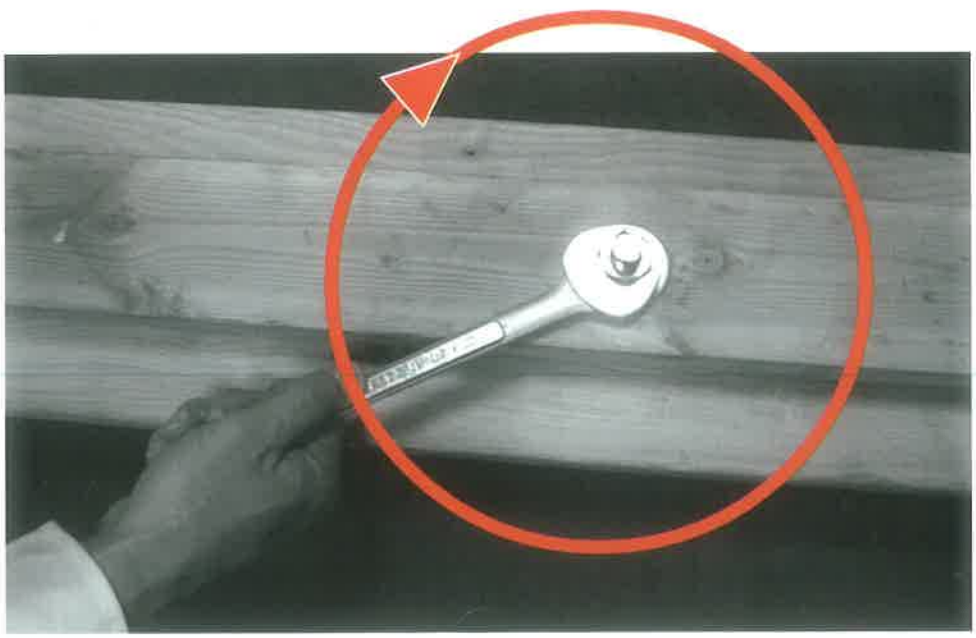
THE WHEEL AND AXLE

The *wheel and axle* is sometimes called a "lever in the round" or a "rotating lever." This simple machine can be an actual wheel with an axle, or it can be a bar that rotates around an axis. When there is an actual wheel, it moves in a circle. A bar that works as a wheel and axle traces an imaginary circle. The center of the circle is the fulcrum. The "wheel" is the circular path followed by the effort. Effort applied to the wheel turns the axle, or effort applied to the axle turns the wheel. They move together. A point on the wheel always moves farther than a point on the axle, but the axle moves with greater force. A wheel and axle can produce a gain in effort or distance, depending on how it is used.



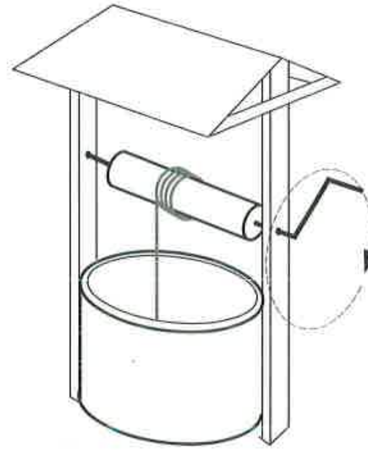
When a lever or bar turns an axle, its circular path becomes a wheel.

A wrench turning a bolt is a wheel and axle. The center of the bolt you tighten is the fulcrum. The handle of the wrench where you apply effort is like the spoke of a wheel. The bolt is the axle. Applying effort out near the end of the wrench handle produces enough force to tighten the bolt securely.



A wrench tightening a bolt is a wheel and axle.

A *windlass* is a crank that can be used to raise a bucket from a well. The windlass is another wheel-and-axle machine. It would take great effort to wind the rope on the axle by hand. However, it's easy to wind the rope by turning the crank. You must move a greater distance to turn the crank, but you need less effort.

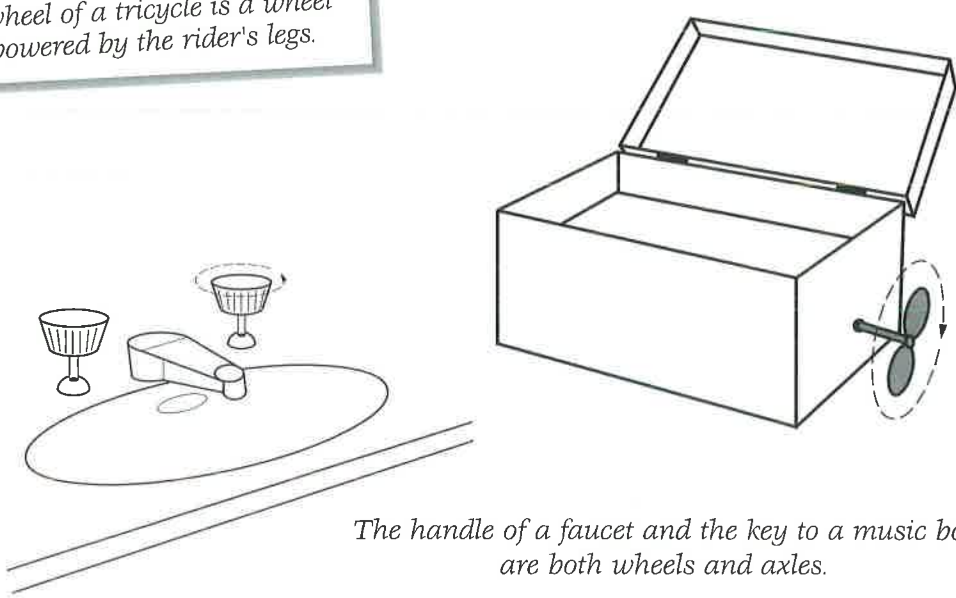


A windlass can be used to lift a bucket from a well. It is another example of a wheel and axle.

The front wheel of a tricycle is a wheel and axle powered by the rider's legs.

The front wheel of a tricycle is a wheel and axle. With this machine, you do not apply effort to the wheel. Instead you apply effort to the axle. The pedals turn in a small circle to turn the wheel in a larger circle. A tricycle offers a gain in distance, but the cost is effort.

The key to a music box and the handle of a faucet are both wheels and axles. Can you guess where the wheel action is and where the axle action is? Can you guess where the effort is applied? Do these wheels and axles offer a gain in effort or distance?

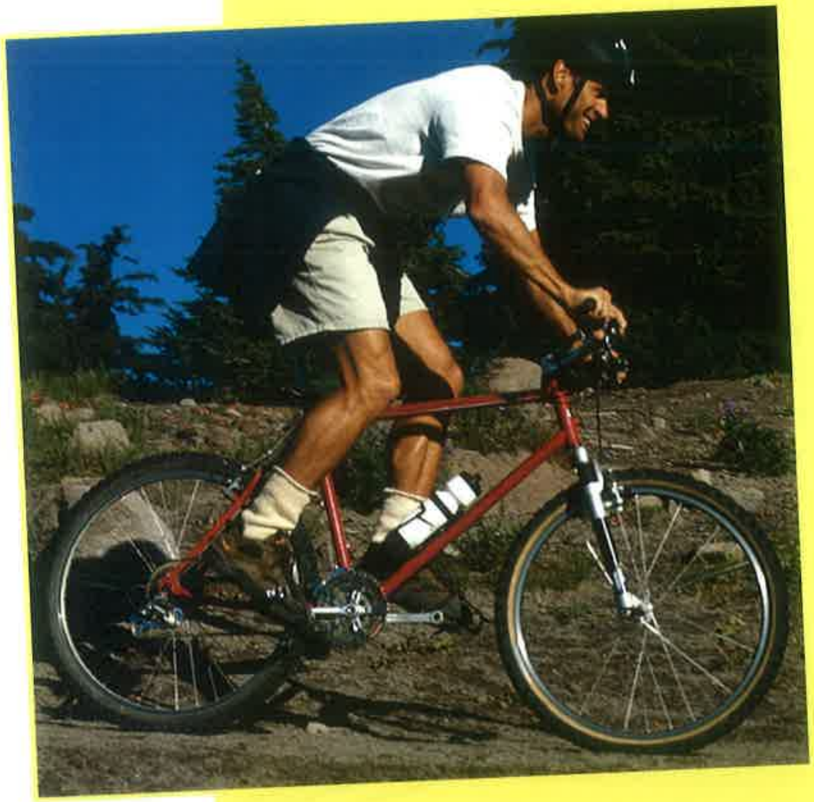


The handle of a faucet and the key to a music box are both wheels and axles.

