

# Robotics Engineering

## DoDEA Career and Technical Education

### BUILDING SIMPLE MACHINES

#### Discussion:

Imagine that you're riding a ten-speed bike and a large hill is looming ahead of you. You reach down to your shifter and shift into "low gear" to climb the hill. After you've shifted gears, you are pedaling faster and the bike is moving slower. But you have more power; you've converted the speed of your pedaling into the power needed to climb the hill. Now you've reached the top of the hill, and a long straight downhill beckons ahead of you. You shift into "high gear", and begin to cruise down the hill. You're not pedaling very fast, but your bike is going at a rapid clip. You think, "Each one pedal turn with my legs makes the back wheel turn many times!"



Let's examine the gearing in these two situations – high gear and low gear on a bike. When we're in low gear, we want high power to climb the hill. Speed is less important, so we trade it for power. Each one pump with our legs turns the rear wheel once. When we're in high gear, we want maximum speed. Power is less important because the gravity of a clown hill is giving us a boost. We select high gear, and each pump gives us ten turns of the rear wheel. This characteristic demonstrates mechanical advantage achieved by sacrificing speed (evolutions) for power (torque) in low gear and torque for revolutions in high gear. If you have a bike, give it a ride. Think about how you choose different gears, and how much speed or power you get.

#### Introduction

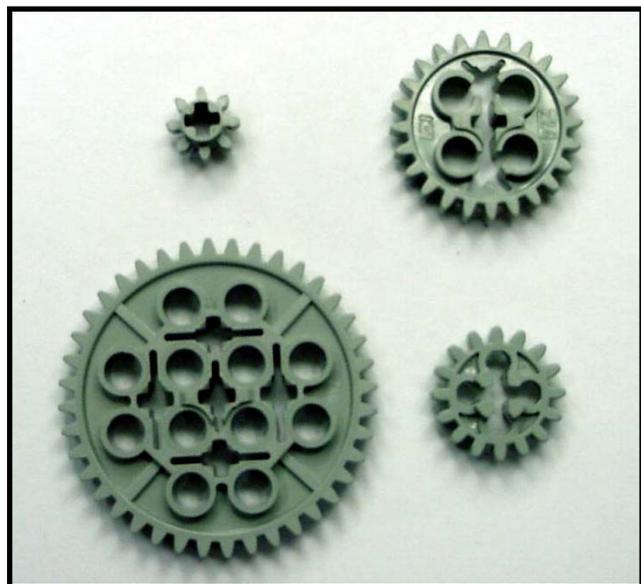
The previous story you just read was there to entice you into learning more about gears, because with your robotics trainer there are lots and lots of gears to play with. These notes describe several different ways of using gears, including meshed gears, chain drives, and belt drives. There are descriptions of other special gears too.

In each section there are questions posed to YOU the reader! (Or readers!) These are meant for you to think about before going on. Usually the answer and an explanation will follow immediately in the text. There also are problem sections, with answers at the end.

If you have some LEGO gears or other gears with you, use them to help you go through the examples.

#### Meshed Gears

- Count the number of teeth on these LEGO gears and write your answer next to each of the gears.

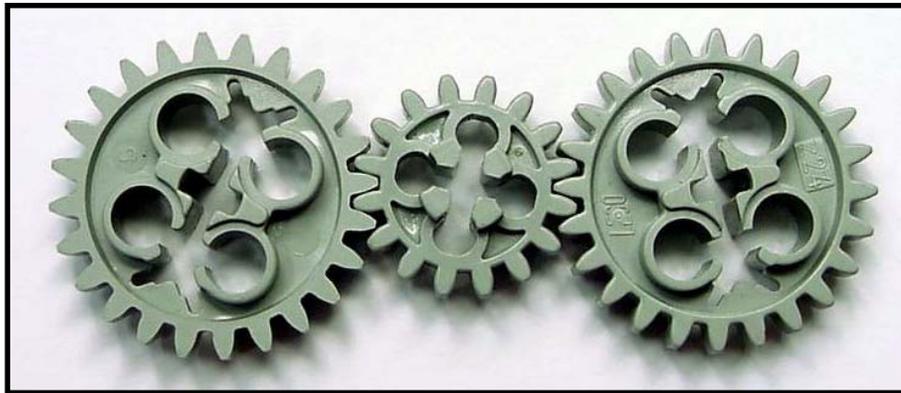


When two gears are used to make each other turn, they are called *meshed* gears.

