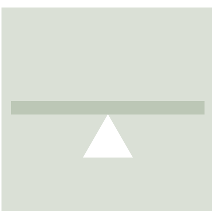
SIMPLE MACHINES

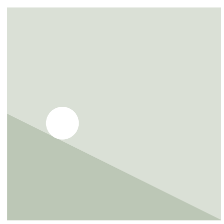
HANDBOOK

Machines are tools that help people do work more easily. In physics, you do work anytime you use force to move an object. Skateboards, cars, bikes, shovels, boats, doors, light switches, and stairs are all machines.

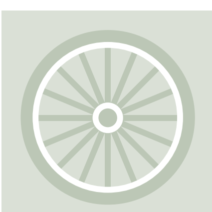
Simple machines are the most simple tools. There are six of them:



LEVER

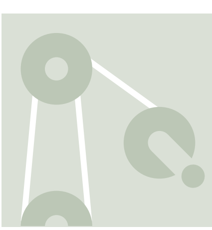


INCLINED PLANE

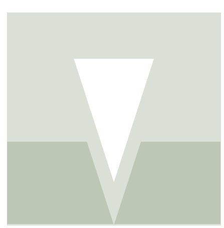


WHEEL & AXLE

SCREW



PULLEY



WEDGE

SIMPLE MACHINES MAKE WORK EASIER BY:

CHANGING THE DIRECTION OF A FORCE. When you raise a flag on a flagpole, you pull down on a rope wrapped around a pulley to raise the flag up.

CHANGING THE DISTANCE OF A FORCE. Imagine you need to move a heavy box up to the second story of a building. It'd be easier to carry it up an inclined plane (like a set of stairs) than to throw it straight up. But as you move the box up the stairs, it travels a longer distance than if you threw it straight up.

CHANGING THE STRENGTH OF A FORCE. A bottle opener is a lever. You can apply a weak force to pull the bottle opener up over a long distance and it exerts a short but strong force on the bottle cap.

Simple machines make work easier, but they don't lessen the work done. While they can change a force, they don't add to a force. There's always a TRADEOFF. If distance is gained, then the strength of the force lessens. If strength is gained, the distance a force travels lessens.

Simple machines need energy or a power source to work. In many cases, you supply the energy to apply a force by pushing or pulling, but energy can come from gasoline or electricity, too. All of these are INPUT FORCES. The machine's reaction or effect is the OUTPUT. The input and output, the total amount of energy, always remain the same.

A bike is a machine that makes getting somewhere easier (and more fun!) but it doesn't make getting there less work. You still have to pedal or push, and sometimes you have to push hard. But together, machines and people can get across town—or build boats and construct skyscrapers!

BEFORE YOU PLAY THE APP

Go on a scavenger hunt. What simple machines can you find in your home? In your classroom? In your neighborhood? Inside a complex machine?

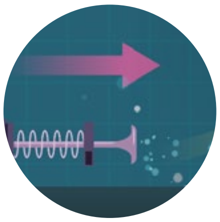
Make a list. Keep track of how many simple machines you use in a day.

IN THE APP

We encourage open play and discovery. Playing with each machine will reveal surprises and rewards that support learning. You and your kids will use a lever to destroy a castle, use inclined planes to make music, use pulleys to decorate the sky, use screws to lift fish tanks, use a wheel and axle to bike through an obstacle course, and use a wedge to break up an iceberg.

Observe each simple machine.

Identify the simple machine, what it does, and how it might be used. Try to identify the parts of the machine that help you do work.

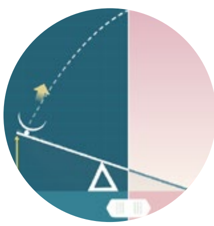


Push and pull, play with each machine.

Apply an input force by tapping or dragging each machine. Observe how the machine reacts to the input.

Make a change to each machine.

Alter each simple machine: move the fulcrum on the lever, add a pulley, change the length or height of an inclined plane, select screws with different threads, and try other wheel and wedge sizes. Notice how a change to a machine affects its response to your input force.



Move the slider to reveal how each machine does work.

Apply an input force on each machine and arrows trace your action and the machine's reaction or output.

The arrow indicates your input force on a machine. The more it fills, the stronger your force.

DISCUSSION QUESTIONS

What are the parts of each simple machine?

What work does each simple machine help you do?

What happens if you try to do the same work without the simple machine?

Have you used a machine like this?

What changes can you make to the machine? How does this affect the work you are doing?

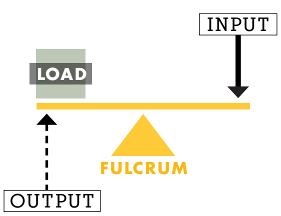
Lever

A lever is a bar that pivots from a fixed point called a fulcrum. Seesaws, wheelbarrows, and tweezers are all levers.

HOW DOES IT WORK?

Levers help lift, launch, and balance objects. There are three different types of levers, each of which help you do work in different ways:

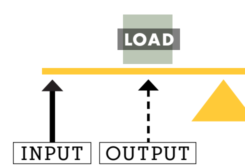
FIRST CLASS LEVER



A FIRST CLASS LEVER has a fulcrum somewhere in the middle, between your input force and the output force. It changes the strength, distance, and direction of your force. You can push down on one end and move a load up on the other side of the fulcrum. This is how a seesaw works. A bottle opener is another first class lever: you can push gently on a long lever arm to lift something forcefully for a short distance. Alternatively, you can give a powerful push on a short lever to move its other end a long distance.