The Tricycle versus the Bicycle

The front wheel of a tricycle is a wheel and axle, but the front wheel of a bicycle is not. Can you see the difference?

Wheels make it easier to move things along by reducing friction. Many things use wheels, including wagons, skateboards, and in-line skates. In each of these examples, the wheels turn on fixed axles. Each wheel and each axle are separate parts. But in a wheel-and-axle system, the wheel and the axle are connected. If you apply effort to the axle, the wheel turns. If you apply effort to the wheel, the axle turns.

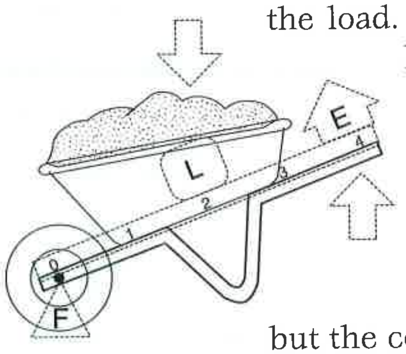


Tricycle pedals are connected to the tricycle's front axle. The front wheel is connected to the axle, too. When the tricycle rider pushes on the pedals, the front wheel turns and the tricycle rolls along. This is a wheel-and-axle system. However, the front wheel of a bicycle simply turns on a fixed axle. The effort to move the bicycle comes from someplace else.

Two wheel-and-axle systems drive the bicycle. The pedals are attached to the front sprocket. The pedals go around in a circle like a wheel. The bicycle rider turns this wheel with leg effort. The front sprocket drives the back sprocket using the bike chain. The back sprocket is connected to the back wheel. When the chain turns the small back sprocket, the much bigger back wheel turns. This sends the rider a good long distance down the road for each turn of the sprocket. The pedals and front sprocket make one wheel-and-axle system. The back sprocket and back wheel make a second wheel-and-axle system.

CLASS-2 LEVERS

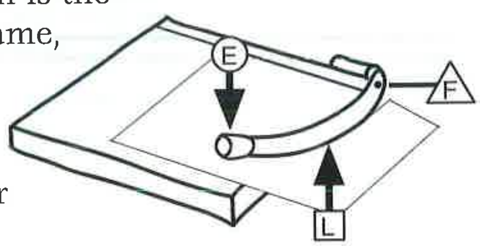
Levers can be arranged in different ways to do different kinds of work. A *class-2 lever* has its fulcrum at one end of a lever arm. The load is between the fulcrum and the effort. With this kind of lever, the direction of effort is not changed. Pushing up on the class-2 lever arm pushes up on the load. Pushing down on the lever arm pushes down on the load. To gain a mechanical advantage, the load is placed closer to the fulcrum than to the effort. The class-2 lever always reduces effort.



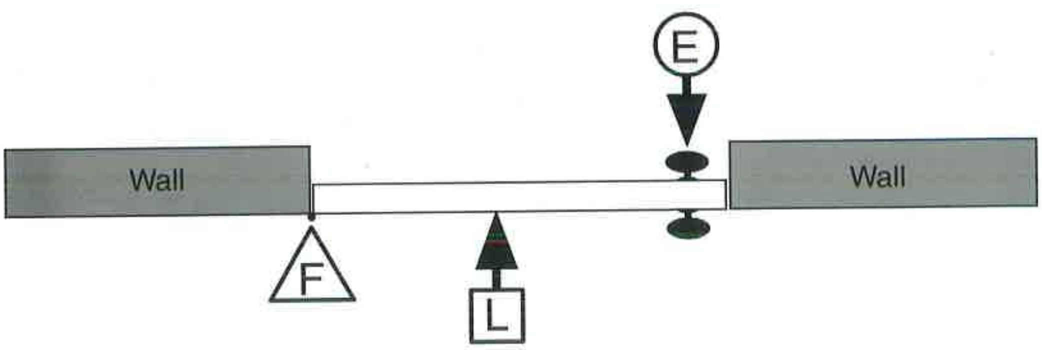
A wheelbarrow is a class-2 lever. The wheel is the fulcrum, and the effort is applied to the handles. The load sits close to the fulcrum. With a wheelbarrow, it takes less effort to lift a heavy load, but the cost is distance. Effort is exerted over a greater distance than the distance the load is lifted.

A paper cutter is another class-2 lever. In this case, the lever arm is a blade, and the paper's resistance to being cut is the load. The paper is placed between the fulcrum and the effort. Effort applied to the handle puts pressure on the paper.

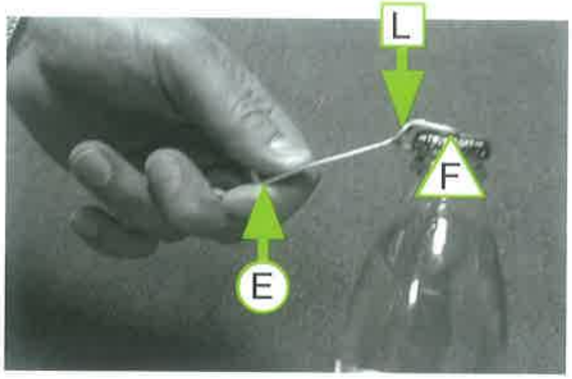
A door is also a class-2 lever. The fulcrum is the place where the door is joined to the door frame, and the effort is applied to the doorknob. What would happen if the doorknob was placed in the center of the door instead of at the outside edge? Would the door be easier or more difficult to open? What would happen if the doorknob was moved even closer to the fulcrum?



A paper cutter is a class-2 lever.

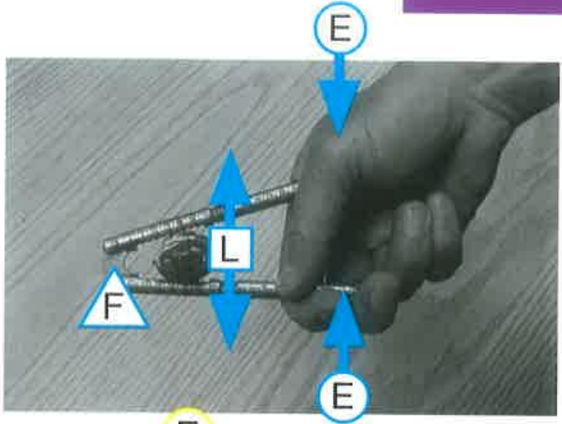


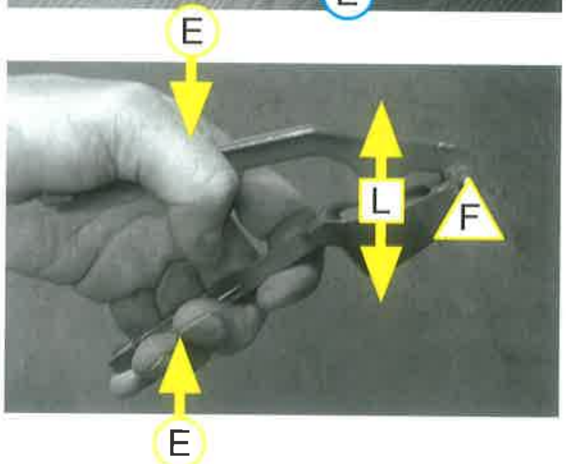
A door is also a class-2 lever.



