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LEGO Mindstorms RIS 2.0
Gears, Pulleys, Wheels, and Tires

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Why Use Gears?

- To transmit torque from one axle to another
- To increase or decrease the speed of rotation
- To reverse the direction of rotation
- To move rotational motion to a different axis
- To change rotary motion to linear motion
- To keep the rotation of two axles synchronized

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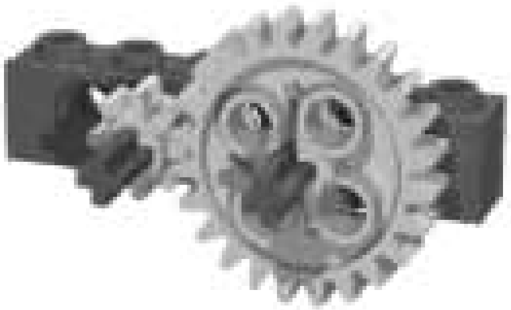
Gears

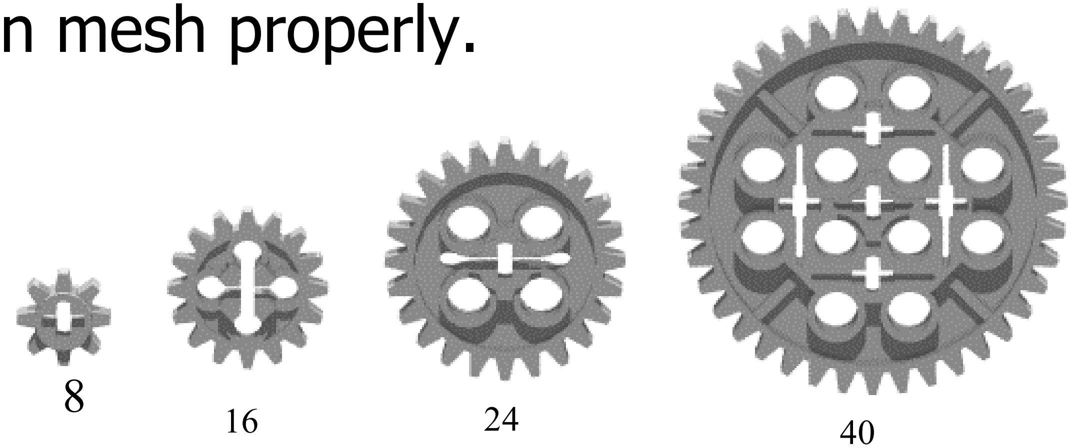
- **Basic jobs of gears:**
  - Transferring motion from one axle to another
  - Changing the direction of motion
  - Changing the speed of motion
  - Changing the torque (strength) of motion



8T and 24T gears

Spur Gear

- Most common gear
- Used when shafts rotate in same plane
- Gear sizes counted by number of teeth
- All LEGO spur gears have the same size teeth so they can mesh properly.



Teeth	8	16	24	40
Radius (studs)	0.5	1	1.5	2.5

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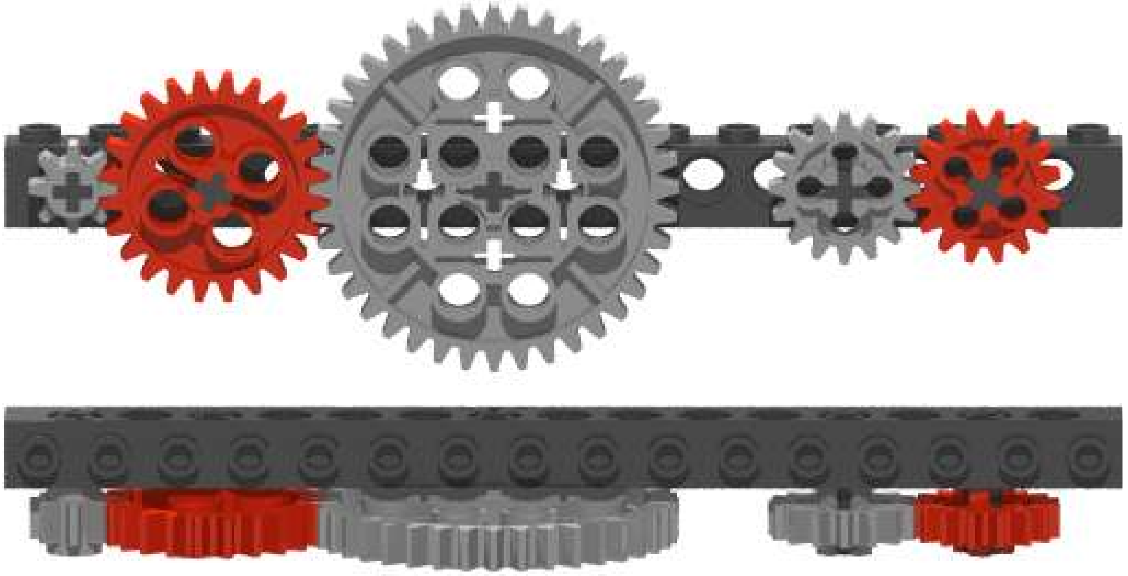
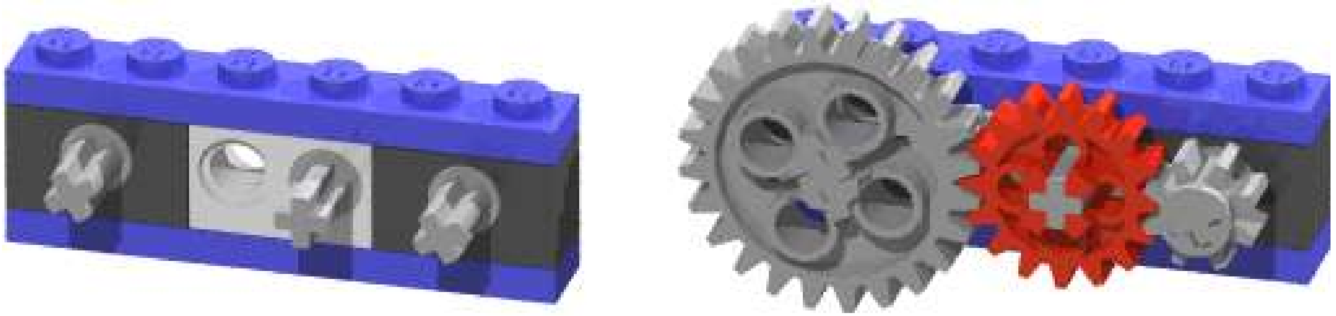
Spur Gear Spacing