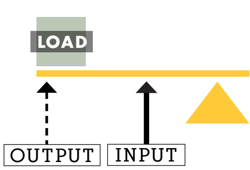
IN A SECOND CLASS LEVER, the output force, or the load being moved, is in the middle, between your input force and the fulcrum. A second class lever changes the strength and distance of your force (unlike a first class lever, the direction of your force does not change). Think of how a wheelbarrow works: as you pull up with a small force over a longer distance from one side of the lever, a heavy load in the middle moves up a smaller distance, more easily, while the fulcrum rests on the other side.

SECOND CLASS LEVER



IN A THIRD CLASS LEVER, your input force is applied in the middle, while the load (or output) and fulcrum are at either end. It changes the distance and strength of your force. As you apply force over a shorter distance at the middle of the tweezers, they move something at the end opposite to the fulcrum over a longer distance, with less strength. Or in other words: more delicately. This is why tweezers are great for tasks our hands are too clumsy for.

THIRD CLASS LEVER



What's the tradeoff?

You can push gently on a long lever to lift something heavy but only for a short distance. To move something a long distance, you have to apply a powerful input force on a short lever.

Some levers exert an output force in the opposite direction of the input force, and some exert force in the same direction.

IN THE APP

Push down on the lever.

What happens to the ball?

As you push down or apply an input force on one end of this lever, the other end moves up. You are able to raise something more easily—or in this case, launch something into the castle—by pushing down with gravity to assist.

What class of lever is this?

The fulcrum is in the middle of the input and output forces so this is a first class lever.

Move the fulcrum and push down on the lever.

What happens to your input force when it is applied closer to or farther from the fulcrum?

When the input force is applied closer to the fulcrum, you have to apply a greater force over a shorter distance, but you are able to move the load on the other side a greater distance. This is how a catapult works.

If you move the fulcrum farther away from your input force and closer to the output, you can apply a small force over a longer distance and the strength of the output force will be greater. This is how a bottle opener or crowbar works.

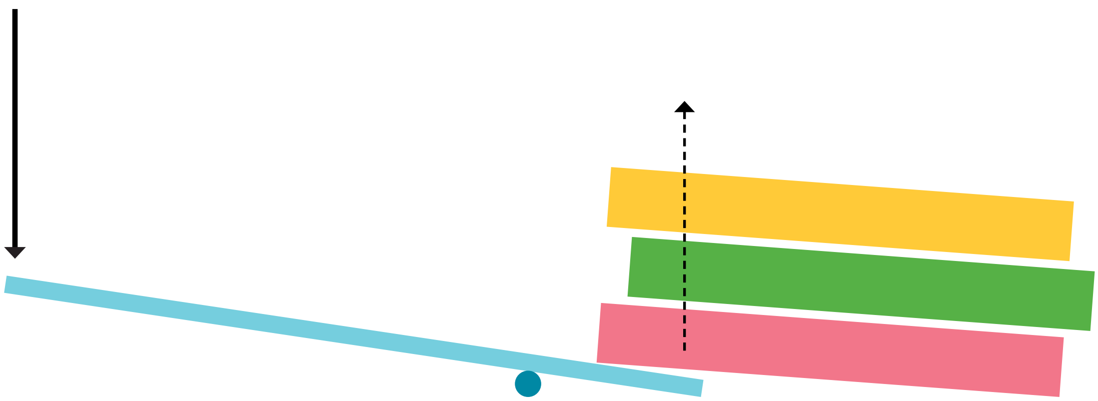
Notice how in both cases, the lever can change the distance and strength of force but does not add any energy to your action.

FURTHER LEARNING
DISCUSSION QUESTIONS

Find a lever in your home and use it. Where is the fulcrum? Where are you applying an input force and where is the output? What class of lever is it?

Levers are used in many sports. Can you think of any levers that athletes use?

EXPERIMENT



YOU NEED:

A FIRM RULER (OR OTHER LONG, FIRM, FLAT OBJECT)

A PEN OR PENCIL

A STACK OF BOOKS

MAKE A LEVER

1. Ask your child to use both hands to lift a stack of books up two inches.
2. Ask if they could lift the books with just two fingers.
3. Slide about two inches of the ruler under the stack of books.
4. Slide a pencil perpendicular to and under the ruler, close to the stack of books but not under it.
5. Hold the pencil in place and ask your child to push down on the ruler with two hands, then with two fingers, and then with one finger.

How many hands or fingers does your child need to lift the stack of books when using the ruler and pencil as a lever? Does it feel easier or harder to lift the stack of books when using the ruler as a lever instead of lifting them straight up?

Wheel and axle

A wheel and axle is just that, a wheel that turns on an axle. An axle is a cylinder that keeps the wheel in place. On a bike, the axle attaches the wheel to the bike frame. Without the axle, the wheel would eventually slide away.

HOW DOES IT WORK?

A wheel and axle helps you move a load, or yourself (or both!), by changing the strength and distance of a force. You can apply a strong input force over a short distance to an axle and move a wheel a longer distance. Or you can apply a weaker input force over a longer distance to a wheel and move an axle with a strong output force.

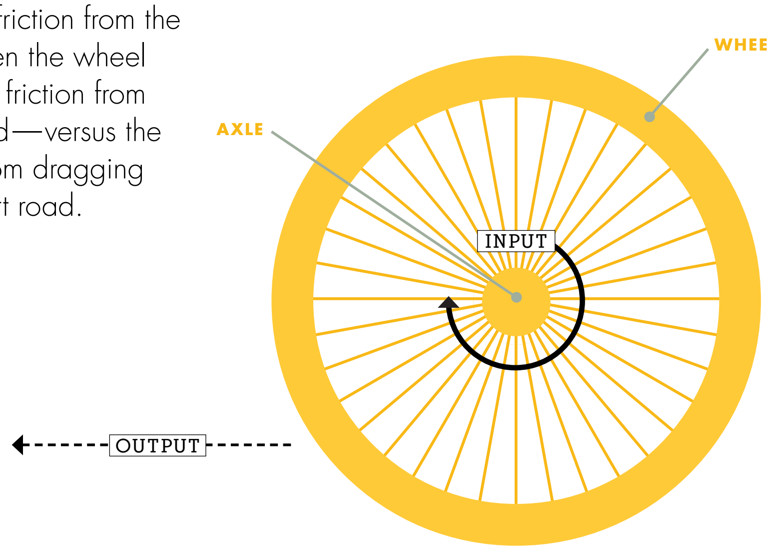
A wheel and axle also changes the direction of a force. As you sit on a bike and turn the pedals in a rotary motion, in circles, the bike moves forward linearly.