- If we turn the left-hand gear clockwise, which way does the right-hand gear turn? Draw arrows on the picture to indicate the directions of rotation. You might get two gears in front of you or try to imagine the printed gears actually turning.
- So... Then two gears reverse direction. What happens with three gears?
- Draw arrows indicating the direction of rotation.



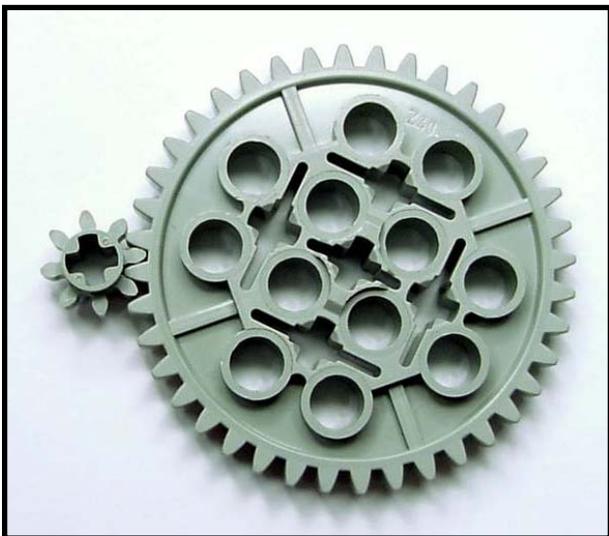
Complete the following example by drawing in arrows to show the directions that each of the gears will turn. Assume that the left-most gear is turning clockwise.



- Now let's look at the how fast or slow the gears actually turn. If we rotate the little gear 5 times, how many times does the big gear turn around?

The formula we use to solve this question is dividing the number of teeth on the driven gear by the number of teeth on the driving gear (driven/driving). There are 40 teeth on the driven gear and 8 teeth on the driving gear or  $40/8$ . Reducing the fraction to  $5/1$  we'll come up with the gear ration. Meaning... If we turn the small gear 5 times the large gear will turn once.

We call this "5 to 1" a *gear ratio* meaning, 5 turns of the first gear make 1 turn of the second gear. Sometimes we say "revolution" to mean one turn. Then 5 revolutions equals five turns of a gears. Although this machine reduces the number of rotations in relation to the driving gear, the amount of power (torque) is proportionally increased. For instance... If we put 1 foot-pound of torque into the machine, 5 foot-pounds of torque are produced.



- Suppose the little gear were turning around at 1000 revolutions per minute (1000 R.P.M.). How many

times would the big gear turn in a minute? How much torque would be produced with 3 foot pounds of torque applied to the little gear?

For each 5 turns of the little gear, we get one turn of the big gear. In one minute, the little gear turns 1000 times. Then the big gear would turn  $1000 \div 5$  times, or 200 revolutions per minute. This arrangement is called "gearing down" since we're making the second gear turn slower than the first. The would be 600 foot-pounds of torque produced.

- If "gearing up" means making the second gear turn faster than the first, describe or draw an arrangement of gears that will speed up the rate of rotation. Write or draw your answer in the box below.

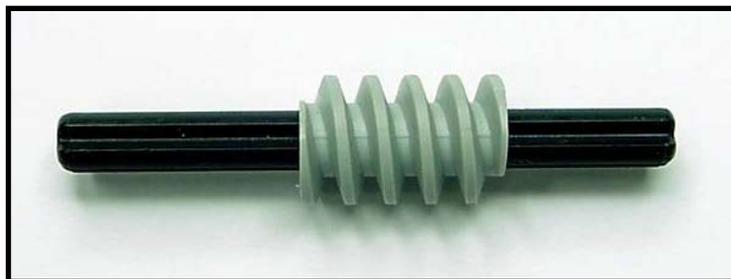
If you have a large gear turning a small gear, then for each one turn of the large gear you will get many turns of the little gear. Try this with two gears to demonstrate to yourself that it works.

- Give an example of a machine that would use gears in this way?