A bottle opener is a class-2 lever. The resistance of the bottle cap is the load.

Class-2 levers can work together. The place where the levers join is the fulcrum, and the effort is applied to the opposite ends of the levers. The load is placed in between the fulcrum and the effort. The garlic press and the nutcracker are double class-2 levers. Should the nut be placed closer to or farther from the fulcrum to gain the greatest mechanical advantage?

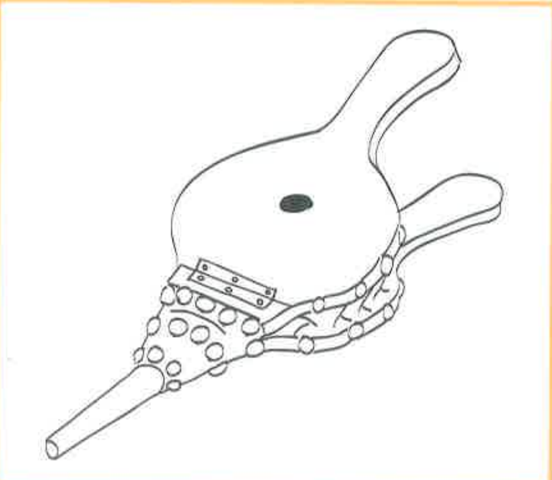




A nutcracker and a garlic press are examples of double class-2 levers.

The Bellows

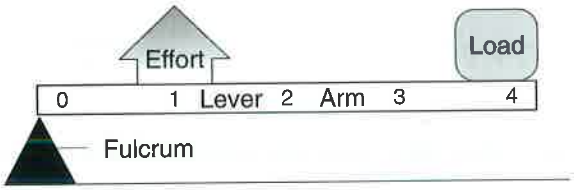
In early times, tools and weapons were made by blacksmiths. A blacksmith shaped metal after heating it to a high temperature in a *forge*, or furnace. The blacksmith used a *bellows* to force air into the forge. That made the fire burn hotter.



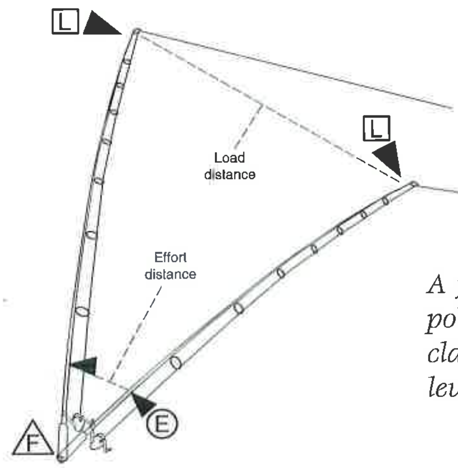
A bellows is a double class-2 lever. Each lever is a board, and the boards are held together by a hinge that acts as a fulcrum. The boards are surrounded by a pleated bag. There is a nozzle at the fulcrum end of the bag. Air is the load, and the effort is applied to the handles. When the levers are separated, air enters the bag through a valve in one of the boards. When the levers are brought together, the air streams out through the nozzle.

CLASS-3 LEVERS

A *class-3 lever* is another arrangement of the lever. In a class-3 lever, the fulcrum is at one end, and the effort is applied between the fulcrum and the load. With this kind of lever, the direction of effort is not changed. The load moves in the same direction as the effort. The gain offered by a class-3 lever is one of distance.

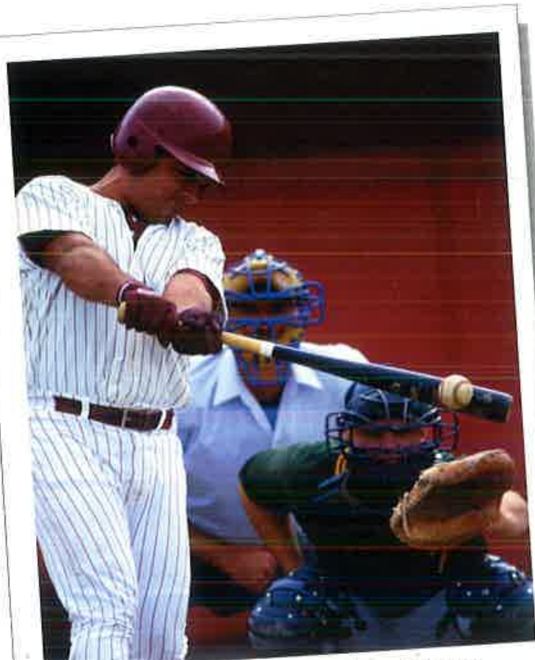


A fishing pole is a class-3 lever. The hand placed at the end of the fishing pole acts as the fulcrum, and the load is the fish that's caught at the opposite end. The hand between the fulcrum and the fish applies the effort. The hand applying effort moves a short distance to move the fish a longer distance. The cost is effort.



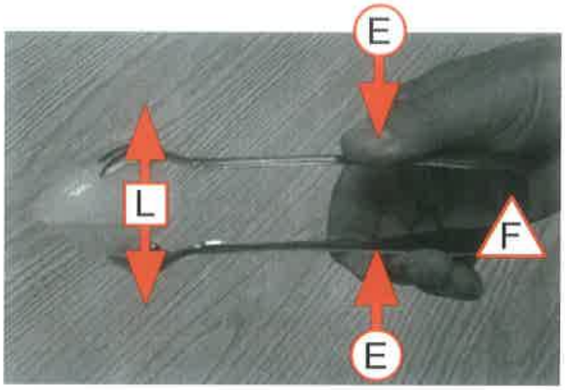
A fishing pole is a class-3 lever.

A hammer used to drive a nail is another class-3 lever. When you hold the hammer's handle, your elbow acts as the fulcrum. The load is the resistance offered by the material into which you are driving the nail. The hitting end of the hammer moves farther than your lower arm does to apply force. The hitting end gains not only distance but speed to do its job.



A baseball bat is a class-3 lever that provides a gain in both distance and speed.

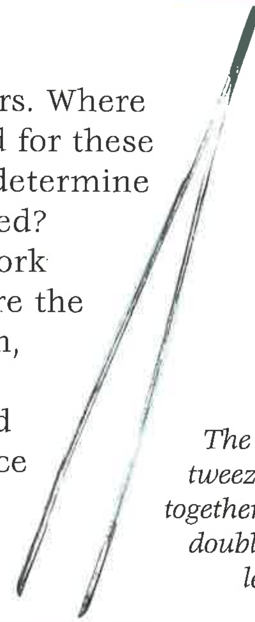
Many sports are played with class-3 levers. Baseball bats, hockey sticks, golf clubs, and tennis and badminton rackets all gain speed because the hitting end moves faster than your arm. Class-3 levers also include many tools. Shovels, pitchforks, hoes, and brooms are all class-3 levers. They provide a gain in distance. Your arms and legs



Ice tongs are an example of a double class-3 lever.

also work as class-3 levers. Where are the fulcrum and load for these class-3 levers? Can you determine where the effort is applied?