A wheel and axle also makes work easier by helping to move things with less friction. A wheel has less contact with the ground than something flat which eliminates friction from dragging.

What's the tradeoff?

Different sized wheels are helpful for different situations. Given the same input force, smaller wheels will have more output force but will travel a smaller distance, while bigger wheels will have less output force but will travel a greater distance.

Also, while wheels help minimize friction from the ground, there is still friction between the wheel and axle, though it is less than the friction from the ground and can be anticipated—versus the friction that might be generated from dragging instead of rolling over a bumpy dirt road.



IN THE APP

Spin the axle.

What happens?

As you are spinning the axle, you are applying a lot of force over a small distance to make the wheel move a greater distance.

What direction is the axle spinning? And what direction is the cyclist moving?

As you apply an input force on the axle in a circular motion, the cyclist, whether he's on a bike or scooter, moves forward linearly. The direction of force is changed by the wheel and axle.

Tap and select different wheels.

How does the shape of the wheel affect how well it works?

Even though the square wheel is attached to the axle in the same way that the round one is, it is not able to move continuously as a round wheel does. Even if you were able to muster enough force to turn a square wheel continuously, your ride would be bumpy!

Whenever one surface contacts another, there is friction, a force pushing in the opposite direction of your input force. Unlike the square wheels, round wheels only contact the ground at a single point of their surface as they turn; they do not generate very much friction from contact with the ground.

In general, more input force is needed to spin larger wheels and less to move smaller ones. While larger wheels cover more distance with each complete turn, you must use more force to maintain a fast speed.

When you push on a scooter, how a wheel and axle is used is reversed. As you push with your foot, you apply a smaller input force over a longer distance around the wheel and in turn move the axle with a larger output force.

Bike over obstacles.

What size wheel works the best?

As you ride along with the cyclist, you will encounter hills, ramps, and jumps. Observe how different size wheels respond differently to these different obstacles.

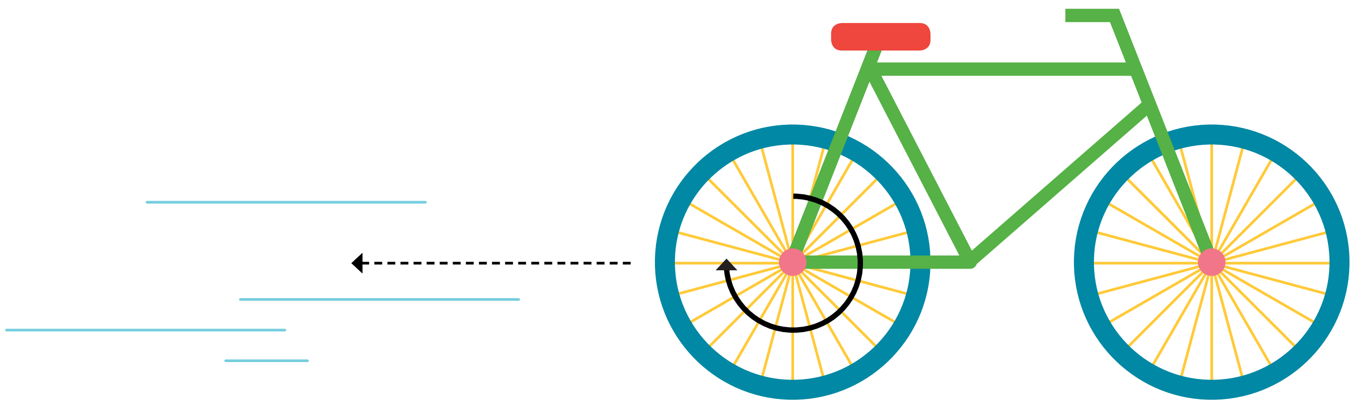
With larger wheels, you're able to climb higher up hills with each turn of the wheel. More force per turn is required than with smaller wheels, but smaller wheels only ascend a short vertical distance with each input force.

FURTHER LEARNING
DISCUSSION QUESTIONS

The wheel and axle is considered a type of lever. Where do you think the fulcrum is? Where is the resistance? Where is force applied?

Why are wheels always round?

EXPERIMENT



YOU NEED:

A BIKE, SCOOTER, OR SKATEBOARD

SEE AND FEEL HOW A WHEEL AND AXLE WORKS

1. Ride a bike, scooter, or skateboard with your child.
2. Notice which direction you're applying an input force.
3. Notice which direction you're moving.

On a bike, the input force is applied in a circular motion, around and around as you pedal. The wheel and axle changes the direction of your force so you move forward in a line. With every pedal, you apply a strong input force over a short distance on the axle to move the wheel a greater distance with less force.

On a scooter or a skateboard, you push down on the ground to move forward. Again, the direction of your force is changed. But, the wheel and axle in a scooter or skateboard work in the opposite way a bike does. You apply a weaker force over a longer distance around the wheel and the axle turns a shorter distance with more force.

Pulley

A pulley is a rope wrapped around a wheel. Flagpoles and piano movers (sometimes!) use pulleys.

HOW DOES IT WORK?