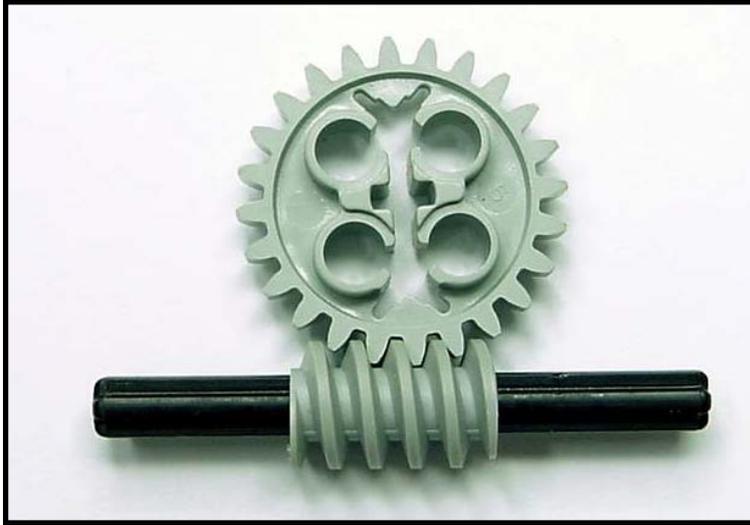
### The Worm Gear

There is a gear which looks like a piece of macaroni but is really a gear! It is called a *worm gear* because of its worm-like appearance when it turns. The worm gear has a spiral groove winding around its body.

Let's examine it in operation.



Put a mark in the middle of the worm gear, turn it one revolution, and look to where the mark has moved. What happened? The mark moved to the right by one groove width. If the groove width is the same as the tooth spacing on a round gear, then we could mesh a worm gear with a round gear. Then turning the worm gear one revolution would advance the round gear by one tooth.



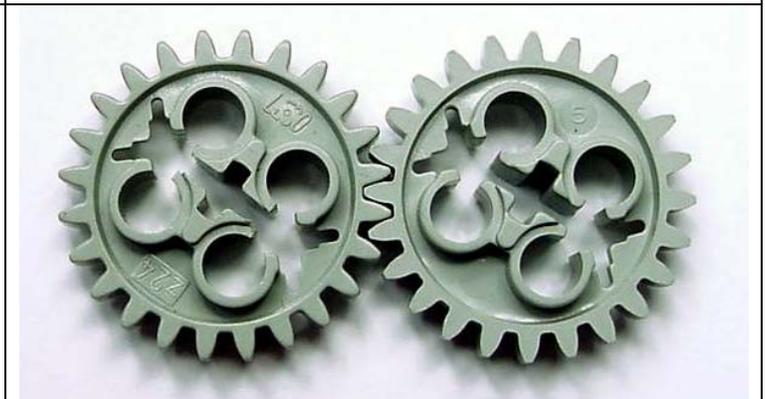
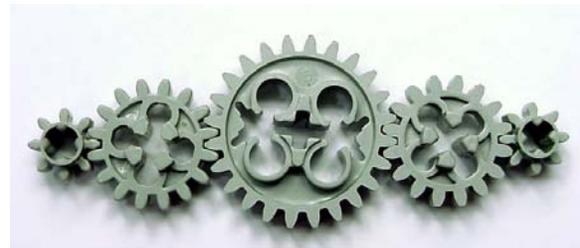
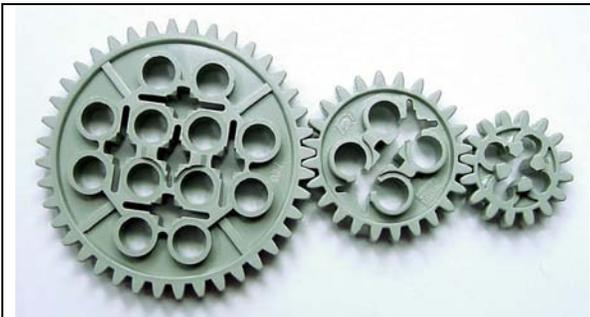
Suppose the round gear has 24 teeth. How many turns (revolutions) of the worm gear would you need to turn the round gear one revolution? What would happen to torque?

Each turn of the worm gives us one tooth's movement. To get 24 teeth (all the way around for the round gear), we'd need 24 worm turns.

- If we use a worm gear in this way, will the round gear be geared up or geared down?

Since the round gear is turning slower than the worm gear, we would be gearing down the round gear. The gear ratio would be (Driven/Driving) or 24:1.

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- In each of the following four pictures, calculate the gear ratios of each of the gears.
- Assuming the left most gear is the driving gear and rotating in a clockwise direction... Indicate the direction of rotation of each of the gears.
- Indicate if the gear train is gearing up or gearing down.