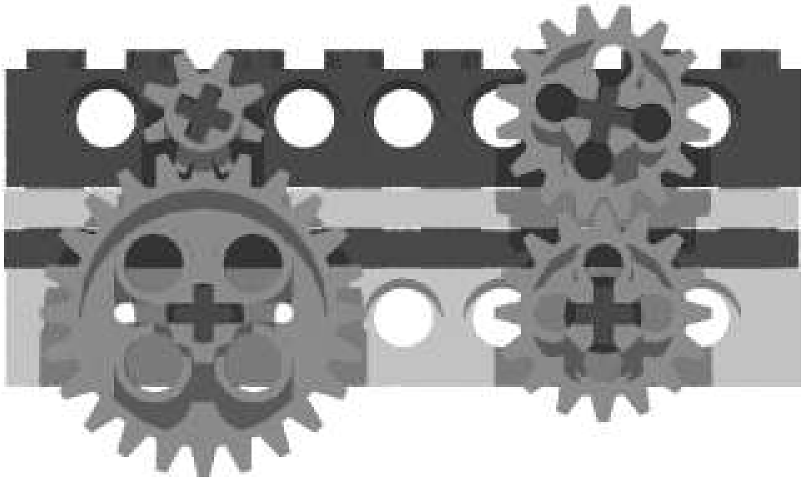
	8 tooth	16 tooth	24 tooth	40 tooth
8 tooth	1.0 studs	1.5 studs	2.0 studs	3.0 studs
16 tooth	1.5 studs	2.0 studs	2.5 studs	3.5 studs
24 tooth	2.0 studs	2.5 studs	3.0 studs	4.0 studs
40 tooth	3.0 studs	3.5 studs	4.0 studs	5.0 studs

Half-Stud Spacing



- Here is a trick to get half-stud spacing using 2 holed 1 x 2 beams

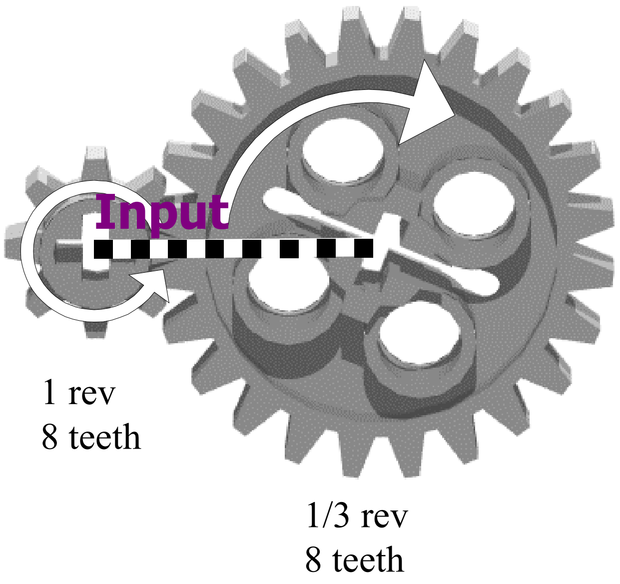
Vertical Gear Spacing



	8 tooth	16 tooth	24 tooth	40 tooth
8 tooth			2.0 studs	
16 tooth		2.0 studs		
24 tooth	2.0 studs			4.0 studs
40 tooth			4.0 studs	

- Vertical spacing is difficult
- Really only 2 and 4 stud distances work well
  - Our old friend 1-2-1

Gear Ratio



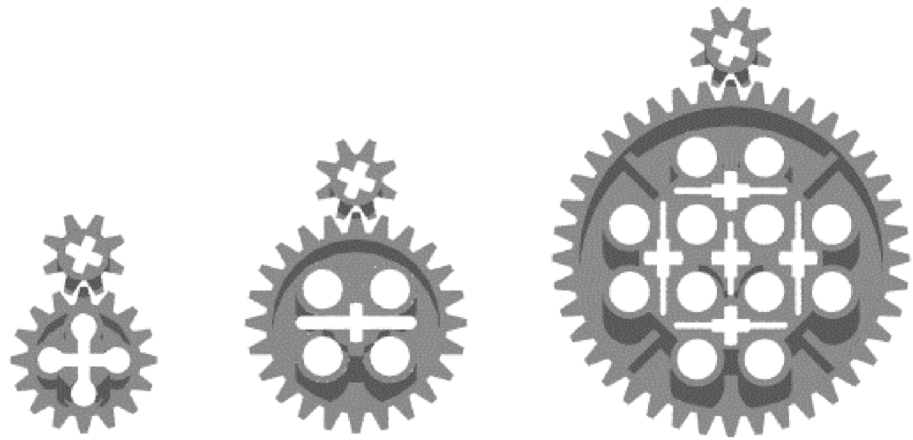
Output

The 24t gear turns 1/3 revolution for every turn of the input 8t gear.