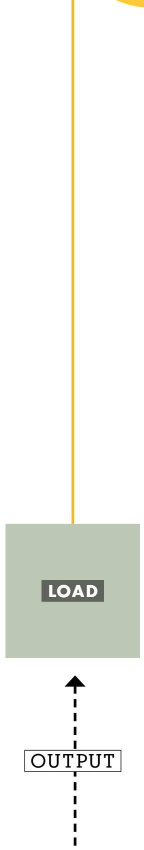
Pulleys help lift or otherwise move a load. You can use a pulley to raise a flag up a flagpole by pulling down. Pulleys can make work easier by changing the direction of your force. When you use a pulley to move something up by pulling down, you get extra assistance from gravity. Imagine instead trying to climb straight up a flagpole with a flag in hand to pin it to the top!

Pulleys also change the strength and distance of an input force. You apply a lesser input force over a greater distance to move a load with more strength a shorter distance. To lift or move heavier loads, you can use more pulleys, but you also need to add more rope. If you double the number of pulleys, you have to double the rope and double the length of the distance over which force is applied.

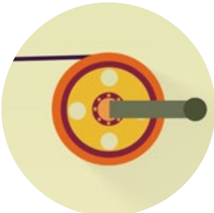
What's the tradeoff?

A pulley can make it easier to lift something heavy with a small force applied over a long distance of rope. While you're pulling or applying force over a much longer distance than the load moves, it's usually easier to add more rope than to apply a larger force.

Pulleys can be pretty powerful tools. Archimedes used pulleys to defend Syracuse with a machine called the Claw of Archimedes. It could tip ships over or pick them up out of the water and drop them on rocks.



IN THE APP

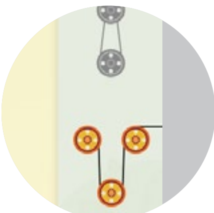


Drag the pulley to an object and spin the winch to raise it.

How does the pulley help you do work?

Pulleys can help move objects up. You apply an input force by pulling down on a rope, and the rope wrapped around the fixed pulley lifts a load up. With a fixed pulley, you can apply force in one direction to move an object in a different direction.

But here you don't just pull the rope down. You use a winch to pull the rope. As you wind the winch, you tighten the rope of the pulley system. As the rope shortens, the object attached to the pulley is raised.



Tap to select and add movable pulleys to the single fixed pulley.

What's the difference between movable and fixed pulleys?

Fixed pulleys are attached to a wall, ceiling, or other fixture. They don't move when you use them.

Movable pulleys are attached to the load you're lifting. They move as the load moves.

How does the number of pulleys affect what you're able to lift?

With multiple movable pulleys, you're able to move heavier loads. But each movable pulley requires a doubled rope. The doubled rope causes the load to move up by half the distance that the rope is pulled. Since it moves half the distance, the strength of the force is doubled. So, while you'll have to pull a longer distance to raise an object the same distance, it'll take less force to do it.

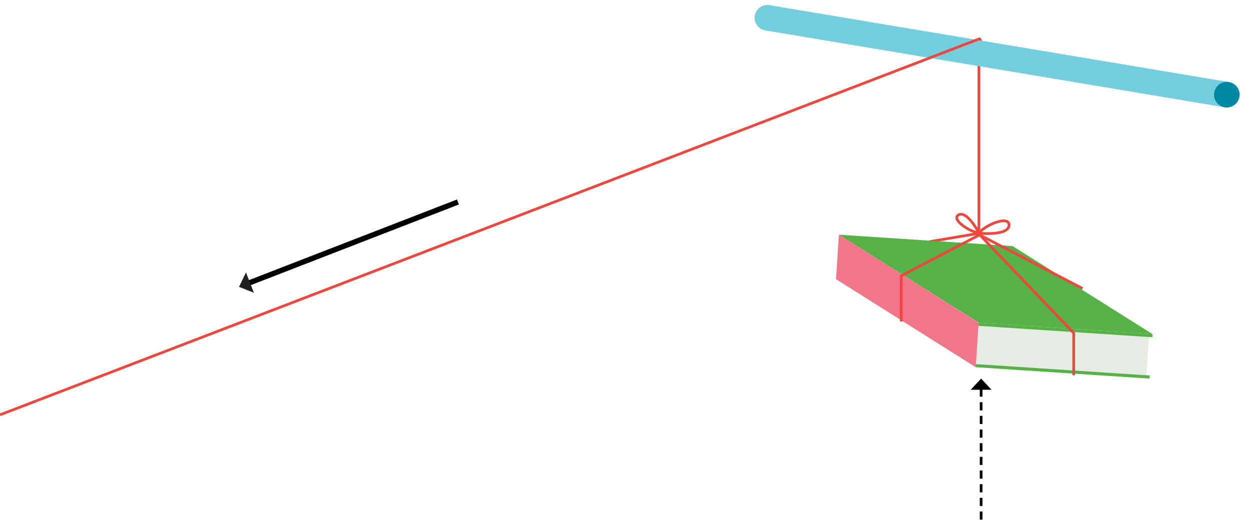
FURTHER LEARNING

DISCUSSION QUESTIONS

Can you think of any chores you do which might be easier if you used a pulley?

What pulleys can you find in your home? In your neighborhood? At school?

