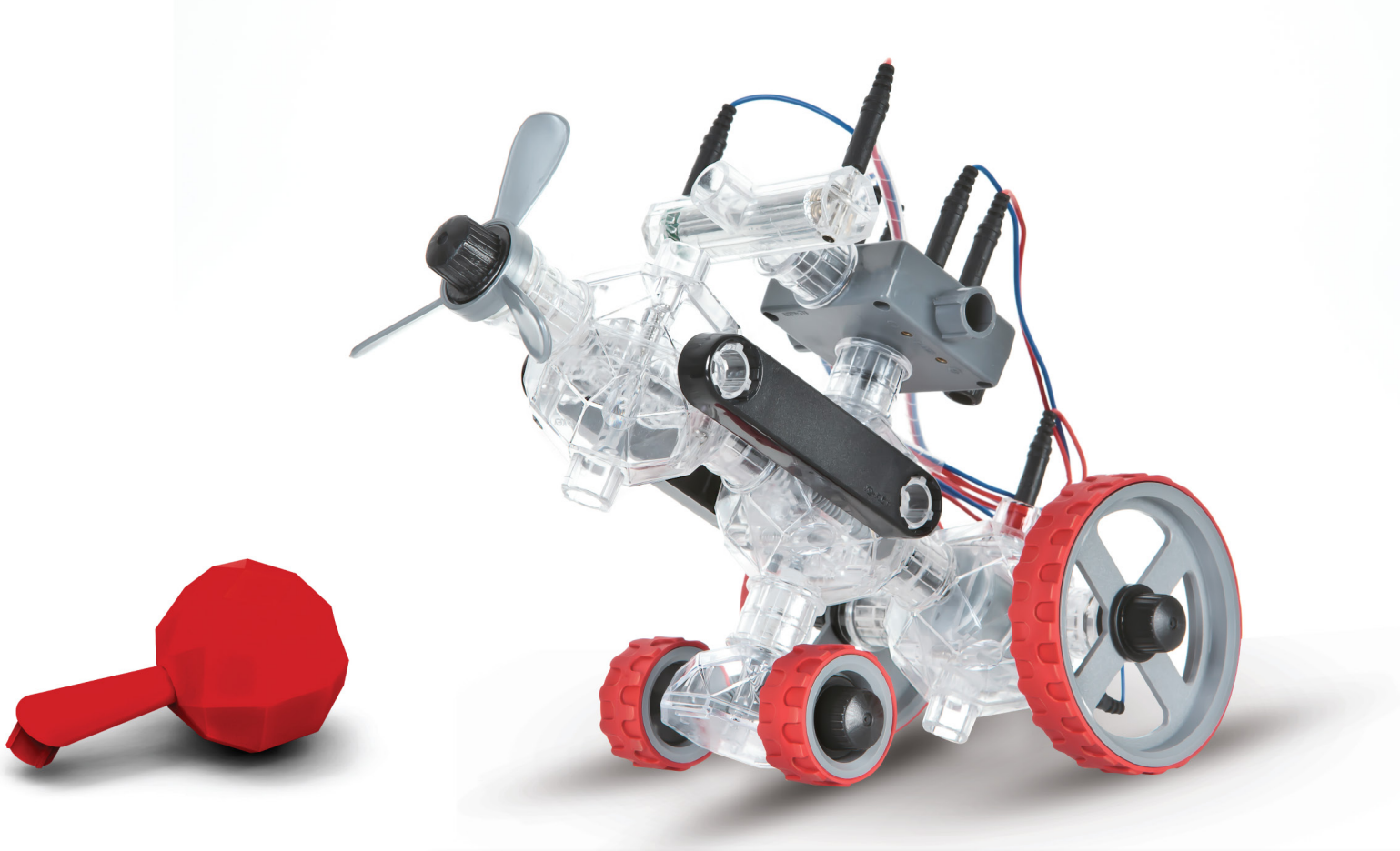
TEACHERS GUIDE



IQ KEY Robotics STEM Kit

MACHINES AND ENERGY TRANSFER

Stimulate right brain creativity by encouraging your students to design and build machines of their own! Use the IQ Key Robotics Kit to identify different simple machines that are working together to transfer and transform energy, all while having fun!

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Introduction

What is IQ Key?