## Chain Drives

Belt-and-pulley drives may slip if it is too hard to turn the pulley wheel. Sometimes this is a desirable trait called slippage. Other desirable traits include the direction of rotation. Meshed gears always turn in opposite directions. The sprockets in chain drives rotate in the same direction. Using chains, we can connect gears (sprockets) without slippage. Your bicycle uses sprockets and a chain.

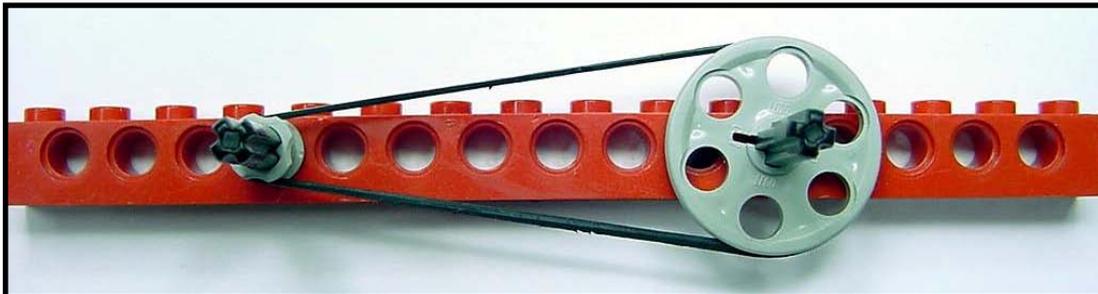
- Name some other machines with sprockets and chains.



Gear ratios using chain drives are treated just the same as simple machines using meshed gears. Suppose the left gear above has 16 teeth, and the right gear has 24 teeth.

- How many turns of the left sprocket would be needed to get 2 turns of the right gear?

## Belts and Pulley Wheels



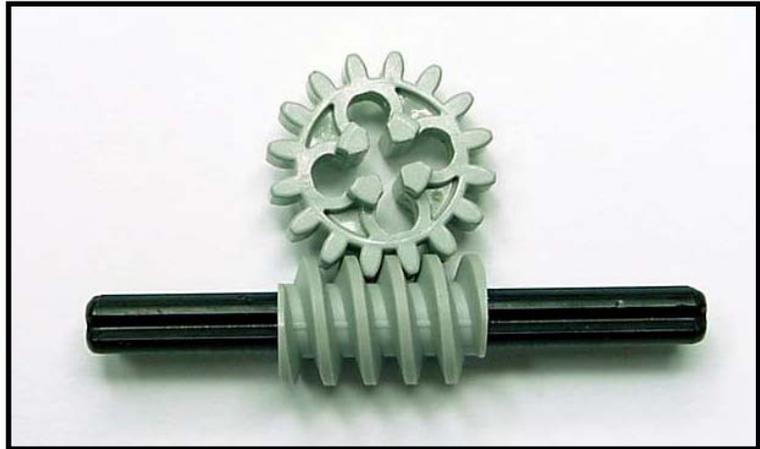
Pulley wheels are "meshed" by slipping a belt around two or more of them. Pulley wheels and belts act like gears and chains. If the belt is tight enough, then turning one wheel will cause the other wheel to turn in the same direction. What would you do to the belt to make the wheels move in opposite directions?

Circumference is the distance around the edge of a circle, or the rim of a pulley wheel. The "number of teeth" on pulleys is figured out by comparing the *circumferences* of the wheels. (Since it is all relative... radius and diameter will also work.) Suppose that the circumference of the little pulley wheels fits exactly 5 times around the circumference of the big wheel. Each time the little pulley wheel turns once it will move the belt by a distance equal to its circumference. The belt will then advance the big wheel by the same amount in relation to its circumference — but it takes 5 circumferences to turn the big pulley wheel around once! Thus, 5 turns of the little wheel makes one turn of the big wheel, and the gear ratio is 5:1.