EXPERIMENT



YOU NEED:
A LONG STRING
A ROCK, BOOK, OR OTHER HEAVY OBJECT
A RAILING OR BANISTER

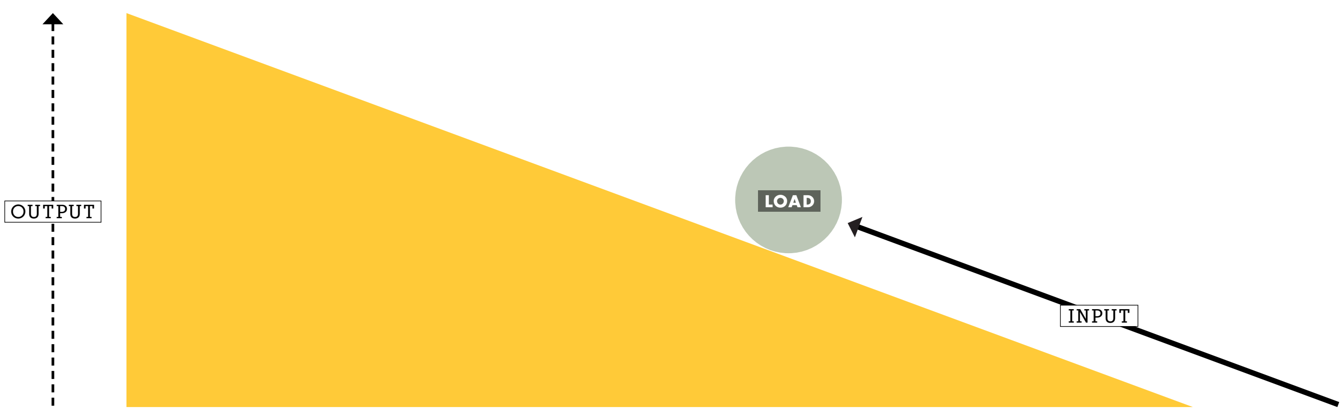
BUILD A SIMPLE PULLEY

1. Tie the string around your heavy object.
2. Try to lift the object straight up with the string. Is it easy or difficult to lift?
3. Loop the loose end of the string not tied to the object around the railing or banister.
4. Pull down on the loose end of the string to pull the object up.

Was it easier or harder to lift the object on the string once it was wrapped over the banister or railing? How did the pulley help you do work?

Inclined plane

An inclined plane is a flat surface with one end propped up higher than the other, like a long piece of wood resting on a ledge. A hill and a flight of stairs are also inclined planes. Inclined planes may have been used to move heavy stones to help construct ancient structures like the Pyramids.



HOW DOES IT WORK?

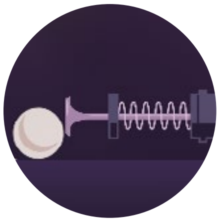
An inclined plane helps you raise or lower something gradually. It changes the direction and distance of your force. You can apply a horizontal input force over a greater distance to raise a load a shorter distance vertically.

Imagine trying to lift a box straight up from the first to the second story of a building. You'd need to use a lot of force to do a lot of work over a relatively short distance. Instead you can take the stairs and raise the box from one floor to the next gradually, over a longer distance.

What's the tradeoff?

Instead of applying a large force over a short distance, you do work by applying a smaller force over a longer distance.

IN THE APP



Tap, hold, and release the springs in the lower corners to launch the pinballs up the inclined planes.

How high do they travel?

The longer you hold a spring, the more force it releases. The pinballs are heavy (try dragging one straight up with your finger) but the inclined planes help lift them.

Drag an inclined plane to lengthen and shorten it.

How much force is needed to move the pinballs up a short, steep plane? How much force is needed to move them up a long, gradual plane?

With a short, steep plane you need a big force to move the pinball up. While more force is required, the pinball travels a shorter distance and takes less time to do so.

With a long, gradual plane, you can use a little force to move the pinball up. But while less force is required, it takes more time for the pinball to travel a longer distance.

While the length of the inclined plane can vary, its height is always the same. Because you are always sending the pinball up the same height, you're always doing the same amount of work.

Drag and adjust the smaller, floating inclined planes.

How does the angle of these inclined planes affect the movement of the pinballs?

As you adjust the angle of these planes, you change their vertical height. Unlike the inclined planes sitting at the bottom, theses planes can send the pinballs up shorter or higher distances. Planes with a steeper angle send the pinballs up a greater vertical distance but require more work, or a greater input force, to do so.

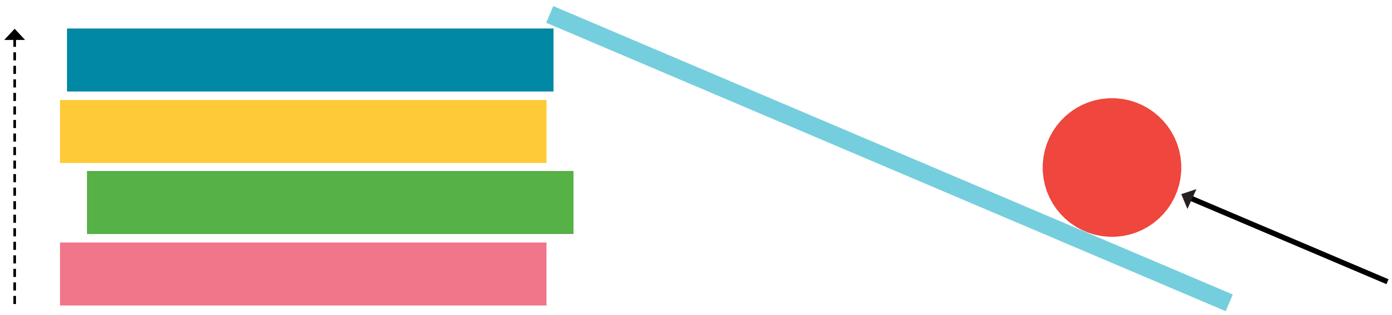
FURTHER LEARNING
DISCUSSION QUESTIONS

Why are a staircase and a hill considered inclined planes?

If you were moving a bunch of stuff from the first floor to the second floor of a building, would you rather move your items up a short ramp or a long ramp? Which one would be easier? Which would be faster?