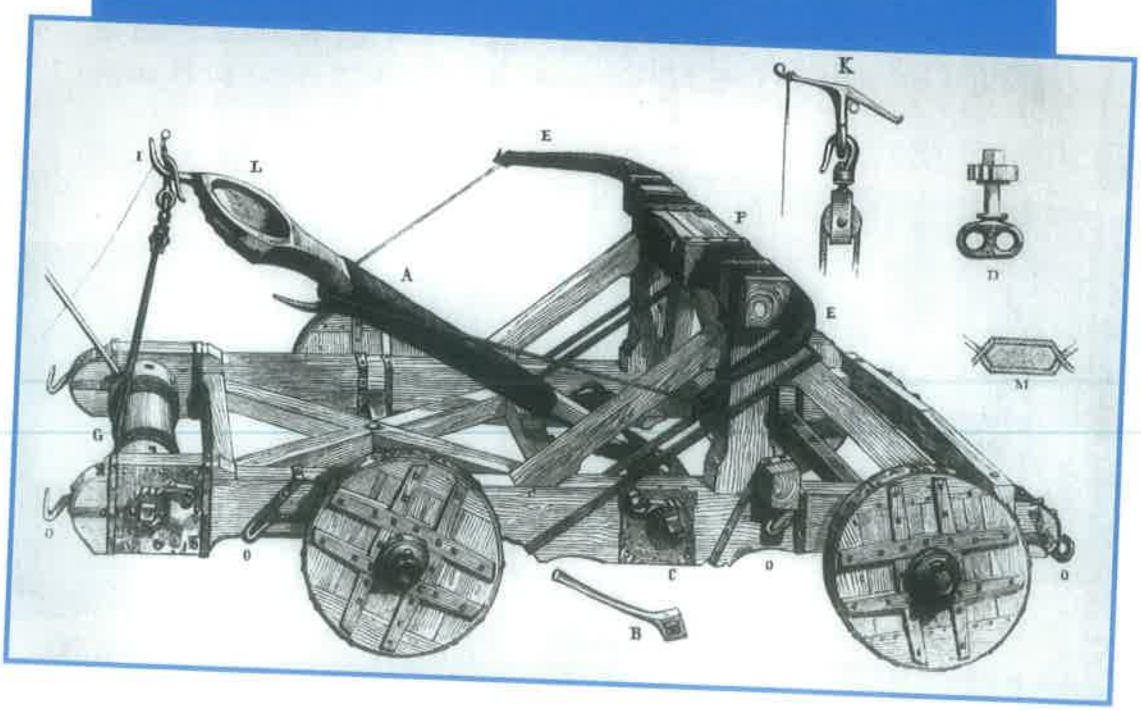
Class-3 levers can work together. The place where the levers join is the fulcrum, and the effort is applied between the fulcrum and the load. Tweezers and ice tongs are examples of double class-3 levers.



The arms of tweezers work together to form a double class-3 lever.

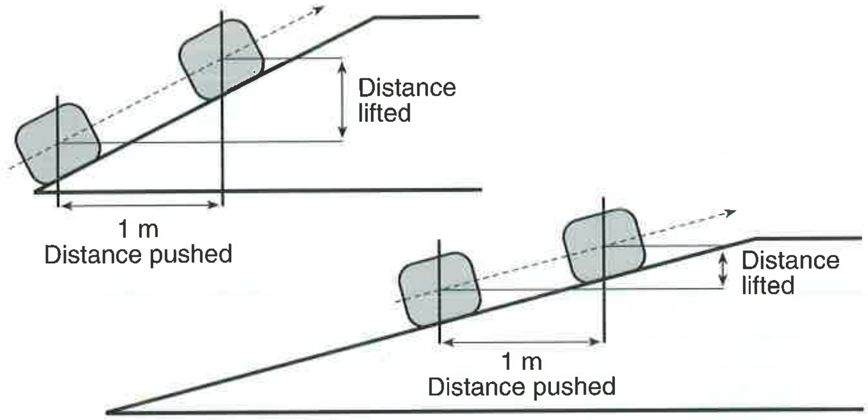
Catapults

In ancient times and in the Middle Ages, people used war machines called *catapults*. Some of them worked as class-2 and class-3 levers to shoot arrows or hurl heavy rocks. One end of the lever acted as the fulcrum. A rock load was placed at the opposite end of the lever. Beyond the load, a rope attached to a windlass (wheel and axle) pulled back the lever. This is a class-2 lever. When the rope was released, the lever propelled the load a long distance with great force. Can you see how the lever throwing the rock is a class-3 lever? Where are the load, the effort, and the fulcrum?



THE INCLINED PLANE

The word *plane* means "flat surface." *Inclined* means "sloped" or "at an angle." The inclined plane is a sloped, flat surface, or *ramp*. It's a one-part simple machine that doesn't move. The inclined plane offers a gain in effort when you are lifting a load. The cost is distance. The inclined plane is used to move things up. Pushing forward on the load makes it go up.



Imagine that you need to raise a heavy weight to a surface 1 meter (3.3 feet) higher than the ground. You can lift it straight up using great effort. You can also use less effort over

A wheelchair-access ramp is an inclined plane.

Lombard Street in San Francisco, California, is a twisting inclined plane that enables cars to climb a steep hill.

a longer distance by pushing the weight up a ramp. A short inclined plane has a steep angle. The angle of a long inclined plane is less steep. The longer the inclined plane, the less effort you need to move the load. However, a longer inclined plane requires you to move the load a greater distance.

A wheelchair-access ramp is an inclined plane. It slopes from the ground level to the level of a building's entrance. It's easier to roll a wheelchair up a ramp than it is to raise it one or several steps.

People who plan roads often take advantage of inclined planes. Rather than build a road straight up a steep hill, they design a road that cuts across the slope at a gentler angle. Although cars, bikes, and pedestrians must travel a longer distance, they use less effort to get to the top of the hill.

A Construction Aid

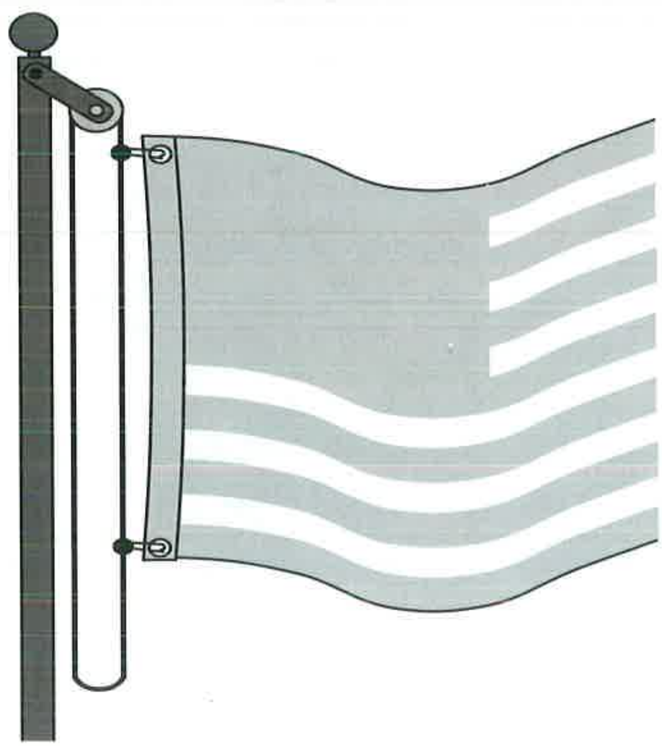
The Great Pyramid of Khufu in Egypt is as tall as a modern 42-story building. Many of the stones used to build the pyramid weigh several tons. People believe ramps were used to move the enormous stones into place. By the time the inner core was completed, the pyramid was probably completely hidden by ramps. It is believed they were removed as the outer casing of limestone was added from the top down.