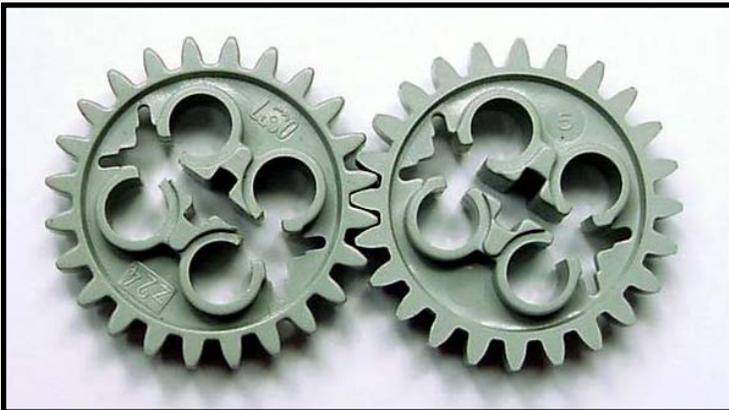
## Changing Axis Direction

In this picture of a worm gear meshed with a round gear, we can see the worm gear axle which is the black rod through the center of the gear.

We saw that when we use two meshed gears, the gears turn in opposite directions. But when we use a worm gear and a round gear, the gears' axes also point in different directions. This is called a change in transmission angle. In this case it is a 90° change in transmission angle.



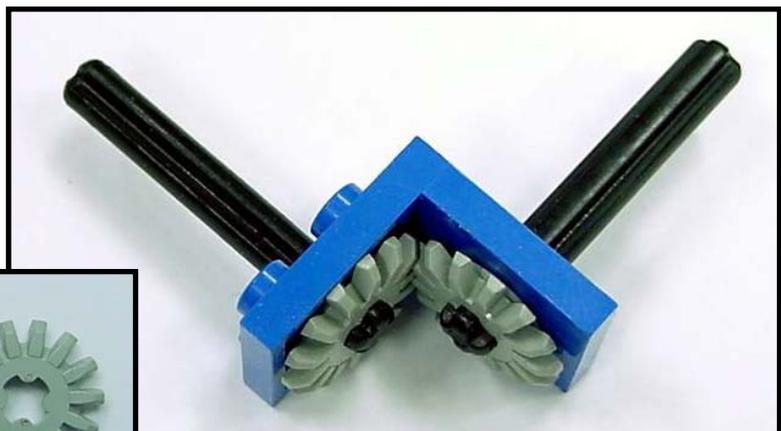
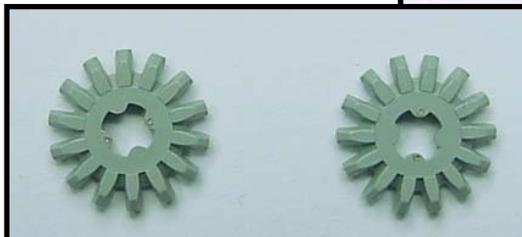
Compare the above picture to this one of two round gears and their axes. Is there a change in transmission angle?



Describe what is necessary to change of direction of axis to apply power to the rear wheels of a car.

There are other types of gears that can be used to change the direction of the gear axis.

Here are two *bevel gears*:

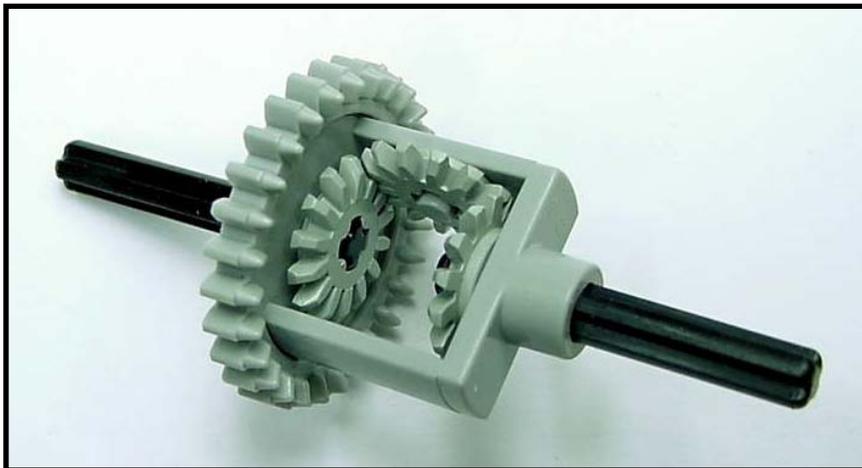
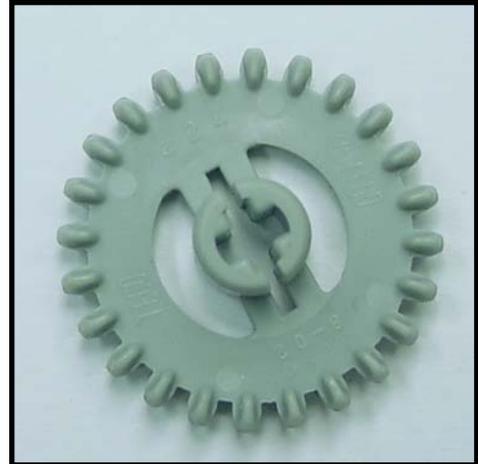