When else could you use an inclined plane to help you do work?

EXPERIMENT



YOU NEED:

- A STACK OF BOOKS, 4–6 INCHES TALL
- A FIRM RULER (OR OTHER LONG, FIRM, FLAT OBJECT)
- A ROUND, HEAVY OBJECT LIKE AN ORANGE, PAPER WEIGHT, OR BALL

MAKE AN INCLINED PLANE

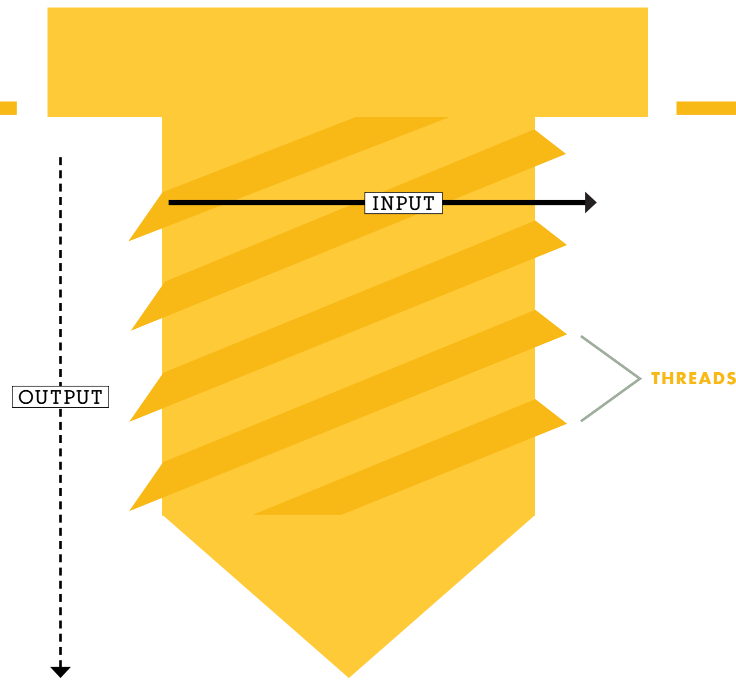
1. Prop the ruler up on the books so that one end rests on the top of the books and the other on the ground.
2. Ask your child to use two fingers to pinch the object and lift it to the top of the stack of books.
3. Ask your child to use two fingers to roll or slide the object up the inclined plane.

Is it easier or more difficult to lift the object than to roll it up the ramp?

It requires less force over a longer distance to roll the object up the ramp, but some kids might say that it's easier to lift the object. Ask them if their answer would change if the object were very heavy and the height to which they were lifting it was very high.

Screw

A screw is an inclined plane wrapped around a cylinder. A wall screw, a threaded jar lid, and a screw jack are all examples of screws.



HOW DOES IT WORK?

A screw is used to hold two things together, to raise, or to lower something. It changes the distance and the direction of your force. You can apply a little input force over a longer distance to turn a screw in circles and it moves a shorter distance up or down.

Apple cider, grape juice, and wine are traditionally made using a screw press. Fruit is placed in a large bucket and a screw is turned many times to lower the bucket's lid a short distance and keep it down to press the fruit and squeeze juice from it.

What's the tradeoff?

To put even a short screw into a wall, you have to turn it in many circles. You spend more time turning the screw over a longer distance, but it's easier than pushing the screw straight in the wall.

Also, because you can turn a screw to make it go into a wall, but you can't push a wall into a screw and make it turn, screws are self-locking. This makes them good for holding things in place.

IN THE APP

Swipe right to twist the screws and raise the fish tanks.

As you apply a small input force over a longer distance to turn a screw in circles, it pushes up or down with a greater output force over a shorter distance. Here, the screws lift or lower heavy tanks.

Tap to select and use different screws.

What's different about how they look and how they work?

Each screw has a different number of threads. A screw with a lot of threads winding at a lower angle is called a fine screw. A screw with fewer threads winding at a steeper angle is called a coarse screw.

A fine screw is like a long inclined plane wrapped around the cylinder. It can bear more weight over a longer distance to help you raise or hold something heavy, gradually.

But there is a tradeoff: each thread is an additional source of friction, making fine screws more difficult to turn. Coarse screws turn more easily but can hold less weight. You might use a coarse screw for something like a jar lid or a light bulb base. In those places, you want a screw that requires relatively little force to turn. But, friction isn't always a bad thing: it's also what makes screws self-locking.

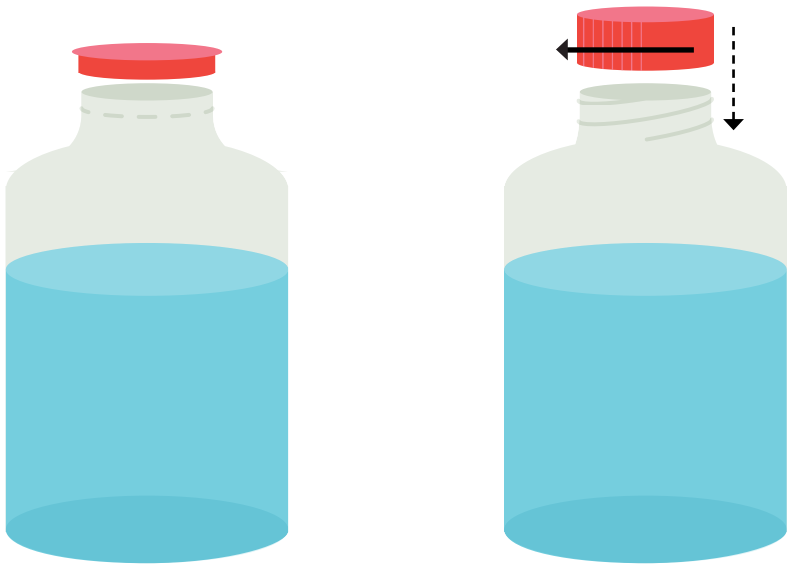
If you remove the threads from a screw, you remove the inclined plane. So, really, it's no longer a screw and doesn't offer any help in lifting a load or holding two things together.