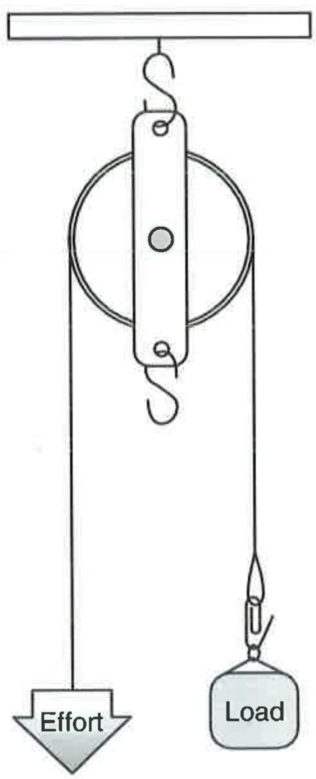
PULLEYS

A *pulley* is a wheel that is free to turn on an axle. The wheel is called a *sheave*. It has a grooved rim that holds a cord or rope. Like the wheel and axle, the pulley is a variation of the lever. It is a circular lever that rotates around its fulcrum.

Pulleys can be *fixed* or *movable*. The wheel of a fixed pulley turns, but the pulley itself does not move. It is attached to a bar, beam, or other solid, elevated position. A fixed pulley offers no mechanical advantage. The force you apply is equal to the force of the load. The distance you apply the effort is the same as the distance the load moves. A fixed pulley is useful because it changes the direction of effort. When you pull down on a rope, the load moves up. Many people find pulling down easier than pulling up. People can use their body weight when pulling down to lift a load.

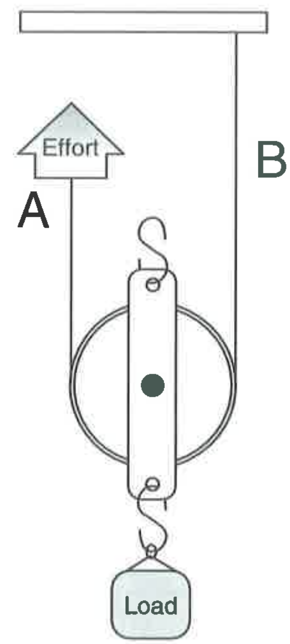
A fixed pulley is found at the top of a flagpole. The flag is attached to a rope which runs through the pulley and forms a loop. Pulling down on one side causes the other side of the rope to go up. The flag can be raised to the top of the pole and





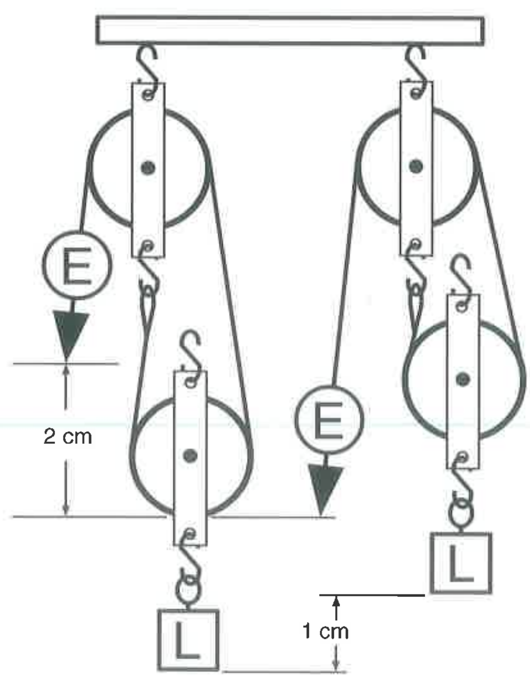
lowered again by a person on the ground. Fixed pulleys also raise and lower window blinds and sails on boats.

A movable pulley is attached to the load. One end of the rope is attached to a fixed surface high overhead. The other end of the rope goes down, through the pulley attached to the load, and then back up to the top. When you pull up on the other end of the rope, the load moves up. Though the movable pulley does not change the direction of effort, it offers a mechanical advantage. The load is supported by rope on both sides of the pulley. (See A and B in the illustration at right). That means half as much effort is needed to lift the load. You gain effort, but the cost is distance. You must exert effort twice as far as the load moves.



A fixed pulley and a movable pulley can be used together. Connected pulleys make a *compound pulley*. The rope runs up to the fixed pulley, down and around the movable pulley, and back up to where it is attached to a fixed surface on or near the fixed pulley. You gain both a mechanical advantage and a change in the direction of effort when you use this compound pulley. The fixed pulley allows you to pull down to move the load up. The movable pulley halves the effort needed to lift the load. Once again, effort must be exerted twice as far as the load moves.

A compound pulley system is called a *block and tackle*. The pulleys are *blocks* because early pulleys were carved from blocks of wood. The rope, cord, or chain used with pulleys is the *tackle*. The more pulleys there are in a block and tackle, the less effort is needed to raise the load. That's because the added pulleys provide more sections of rope to help support the load.



Using a compound pulley, effort must be applied over 2 centimeters to lift a load 1 centimeter.

Making a Fixed Pulley

What you need

An empty spool

A wire coat hanger

1 meter (3.3 feet) of ribbon wide enough to fit between the spool rims

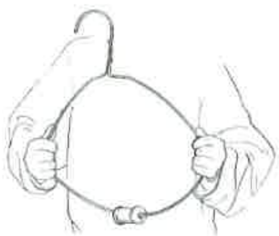
A bag with looped handles or a small plastic bucket

Small objects to lift

What you do

1. Untwist the wire to separate the two ends of the coat hanger. Be careful when handling the untwisted hanger. The ends can be sharp!

2. Thread the center of the spool over one end of the wire. Twist the wire back together. The hanger will again be a closed triangle shape, with the spool threaded onto the wire.



3. Grab the hanger at the two side corners of the triangle. Push the corners toward each other so that the wire begins to form a circle. Move the spool to the section of wire farthest away from the hook.

4. With the spool opposite the hook, continue to push the sides of the hanger together. Form the wire into a long, straight loop. Shape the wire so that the spool is held in place but is able to turn freely.

5. Hook the hanger onto a rod in a closet.

6. Tie one end of the ribbon to the bag handles or the handle of the bucket. Slide the other end of the ribbon over the spool.

7. Place the small objects into the bag or bucket. Now pull down on the free end of the ribbon. You have created a working pulley. Be careful not to let go of the ribbon while you have objects in the bag or bucket. The objects might fall and land on your toes!

DEAR BOSS

Dear Boss, I write this note to you
To tell you of my plight.
And at the time of writing
I am not a pretty sight.
My body is all black and blue
And my face a deadly gray.
And I hope you'll understand
Why Paddy's not at work today.

I was working on the 14th floor.
Some bricks I had to clear.
And throwing them down from such a height
Was not a good idea.
The foreman wasn't very pleased,
He being an awful sod.
He said I'd have to take them down
The ladder in my hod.