The name IQ Key stands for a tool that is playing the role of a key to enhancing children's IQ (Intelligence Quotient). Differentiated from play-oriented assembly toys, children can learn the principles of science while playing with the IQ Key. This helps children by engaging their imagination, prompting creativity, and developing their problem solving abilities.

How it Works

Engineering is part art and part science. It even means cleverness, and is the application of scientific knowledge to conceive, invent, and build devices to benefit society. Scientists are continuously investigating how things work and why. The engineer uses that knowledge to solve problems by designing machines – some simple and some very complex. Our machines make work easier by allowing us to change the direction of pushes and pulls, and to control the distances our pushes and pulls move objects.

The complexity of the machines that we use in our daily life is astonishing, yet every single one of these machines are constructed from basic simple machines – tools that allow us to manipulate forces to do work. Society depends on engineers and inventors to find ways to make work easier, and engineers depend on science to create the knowledge they need about how and why things work the way that they do in order to fill this need.

The nature of work can be understood as a change in energy of a system, and a system can be anything we define it to be. Machines allow us to do something to a system which changes its energy in some way to benefit us. Students find this concept even more confusing once they hear the definition of energy – the ability to do work.

Work is one of three ways that energy can be transferred between system and surroundings. During transfer the energy can be transformed into many different kinds of energy (electrical, gravitational, chemical, sound, heat, light, etc.), but all kinds are always one of two basics forms – kinetic and potential energy.

The IQ Key comes with plans to build many different machines. Stimulate right brain creativity by encouraging students to design and build machines of their own! Use the IQ Key to identify different simple machines that are working together to transfer and transform energy - all while having fun!

It allows you to build complex machines using an easy to use key of parts. The parts are transparent and you can watch the levers, wedges, gears, drive shafts, and pulleys.

Safety and Care

Before Using this Product

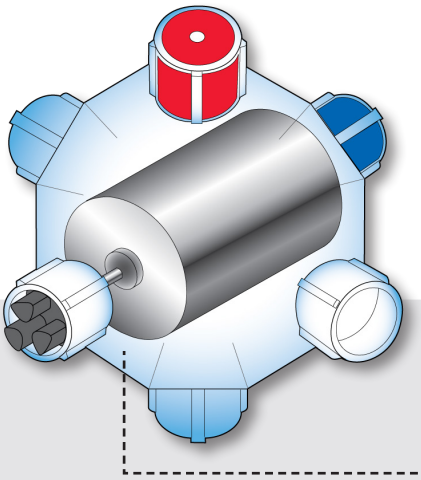
Safety

- The recommended age for using the IQ Key is 7 years and older. Children younger than 7 should be accompanied by an adult.
- Do not let children under the age of 3 use the product in order to prevent them from swallowing small parts.
- Be careful not to hold fingers between parts when assembling and disassembling.
- Do not leave the motor in operation for long periods of time, since there is a possible danger of overheating.
- Do not store or operate near inflammables or in high humidity.
- Used batteries should be collected to be recycled.

Care

- Forcing parts to connect may result in breakage.
- Make sure that you understand the function of each part for correct operation of the model you are building.
- When the product is operated on a table or desk, pay close attention to prevent falls and breakage.
- Batteries that are left in the machines when not in use for a long time can damage the product. Store batteries separately after use.
- Motor, switch box, and battery case may get wet when using the IQ Key in the water. Dry the product properly after it has been in the water, before storage or reuse.

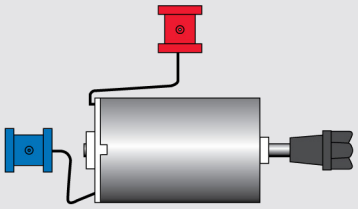
1 Major Components - Capsules

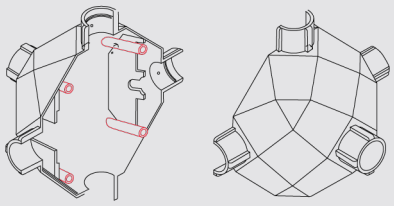


Motor Capsule

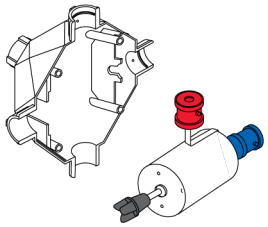
- The Motor capsule receives power from the dry cell batteries and converts it into rotating force. Rotation to either direction is possible, according to the polarity of the received power (node or cathode).
- It can be operated in the water; however, be cautious, as the motor could get damaged if capsule remained underwater, and got wet for long periods of time.