This is a 3:1 gear ratio

Gear ratio is defined as the ratio of how much the output shaft of a gearbox turns for a given rotation of the input shaft.

Gear Ratios



16 : 8 or 2 : 1

24 : 8 or 3 : 1

40 : 8 or 5 : 1

Output Shaft or Driven Gear

Input Shaft or Driving Gear

	Driven 8 tooth	16 tooth	24 tooth	40 tooth
Driving 8 tooth	**1:1**	**2:1**	**3:1**	**5:1**
16 tooth	**1:2**	**1:1**	**3:2**	**5:2**
24 tooth	**1:3**	**2:3**	**1:1**	**5:3**
40 tooth	**1:5**	**2:5**	**3:5**	**1:1**

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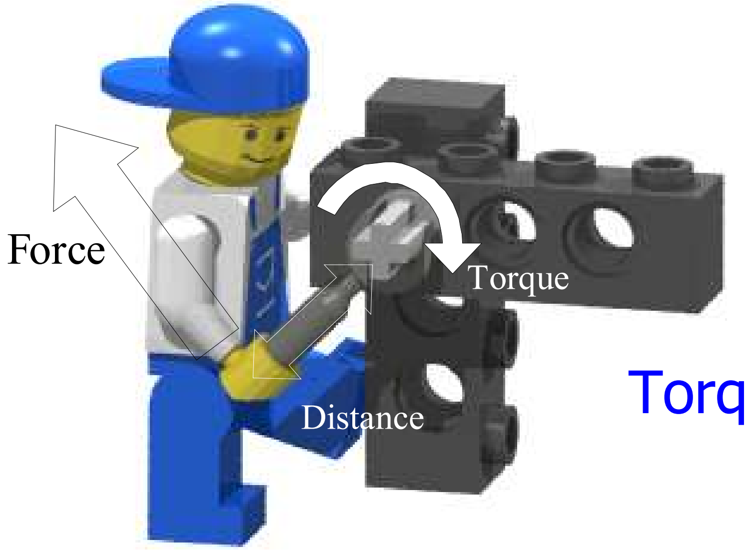
Gear Ratio and Torque

- Gears operate by transmitting forces at the teeth of the gear.
- When two gears mesh, the force that is transmitted can be multiplied by the radius to obtain the torque applied to the gear.
- Torque is a force that tends to rotate or turn things. For example, you generate a torque any time you apply a force using a wrench. When you use a wrench, you apply a force to the handle. This force creates a torque on the nut, which tends to turn the nut.

Torque

- A force applied to the teeth of a large gear will generate more torque than the same force applied to the teeth of a small gear. This also means that for a given torque, a larger gear will transmit less force than a smaller gear



Torque = Force * Distance

Torque

- The teeth of a large gear travel faster than the teeth of a small gear at a given angular velocity.
- So there is no free lunch. If you gear down to get an increase in torque, you will also get a proportional decrease in angular velocity.
- The driven gear will turn stronger and slower.

Strong and Slow

or

Fast and Weak

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Power, Speed, and Torque

- Rule of Physics: P = T * S
  - P = Power (of, say, a motor)
  - T = Torque (strength, resistance to opposing force)
  - S = angular Speed (how fast motor turns)
- Lego motors have constant power
  - Since P = T * S, it follows that T = P / S and S = P / T
  - The faster the speed for fixed P, the less the torque.
  - The faster the torque for fixed P, the less the speed.

Gearing Up and Down

- The 3:1 gear ratio tells us that the input shaft (attached to the 8t gear) has to complete three full revolutions for the output shaft (attached to the 24t gear) to rotate all the way around just once.
- Using gears to slow down rate of rotation or decrease the amount of rotation is called gearing down.
- If we were to switch the 8t and 24t gears around the output shaft would spin three revolutions for each revolution of the input shaft.
- This is gearing up, and the gear ratio would be 1:3

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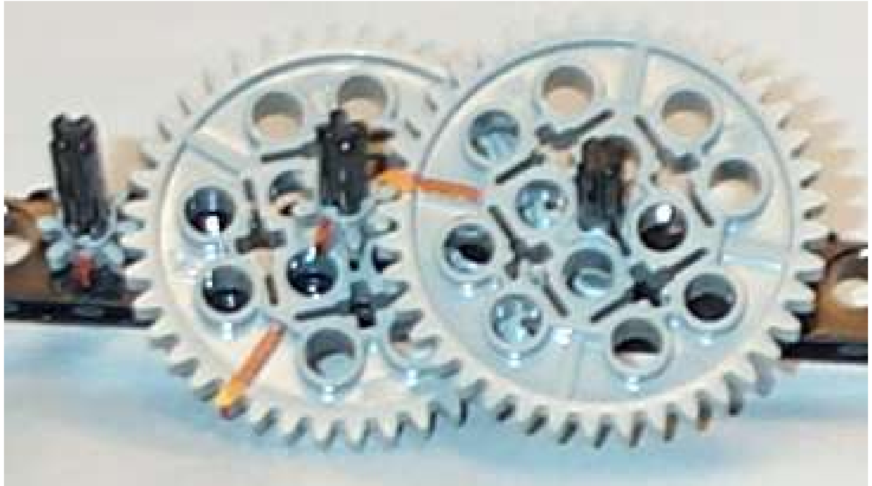
Gearing Up and Down