There is also a *crown gear*, which meshes in a similar fashion with an ordinary round gear:

## Differential Gear

This special gear assembly is used in automobiles to distribute power evenly to both rear wheels. When a car goes around a curve, one wheel has to cover more distance than the other. The differential gear assembly lets one wheel go slower if the other is going faster.

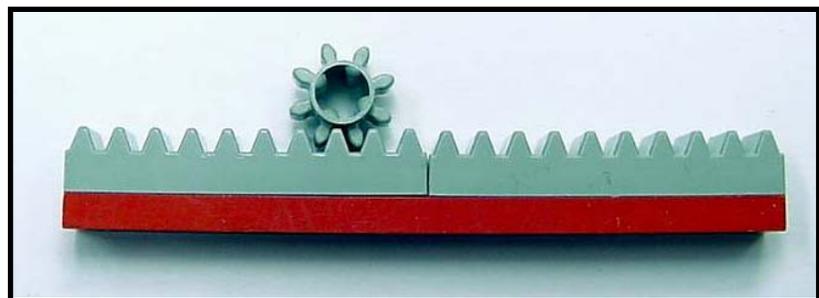
The three little gears in the middle of the assembly connect the two outer axles to that the wheels can turn in opposite directions. Power is applied to the outer ring of teeth and the whole assembly spins around, carrying the two axles around also. If one wheel slows down (on the inside of a curve, for example), and then the other wheel “turns opposite” and speeds up.



## Rack and Pinion

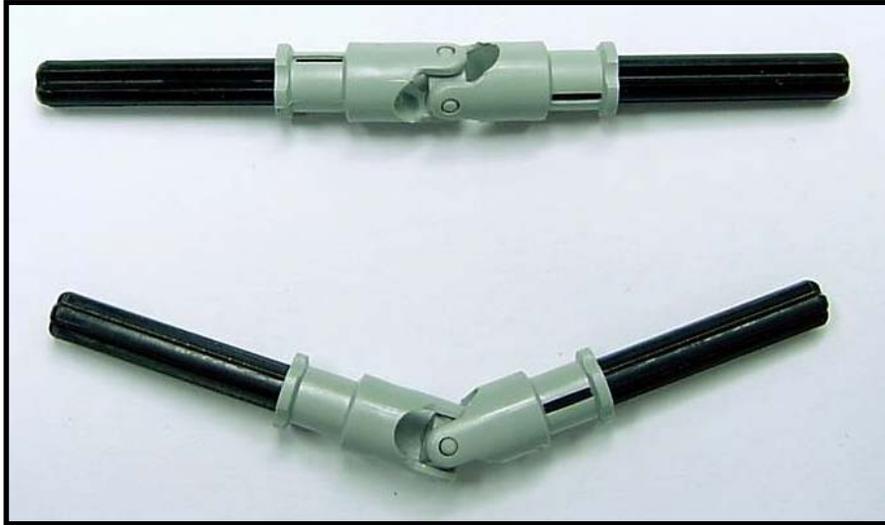
Suppose you want to turn the rotational motion of gears into back and forth. Then you might use the rack-and-pinion. Cars use a rack-and-pinion to steer their front wheels. When the gear spins, the rack moves left and right.

- Which way should we turn the gear to get the rack to move to the left?



## Universal Joint

This part lets you move the axis of rotation to connect gears that are far apart.



Cars use the universal joint to connect the power from the transmission to the rear wheel's differential gear. This connection is called a drive shaft. Since the wheels of a vehicle bounce up and down, a rigid drive shaft would also bounce up and down. That's not very good for the transmission. The universal joint allows the drive shaft to move in all directions while still transferring power to the rear wheel differential.

- Why do you think this mechanism is called a “universal joint”?
- Can you think of other machines that could use a universal joint?