FURTHER LEARNING
DISCUSSION QUESTIONS

When have you used a screw to hold two things together? To lift something?

Why is a screw like an inclined plane? How do they work similarly? How do they work differently?

EXPERIMENT



YOU NEED:

2 PLASTIC BOTTLES, 1 WITH A SCREW TOP AND 1 WITH A PUSH TOP (IF YOU CAN'T FIND A PUSH TOP, GET 2 SCREW TOPS)

WATER (TO FILL THE BOTTLES)

TEST OUT SCREWS' SELF-LOCKING ABILITIES

1. Fill the water bottles.

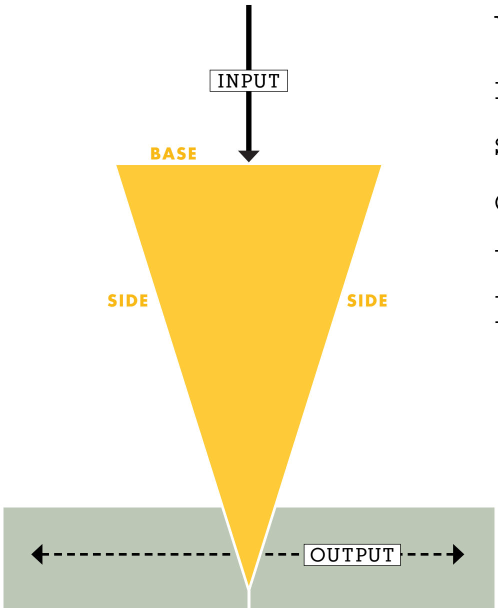
2. Push the top closed on one bottle and screw the top closed on the other.

3. Go outside!

4. Drop the bottles.

Which bottle stays shut and which bottle bursts open?

Wedge



You can think of a wedge as two inclined planes that meet at a point. Teeth, axe blades, knives, and door stops are all wedges. If you look closely at the front of a boat or airplane, you might notice wedges there, too. They help cut through water and air as a knife helps cut through bread.

HOW DOES IT WORK?

A wedge helps separate two objects, split an object in two, lift an object, or hold an object in place. It changes the direction of your force. You can apply an input force in one direction to its base and it applies an output force in two different directions from its two sides.

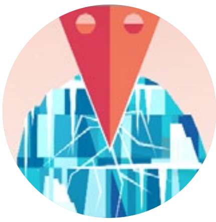
Wedges are especially helpful because a pushing force turns into a splitting force. It's much easier to split an apple with a knife than it would be to push or pull it apart with your hands.

A wedge also changes the distance and strength of your force. Your input force is applied over a longer distance and the output force is greater but applied over a shorter distance.

What's the tradeoff?

Wedges help you apply a strong force over a short distance, and in a different direction than the force was applied. So, they're good for moving heavy or strong things a short distance apart, but they're not very helpful for moving things long distances.

IN THE APP



Apply force to drive the wedges into the icebergs.

What makes the shape of the wedge useful for cutting and separating things?

The two sides of a wedge help you split an object or separate multiple objects. When you apply an input force to the base of the wedge, the wedge's output is an outward push from its two sides.

How does the output of a wedge with a thin base differ from the output of a wedge with a fat base?

Apply a little force to a wedge with a thin base and it will split an object easily. The input force travels down a greater distance (the height of the wedge) than the output force travels out (the width of the wedge). So the output force from the sides of the wedge is greater than the input force applied to the base.

A wide wedge can still help you do work. You might be able to split something faster with a wide wedge than you would with a thin one. But you will need to apply a bigger force to split an object with a wide wedge.

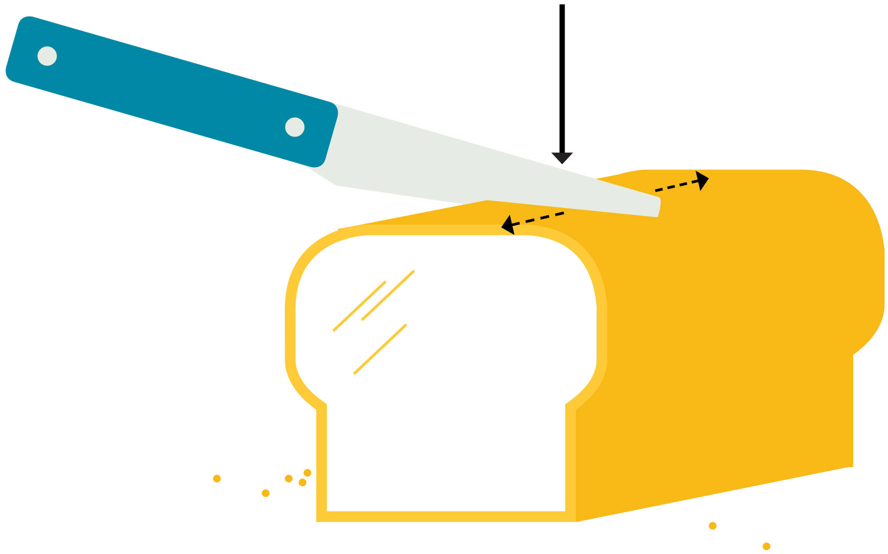
FURTHER LEARNING
DISCUSSION QUESTIONS

What would happen if you tried to split an object without a wedge?

Can you think of any items in your home that are shaped like a wedge? How do you use those items?