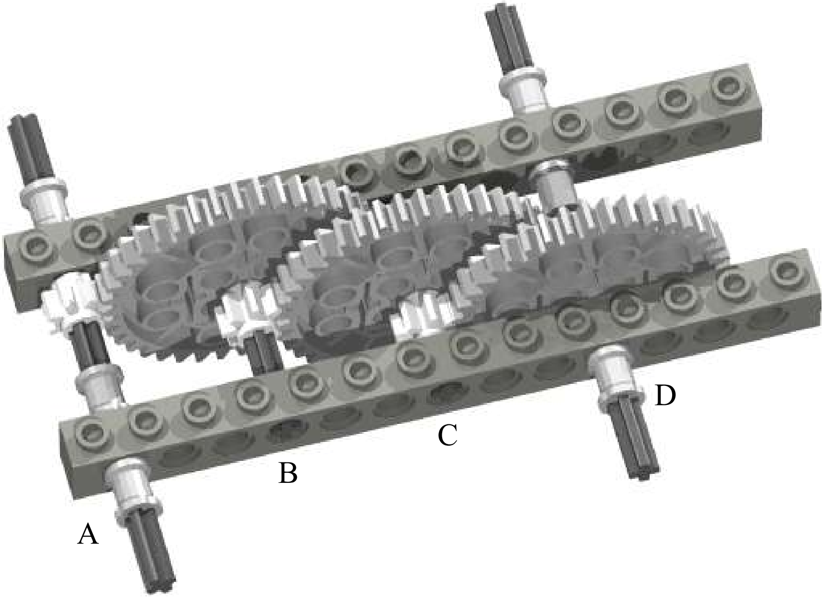
- By using two or more gears, we can alter the speed or torque produced by a Lego motor
- Increasing one always decreases the other
- Basic idea:
  - Attach motor to one axle with a gear on it;
  - Attach a wheel to another axle, with a second gear on it that is meshed with the first
- Gearing up: Using gears to increase the speed
- Gearing down: Using gears to decrease the speed (so increase the torque)

Gear Trains

- We can multiply gear ratios by using gear trains: multiple meshings ...
- This gear train uses 8-tooth and 40-tooth gears.
- What's the final gear reduction?



Gear Trains

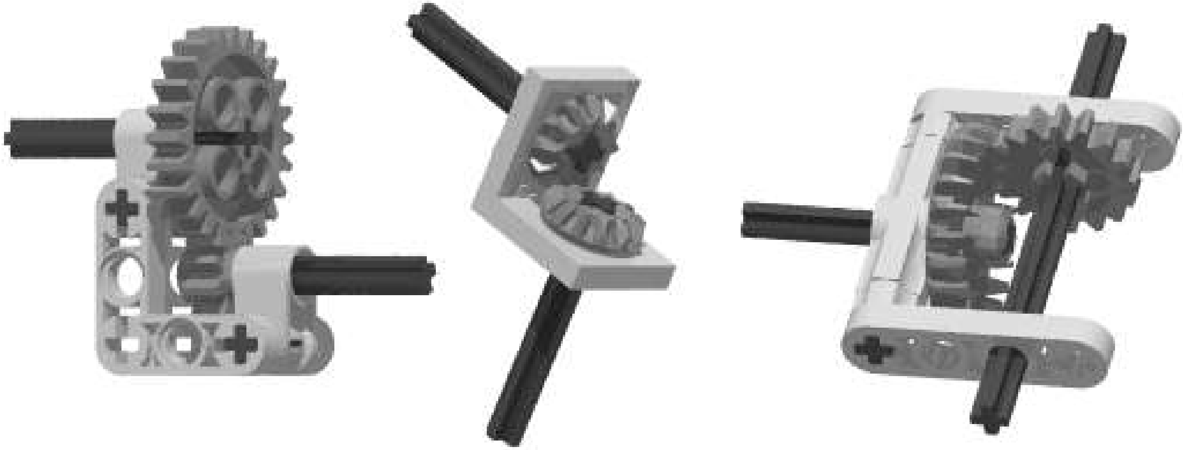


A->B = 5:1
B->C = 5:1
C->D = 5:1
A->D = (A->B) x (B->C) x (C->D)
= 5:1 x 5:1 x 5:1
= 5 x 5 x 5:1 x 1 x 1
= 125:1

If you connect shaft A to a motor spinning at 300 revolutions per minute (rpm), shaft D will spin at 2.4 rpm or 1 revolution every 25 seconds. Shaft D will have A LOT OF TORQUE!!! It could break gear teeth or snap axles.

Reinforcing Gear Trains

- Gears will undergo the biggest forces on your robots. Here are some simple examples of sturdy frames for gears.