Now shifting all those bricks by hand,
It seemed so awful slow.
So I hoisted up a barrel
And secured a rope below.
But in my haste to do the job
I was too blind to see
That a barrel full of building bricks
Was heavier than me.

Now when I came down, I cut the rope.
And the barrel fell like lead.
And clinging tightly to the rope,
I started up instead.
I shot up like a rocket,
And to my dismay I found
That halfway up I met
The bloody barrel coming down.

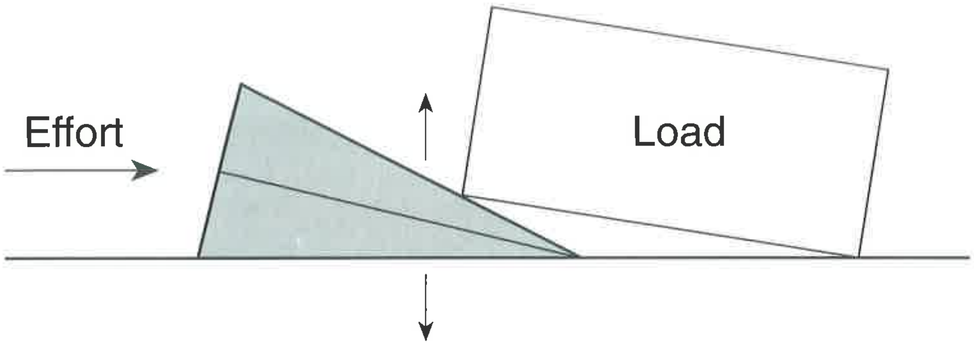
Now the barrel broke my shoulder
As to the ground it sped.
And when I reached the top, I struck
The pulley with my head.
I still clung on, though numbed and shocked
From this almighty blow,
And the barrel spilled out half the bricks,
Fourteen floors below.

Now when the bricks had fallen
From the barrel to the floor,
Sure I then outweighed the barrel,
And I started down once more.
Still clinging tightly to the rope,
I headed for the ground,
And I fell among the broken bricks
That were all scattered 'round.

As I lay there moaning on the floor,
Sure I thought I'd passed the worst
And the barrel struck the pulley wheel
And didn't the bottom burst.
A shower of bricks came down on me,
Sure I hadn't got a hope
And as I was losing consciousness
I let go the bloody rope.

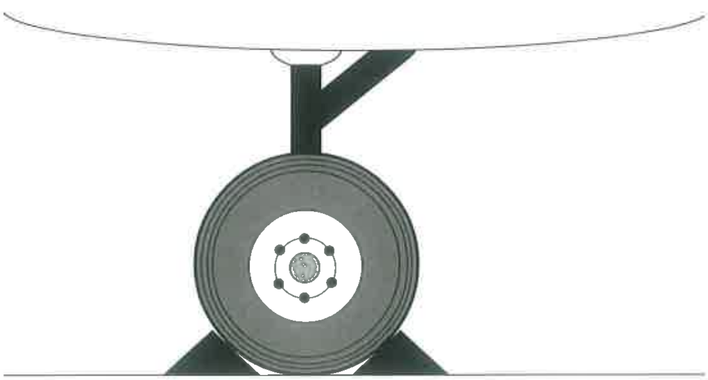
Now the barrel being heavier,
It started down once more.
And it landed right across me
As I lay there on the floor.
I broke three ribs and my left arm,
And I can only say
That I hope you'll understand
Why Paddy's not at work today.

THE WEDGE



The *wedge* is a variation of the inclined plane. It is really two inclined planes placed back to back. But while the inclined plane does not move, the wedge can. Effort applied to the wedge moves it forward. The wedge changes the direction of the force. When you push forward, the inclined planes of the wedge push up and down or side to side.

The wedge can be used in different ways. A box lying on the ground may be difficult to lift, but pushing a wedge underneath the box raises it. The wedge lets you get your fingers underneath the box to grab it more firmly.



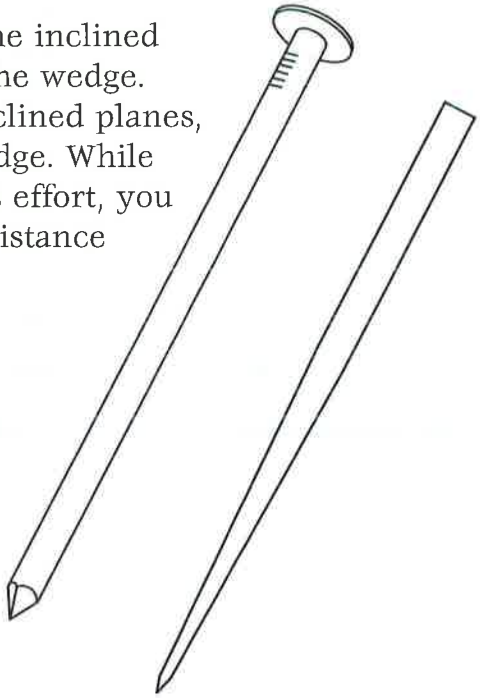
Airplane wheel blocks are wedges.

When a wedge is used as a type of doorstop, it holds the door in place. A wedge can be tapped into other spaces, as well. The inclined planes push up and down to hold the surfaces tightly in place. Airplane wheel blocks are wedges.

Wedges can also be used to push things apart. The end of a chisel is a wedge. When the chisel is tapped into wood, it splits the wood. The ends of needles, pins, and nails are wedges. So are the blades of cutting tools such as knives, axes, saws, and scissors. The bow of a ship works as a wedge to cut through the water. The blades of plows, hoes, shovels, and bulldozers are wedges that cut into dirt. A woodpecker's beak acts as a wedge to reach insects under wood!

The steeper the slope of the inclined planes, the duller the edge of the wedge. The gentler the slope of the inclined planes, the sharper the edge of the wedge. While the gentler slope cuts with less effort, you must push it through greater distance to do the work.

The blade of a chisel uses a wedge to penetrate wood or other materials.



Compare a nail and an ice pick. The steeper the slope of the inclined planes, the duller the edge of the wedge.

QUESTIONS TO EXPLORE

- **How is a wedge related to an inclined plane?**
- **What are some of the wedges you have seen in use?**
- **How does the slope of a wedge's planes affect the sharpness of a blade?**

THE WORK OF PULLEYS

This enormous power shovel uses pulleys to move huge quantities of earth at a mine in Hanna, Ohio.

Pulleys are used to do many kinds of work. Small pulleys can be found inside cuckoo clocks and the engines of cars. Larger pulleys are used on cable cars and ski lifts. Block-and-tackle systems are often located at the ends of long poles called *booms*.

Derricks and cranes use blocks and tackles. Derricks are used to drill for oil and in mining and construction. Movable cranes transport materials inside factories and warehouses. Tower cranes raise and move building materials into place. Overhead gantry cranes move heavy loads on and off ships and trains. Other cranes move logs, lumber, and farm equipment. Some heavy loads need to be moved in places that are hard to reach. A helicopter with a block and tackle can work like a flying tow truck in such places.

A *chain hoist* uses a chain looped around three pulleys. Two of the pulleys in a chain hoist are fixed together, and they are different sizes. When the two-pulley system rotates once, more links of chains pass over the large pulley than pass over the smaller pulley. The load moves a smaller distance than the chain is moved, but there is a gain of effort. Chain hoists easily lift engines from cars.