Why do you think a wedge is sometimes called a version of an inclined plane?

EXPERIMENT



YOU NEED:

A BUTTER KNIFE OR FORK (CHOOSE A UTENSIL THAT YOU ARE COMFORTABLE WITH YOUR CHILD HANDLING)

BREAD, CLAY, OR AN APPLE (CHOOSE AN OBJECT YOUR CHILD CAN CUT)

SEE HOW A WEDGE WORKS

1. With your child, try splitting or cutting the object in half without using the wedge.
2. Identify which part of the utensil is the wedge.
3. Use the wedge to split or cut the object in half.

Were you able to split or cut the object without the wedge? Was it harder to do? Why? Why would you use different wedges for different tasks? Would you use a fork to cut something and a knife to pick up something to eat? Why or why not?

SOURCES

BASIC MACHINES AND HOW THEY WORK, NAVAL EDUCATION AND TRAINING PROGRAM

CHICAGO MUSEUM OF SCIENCE AND INDUSTRY, SIMPLE MACHINES PRE-VISIT ACTIVITIES
www.msichicago.org/fileadmin/Education/exhibitguides/SM_PreVisit.pdf

HOW TO SMILE
www.howtosmile.org/

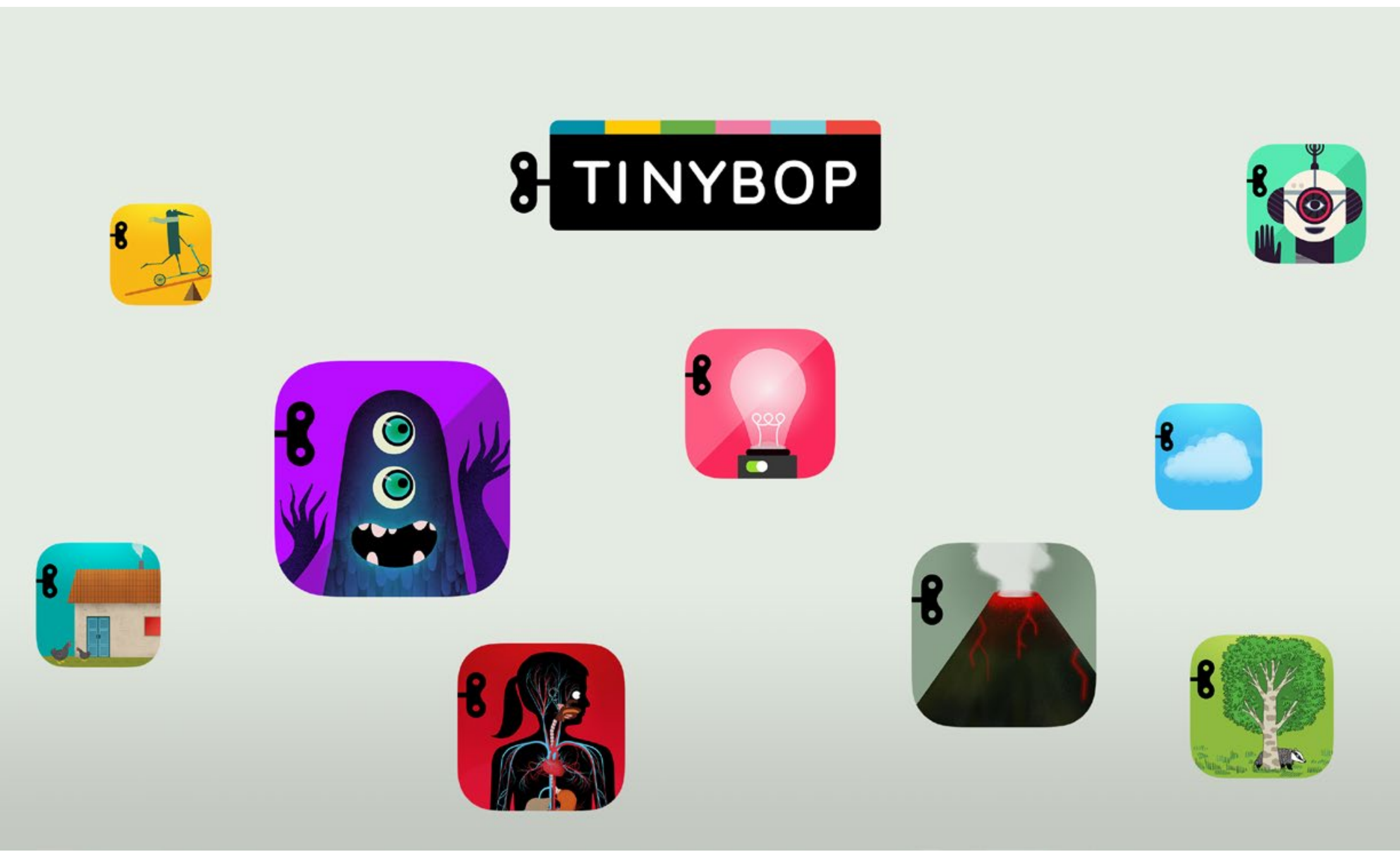
MILTON J. RUBENSTEIN MUSEUM OF SCIENCE AND TECHNOLOGY, SIMPLE MACHINES
www.most.org/curriculum_project/simple_machines/elementary/prior/simple_machines_prior.pdf

SEAN SPILLANE, MECHANICAL ENGINEER, FOUNDER OF BK BOTS
www.bkbots.com

Thanks for playing SIMPLE MACHINES.

If you have feedback or questions about the SIMPLE MACHINES Handbook, let us know at support@tinybop.com.

To keep learning and exploring, follow us on Twitter, Facebook, and Instagram, and take a look at our blog.



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