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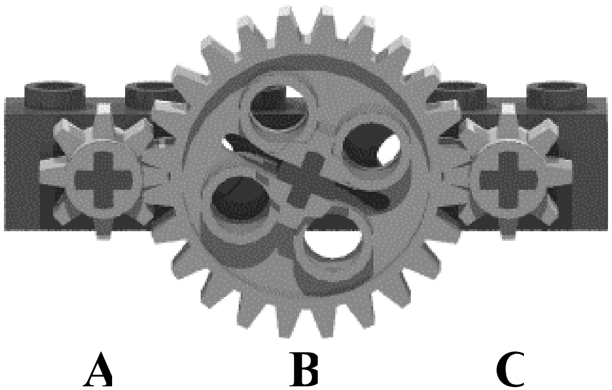
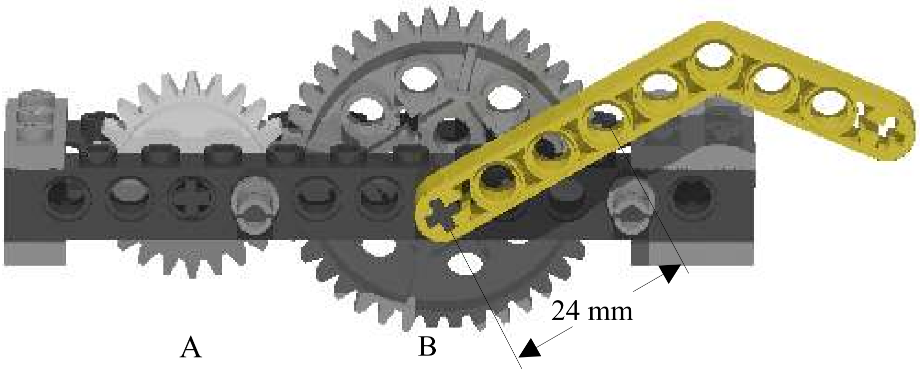
Idler Gear



- The 24 tooth gear is an idler gear. An idler gear does not affect the gear ratio of a gear train.
- Idler gears are quite common in machines where they are used to connect distant axles. Idler gears may also used to change the direction of rotation of the output shaft.

Clutch Gear



- The white gear with writing on it is called a clutch gear.
- The clutch gear is special in that the gear teeth are able to rotate about the shaft.
- It has an internal clutch mechanism that starts to slip when its maximum rated torque is exceeded. The clutch gear is used to limit the torque of a geared system, saving motors and preventing your robot from tearing itself apart.

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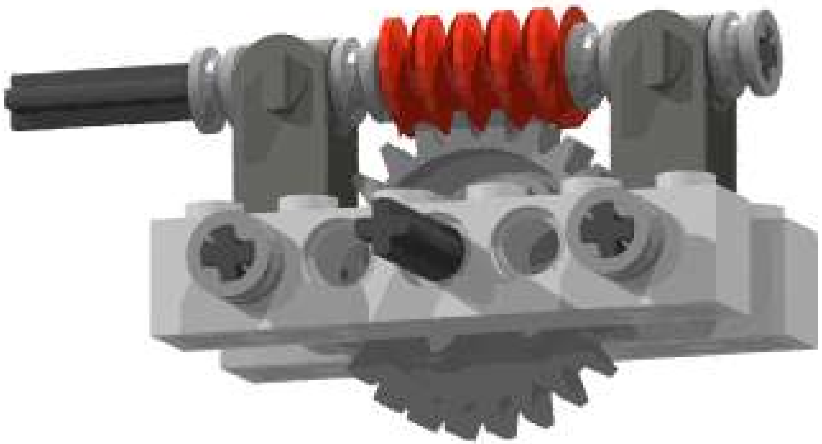
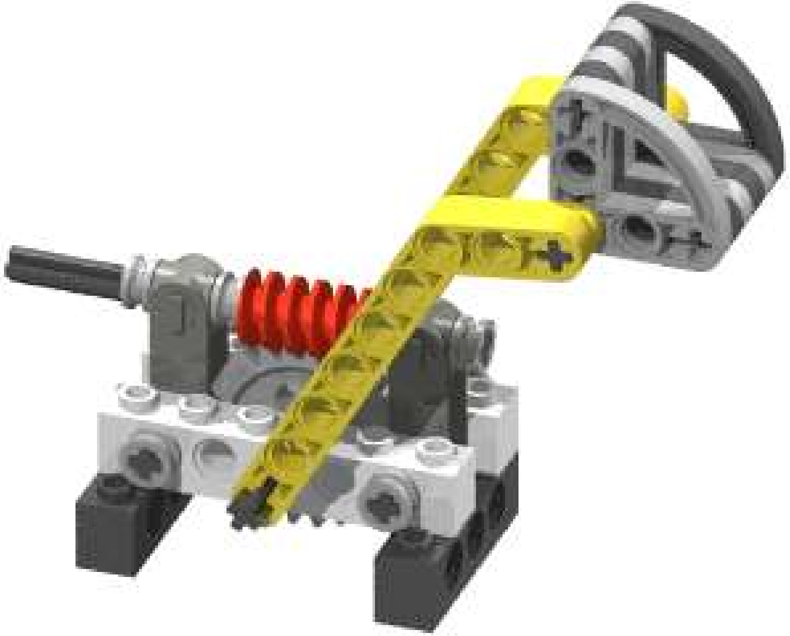
Worm Gear



- A worm gear is a screw which usually turns along a spur gear.
- Motion is transmitted between shafts that are at right angles.
- Can create very high gear ratio as each time the shaft spins one revolution, the spur gear moves one tooth forward.