The pulleys that move ski gondolas are often hidden from view. However, they provide the mechanical advantage that allows this cable car to climb the steep slope.

A chain hoist can also lift an entire car. However, cars can be worked on more easily when they are pushed off the ground rather than pulled up. A *hydraulic lift* in a gas station allows the car to sit on a platform. This is safer and easier than hoisting the car into the air on pulleys.

Today *hydraulic systems* do much of the work previously done by pulley systems. Hydraulic systems are simple in design, have fewer moving parts, are smaller, and are easier to maintain. Hydraulic systems use fluid pressure to do work. Two fluid-filled cylinders are connected to one another by a rigid hose. When pressure is applied to one cylinder by pushing on its piston, pressure goes throughout the system. This pushes the piston out of the other cylinder. The second piston pushes, lifts, and moves a load.

Shiny silver cylinders can be seen on the arms of backhoes, under the scoops of earth movers, or lifting up cars for repair in garages. These are examples of

Large cranes use compound pulleys to lift heavy loads.

hydraulic systems at work. Hydraulic systems are much more efficient for powerful, precision lifting and pushing than the more traditional pulley systems.

QUESTIONS TO EXPLORE

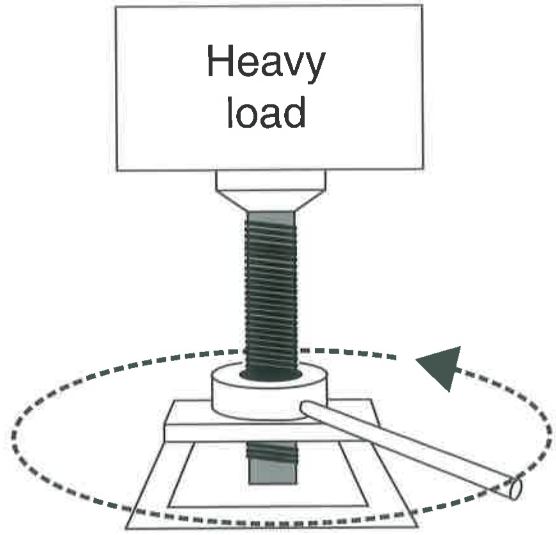
- **Where can pulleys be found in the real world?**
- **How does a chain hoist work?**
- **What modern invention has replaced pulleys?**

THE SCREW

Screws are inclined planes that change circular motion into forward motion.

Like the wedge, the *screw* is a variation of the inclined plane. A screw is an inclined plane spiraled around an axis or cylinder. Some screws such as the machine screw have a ridge (inclined plane), or *thread*, wound tightly around the central cylinder. Others such as the wood screw have more space between the threads. Still other screws such as fans and propellers have very short sections of inclined planes sticking out from the central axis.

Whatever the appearance, screws are designed to change the direction of effort. When a wood screw is placed against a piece of wood, turning the screw in a circle with a screwdriver makes the screw go down into the wood. Circular motion is turned into forward motion. This is how a rotating propeller on a power boat or airplane makes the vehicle go forward. In a similar way, if a propeller is held in a fixed position, when it rotates, it will push air forward. This is how a fan creates a nice current of air to cool you on a hot summer day.



A jackscrew

Screws can be used to produce mechanical advantage. People who lift houses in order to repair foundations use *jackscrews* for the job. A jackscrew is a threaded shaft with a platform on one end. A nut with a handle is screwed onto the threaded shaft and positioned on a solid base. When effort is applied to the handle, the screw changes the direction of the force upward. The effort applied to the handle is multiplied many times so that the jackscrew user can lift incredibly large loads.

Metal screws, nuts and bolts, vices, and C-clamps all use screws to hold things together securely. The mechanical advantage of a nut on a bolt (screw), combined with the mechanical advantage of a wrench (wheel and axle), provides a lot of force. That force is enough to hold together bridges, cars, trucks, trains, and heavy machinery under the most demanding conditions.

The Wood Screw

A wood screw holds materials together better than a nail does. The screw threads cut grooves into the wood. The grooves keep the screw from slipping.

When you put a screw into wood, you demonstrate several simple machines at once. The tip of the screw is a wedge that separates the wood. The ridges of the screw are an inclined plane. If you use a screwdriver to turn the screw, the screwdriver's handle acts as a wheel, while the tool's shaft and the screw act as an axle.

THANK YOU, MR. CLUMPET

Picture me, Kevin Hatcher, on summer vacation. I was staring out at the most beautiful bay this side of Pago Pago. Six small boats were rounding a buoy. The wind caught their sails, and they swayed in unison like a flock of exotic, white-winged birds. It was an awesome sight. But what was on my mind? School! Even worse, I was thinking about Mr. Clumpet, my science teacher! He'd been on my mind ever since I'd come to this sailing camp. Let me explain.

At least once a month, the kids in my science class had made the same complaint. "You're making us learn a bunch of useless stuff, Mr. Clumpet!"

He'd always lift his chin and smile without showing any teeth. "Mark my words," he'd say. "Someday you'll need to know the things I'm teaching you."

The boats were halfway back to the dock. My turn was next. It was the final of my sailing course. Rubbing my hands against my pants nervously, I knew Mr. Clumpet's "someday" had arrived. When Mr. Clumpet had taught us the unit on simple machines, levers, and pulleys, I wondered what he could have been thinking. I mean, what was I, a cave man?

No, I'd thought, when I needed to do something, I'd flip on a switch. I'd get some machine's motor revving. I wouldn't need any simple machines.

Of course, that was before Mom and Dad signed me up for sailing camp. It didn't take me long to decide they should have called it "simple-machine camp." When you're sailing, there just aren't any switches to flip or motors to rev.

On the first day of camp, Sue, the head instructor, took the class onto her own boat and gave us a tour. The boat was huge, and it had a cabin with bunks and a galley.

"My boat is steered with a wheel," Sue had said. *A wheel and axle*, I'd heard Mr. Clumpet say inside my head. "The boats you'll be learning on use a tiller." *That's a class-1 lever*, I'd heard Mr. Clumpet say.

"The sail is attached to a pole called the *boom*," Sue explained. "The boom is controlled by a block and tackle." *A pulley system*, Mr. Clumpet added.

"You raise the sail by pulling on the main halyard," Sue went on. *It works with a fixed pulley*, Mr. Clumpet explained. *The sail goes up like a flag on a flagpole*.

As Sue took us over the boat, I saw simple machines everywhere. There were turnbuckles to tighten the shrouds that kept the mast fixed. *Screws,* Mr. Clumpet said. There were winches to haul in the jib sheet, or forward sail. *More wheels and axles*. The bow was a simple machine itself. *Wedge-shaped to cut through water*. Even the toilet worked with a lever-operated pump! *Class-2 lever. Load between the fulcrum and effort*.

Sue had finished the tour saying, "By the end of the course, you should be qualified to crew on a boat like this. Here's my offer. Pass the final, and you're invited for a day's sailing."

I'd had mixed feelings about the course up until that point. I'd thought most of the boats I'd be sailing wouldn't be much bigger than a bathtub. But Sue's boat was something else. It made me think of tropical islands and sandy beaches, of treasure and pirates. I just had to pass the final!

All too soon, the boats were back. As I climbed into my boat, the sail flapped madly. Was the wind getting stronger?

"Okay," Sue called to my group. "You know the course. And don't worry. If you need help, Greg will come out to you in the motorboat."

As I checked to be sure my life jacket was strapped tight, my brain was suddenly awash with memories, all of them bad. I thought about the day I'd gotten stuck heading up into the wind. And the time I'd frozen and let a gust of wind overturn my boat. "Maybe," I thought, "Greg should rescue me right now." For a moment, I couldn't even remember what I was supposed to do first.