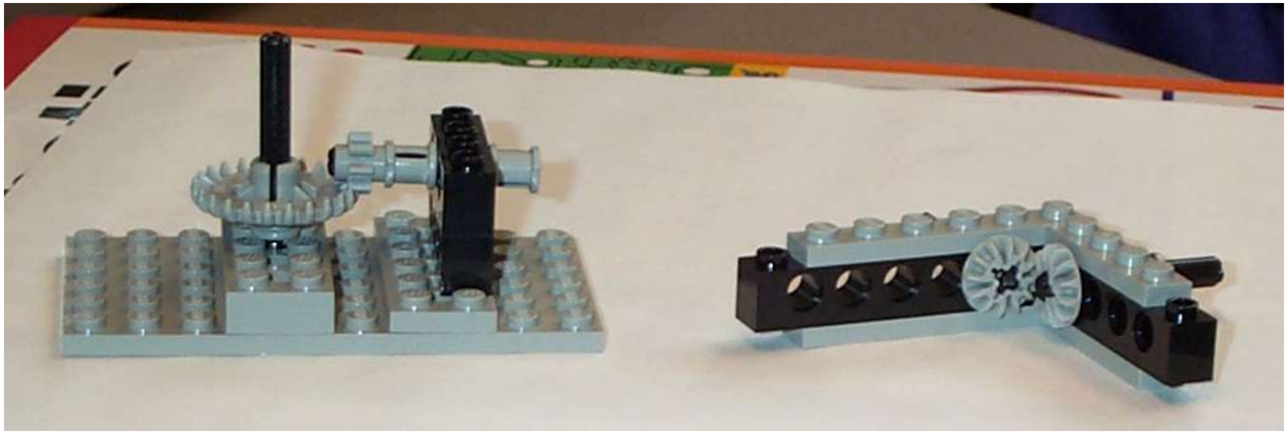
Worm Gear is Self Locking



- Your can turn the input shaft to drive the output shaft, but you cannot turn the output shaft to drive the input shaft.
- Very useful for arms as no torque is required to keep it in place.

Crown and Bevel Gears

- These gears let you change the plane of rotation



Crown Gear meshed with 8-tooth gear

Two meshed bevel gears

Crown Gear

- The crown gear has teeth that are raised on one side and rounded-off on the other to give it a crown-like appearance.
- Used when the shafts to be turned meet at an angle. It can be meshed to spur gears and worm gears, but it doesn't mesh well with other crown gears.
- Can also be used in place of a 24 tooth spur gear.

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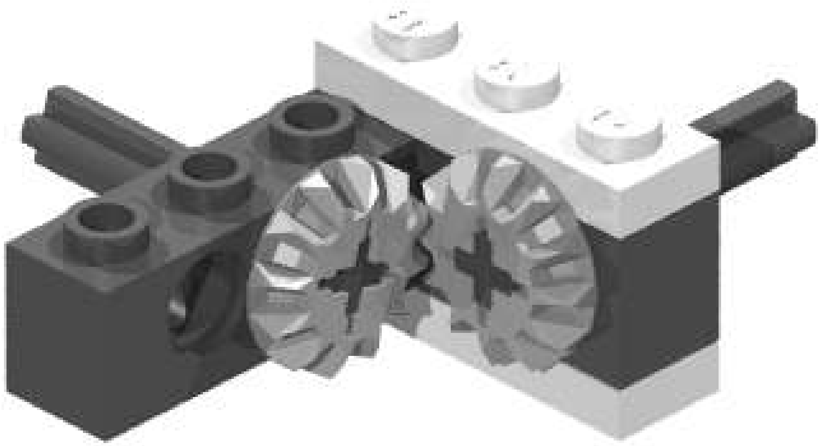
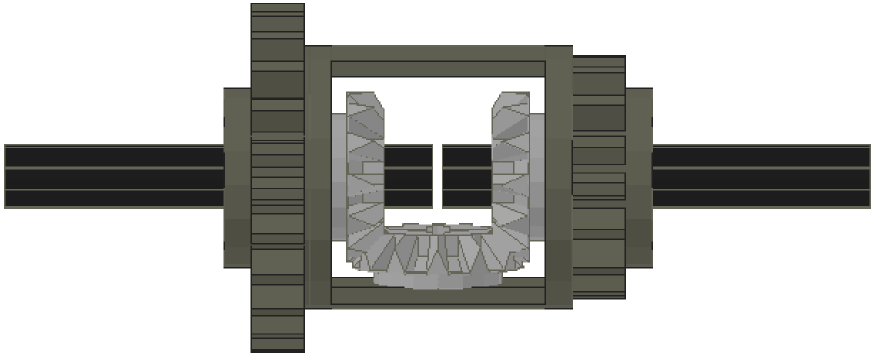
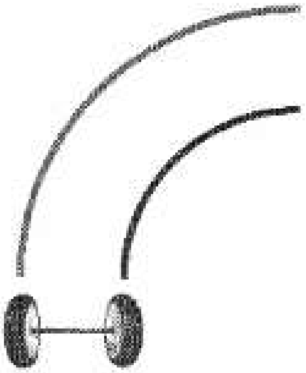
Bevel Gear



- The bevel gear has teeth that slope along one surface of the disc. It is used when the shafts to be turned meet at an angle.
- It has less friction than the crown gear, but can only mesh with another bevel gear.
- Can also be used as a small wheel.

LEGO Differential





- A differential is a device takes a torque applied to its housing, and evenly distributes it to two output shafts, allowing each output to spin at a different speed.
- Necessary because going around a turn, car wheels turn at a different speed.

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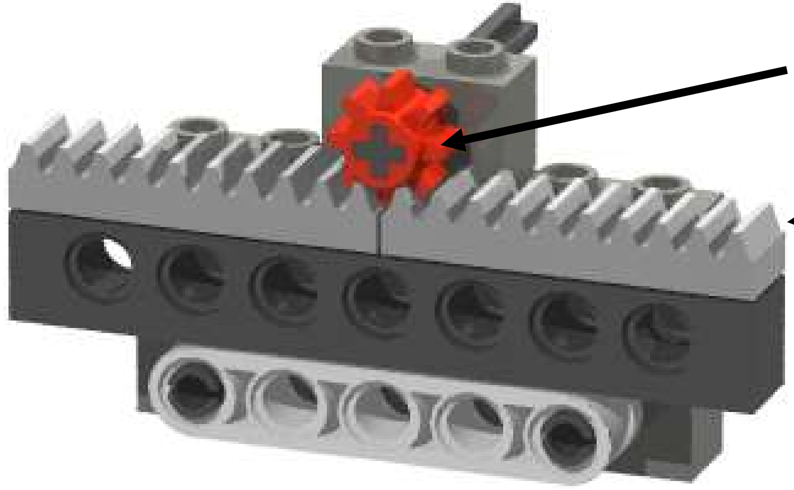
LEGO Gear Rack and Pinion



- The gear rack looks like a spur gear laid out flat. It is usually used in conjunction with a spur gear (which is referred to as the pinion).
- Used to convert rotation into linear motion.

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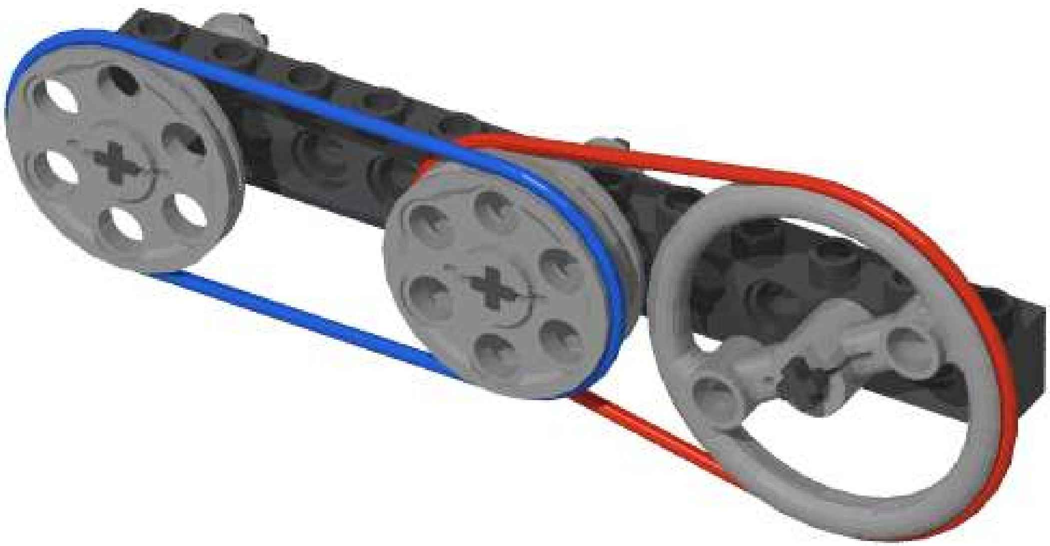
Pulleys and Belts



• A pulley is a wheel with a groove about its diameter. The groove, called the race, accepts a belt which attaches the pulley to other pulleys.

• LEGO belts are color coded; small (white), medium (blue) and large (yellow).

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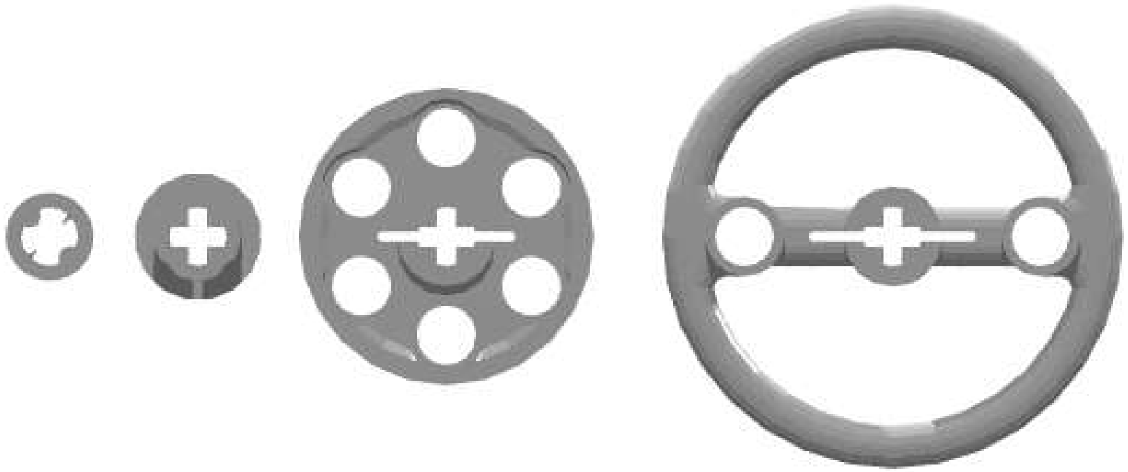
Lego Pulleys



- With four different sized pulleys, it is possible to “gear” up and “gear” down.
- Pulleys may be used in place of gears in many applications. Since there are no teeth to mesh, placement is much more forgiving. But because it has no teeth a pulley cannot be used to transmit high torques. The belt will slip first.