The wedge, Mr. Clumpet's voice said in my head.

"Huh?"

The daggerboard acts as a wedge in the water, Kevin. It keeps the boat from slipping sideways in the wind. Push it down into the water, and then use the block and tackle to haul in the sail. Look lively!

The first leg of the course was upwind. To reach the buoy, I had to cut back and forth at an angle to the wind. Three times, I levered the tiller to change direction and used the pulleys to adjust the sail. *Imagine how difficult it would be to move the rudder and control the sail without simple machines,* Mr. Clumpet pointed out.

When I passed the first buoy, I pushed the tiller starboard and came about. When the wind hit the sail, the boat heeled onto its side. *Let out the sail,* Mr. Clumpet advised. *The pulleys will give you enough strength to move it. Remember that simple machines give you a mechanical advantage.*

At the second buoy, I came about again. Only one leg of the course to go. I was running with the wind now, so all I needed to do was hold on to the tiller and steer my way home.

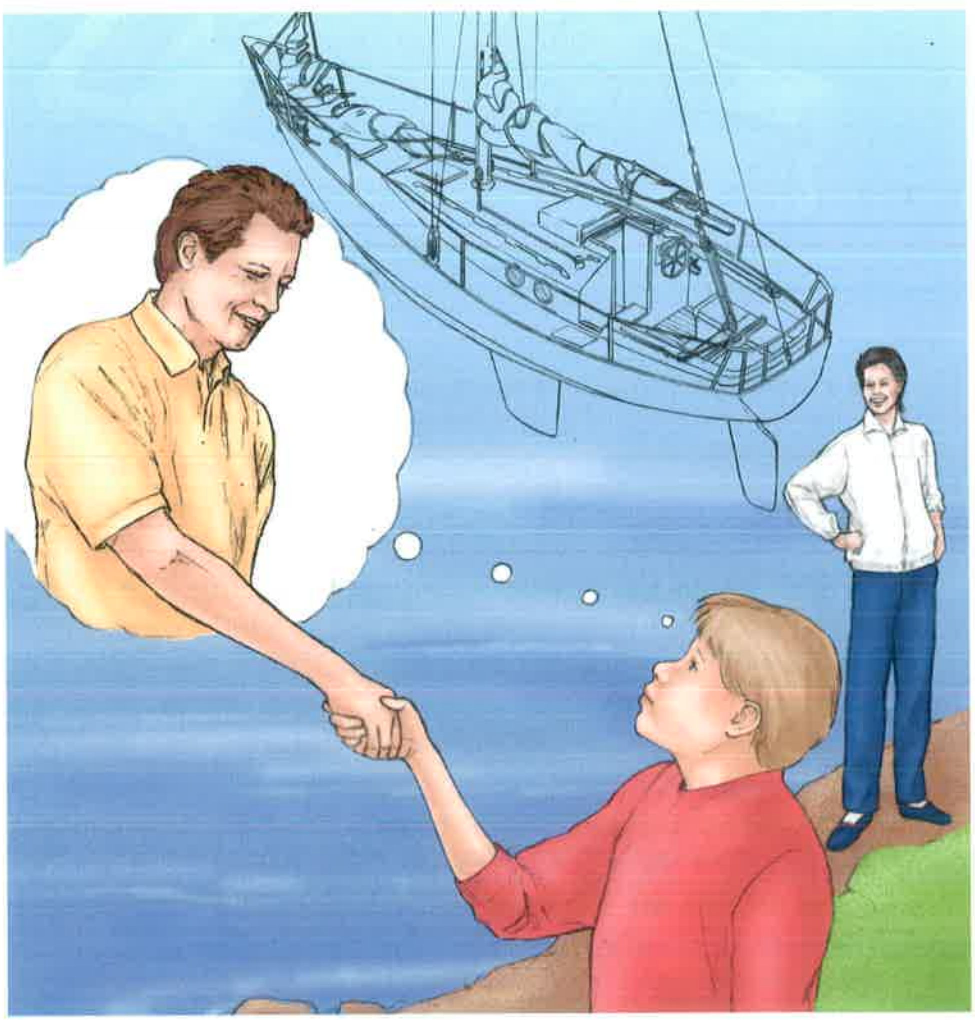
I pulled up the daggerboard when I reached shallow water. Then I sprang out of the boat to haul it onto shore. The boats were stored about 3 meters (10 feet) above water level. Dragging the boat up the sandy slope, I said aloud, "Now I'm using an inclined plane. Much easier than lifting the boat, eh, Mr. Clumpet?"

"Did you say something, Kevin?" said a voice behind me.

It was Sue. I shook my head and vowed to control my imagination better.

"I don't think I've ever seen you sail so well," Sue told me. "I'm going to have one capable crew member for my boat. Congratulations, Kevin!"

"Thanks," I said. And as Sue went off to help another camper, I added, "Thank you, too, Mr. Clumpet!"



GLOSSARY

Advantage A gain in effort or distance or a change of direction resulting from the use of a simple machine.

Axis An imaginary line that passes through an object or system, around which the object or system rotates.

Bellows A device that takes in air when the sides are spread apart and expels it through a tube when the sides are brought together.

Block and tackle Another name for a pulley system.

Catapult A large class-3 lever system used in ancient times to launch heavy objects.

Chain hoist A compound pulley system using chain instead of rope.

Class-1 lever A lever in which the fulcrum is between the load and the effort.

Class-2 lever A lever in which the load is between the fulcrum and the effort.

Class-3 lever A lever in which the effort is between the fulcrum and the load.

Complex machine A machine that is designed using a number of simple machines, often run by a motor.

Compound pulley Two or more pulleys working together.

Counterweight A weight or influence that balances another weight or influence.

Double lever A machine that uses two levers working together.

Effort The force applied to move a load using a simple machine.

Equal-arm balance A scale used to compare masses placed at equal distances from the fulcrum.

Fixed pulley A pulley attached in position above a load to be lifted.

Force A push or a pull.

Fulcrum The point at which a lever arm pivots.

Hydraulic Operated by means of fluid pressure.

Inclined plane A flat surface set at an angle, used to change the direction of a force.

Jackscrew A device used to raise extremely heavy loads, consisting of a platform sitting on top of a screw.

Lever A beam, free to pivot around a point, used to move a load.

Lever arm A beam, free to pivot around a point.

Load The weight or resistance that is moved using a simple machine.

Mechanical advantage A ratio of the load or resistance to the effort or force.

Movable pulley A pulley attached to a load that is being lifted.

Newton The metric unit used to measure force.

Piston A solid cylinder inside a cylindrical chamber, used to receive or transmit motion.

Pulley A wheel with a grooved rim in which a rope can run to change the direction of the pull and so lift a load.

Resistance An opposing force tending to prevent motion.

Screw An inclined plane spiraled around an axis.

Sheave A grooved wheel used in a pulley.

Simple machine Any of the six elementary devices (including levers and pulleys) that provide mechanical or other advantage.

Slope The slant of an inclined plane.

Thread A ridge or groove that spirals around a screw.

Wedge A double inclined plane that tapers to a point or sharp edge, used to change the direction of force.

Wheel and axle Two wheels of different diameters attached and rotating on the same axis.

Winch A wheel-and-axle system that has a cylinder on which a rope is wound.

Windlass A wheel-and-axle system used to apply force to a rope while winding it around the axle. A windlass can also be called a winch.