Pulley Ratios

	Half Bushing	Small Pulley	Medium Pulley	Large Pulley
Half Bushing	1:1	1:2	1:4	1:6
Small Pulley	2:1	1:1	1:2.5	1:4.1
Medium Pulley	4:1	2.5:1	1:1	1:1.8
Large Pulley	6:1	4.1:1	1.8:1	1:1

Lego Wheels and Tires

Small Solid
24mm x 7mm

Medium Solid
30mm x 10.7mm

Large Solid
43mm x 10.7mm

Large Balloon
81.6mm x 15mm

Small Balloon
30.4 mm x 14 mm

Medium Balloon
49.6 mm x 28 mm

Pulley Wheel
30 mm x 4 mm

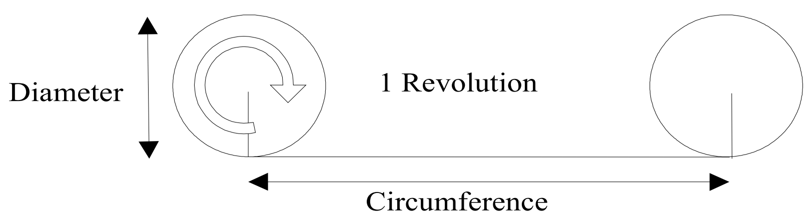
- Wheels affect your robot's speed, power, accuracy and ability to handle variations in terrain.
- What you choose will have a profound effect on your robot's success or failure.

Speed Calculation

- Circumference = PI x Diameter
- Use this to calculate speed and distance (details in slide notes)

ω = Motor RPM x Gear Ratio
= 300 rpm x 3:1
= 900 rpm

v = ω x Pi x d
= 900 rpm x 3.14 x 81.6mm
= 230,601 mm per minute
or 8.7 mph – Wow!!!



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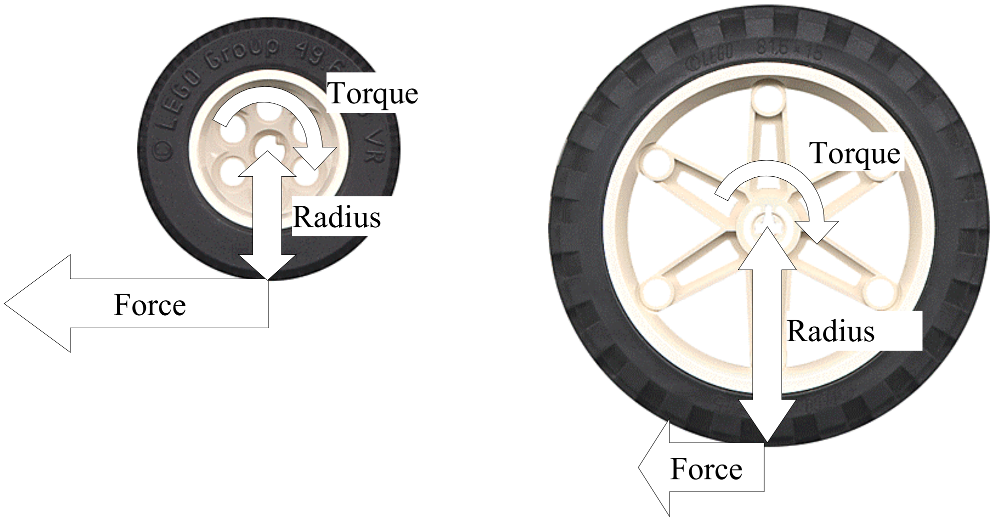
Force = Torque/Radius



- Gears and wheels have the same relationship between force, torque, and radius.

- When you use big wheels to increase speed you have to give something up, and that something is force. A robot with big wheels cannot pull as much as a robot with small wheels can pull.

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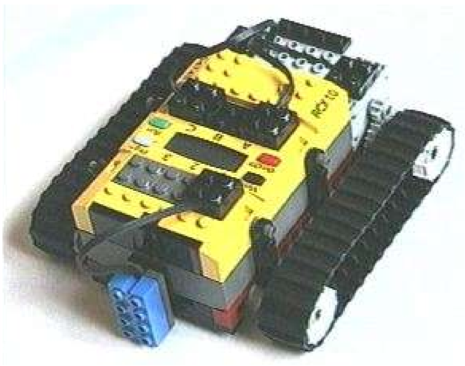
Tracked Robot



- Advantages:
    - Good traction on rough surfaces
    - Stable
    - Agile (turns in small space)
- Disadvantages
    - Poor traction on smooth surfaces (slips a lot), making some methods of navigation difficult
    - A lot of power loss due to bending of tread, etc.

Robot Balance

- Proper balance is very important in robot design.

•All wheels must be in contact with the ground at all times, and the weight carried by each wheel must be consistent.

- Balance is dependant upon two factors: wheel base and center of gravity

- Center of gravity should remain within the wheel base.

Finding the Center of Gravity

Lateral Balance Plane

Longitudinal Balance Plane

CG is on this line

- The balance point is located on the lateral, longitudinal, and vertical axes.

- You need a fulcrum, 2x4 curved top brick, that will support the weight of the robot while still allowing it to tip easily. Place the robot on the fulcrum such that the fulcrum is parallel to the balance plane you are trying to locate. Slowly adjust the position of the fulcrum until the robot balances. This is the balance point.

References

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- InSciTE: Innovations in Science and Technology Education, www.HighTechKids.org
- LEGO.com Mindstorms Home, mindstorms.lego.com