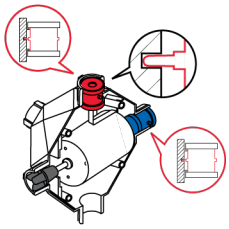
Parts

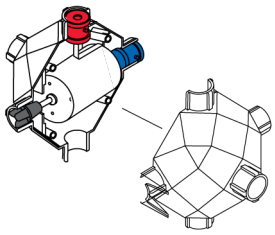


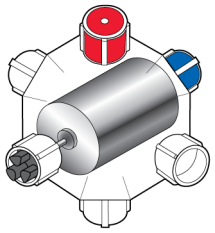


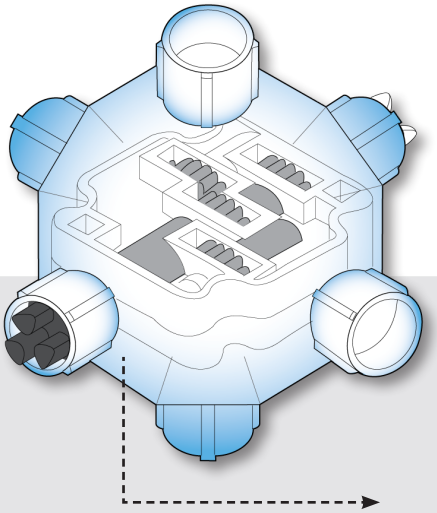
Assembly







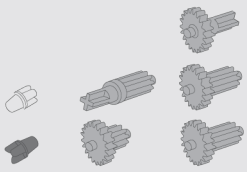


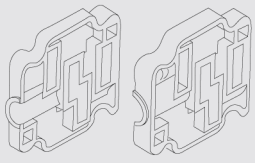


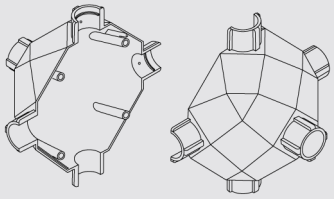
Speed Reduction Capsule

- The Speed Reduction Capsule reduces speed and increases rotating force received from the Motor Capsule.
- The black gear (output part) of the motor capsule and the black gear (input part) of Speed Reduction Capsule should be connected for correct operation.

Parts







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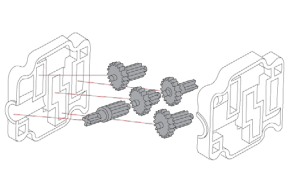
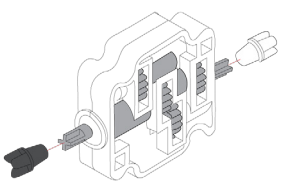
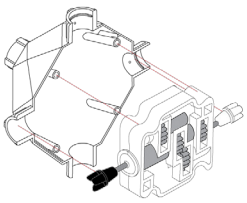
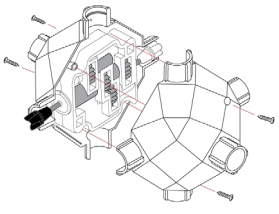
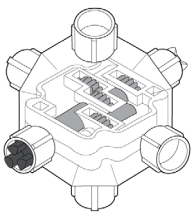
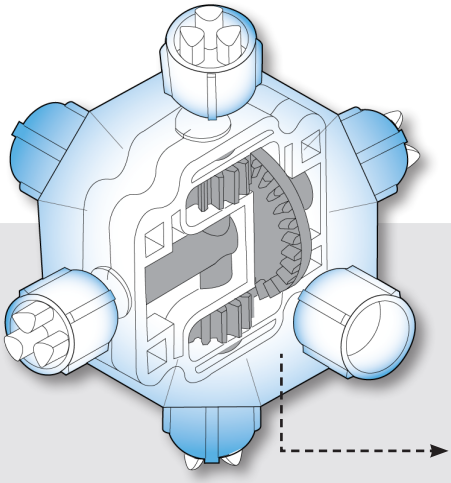








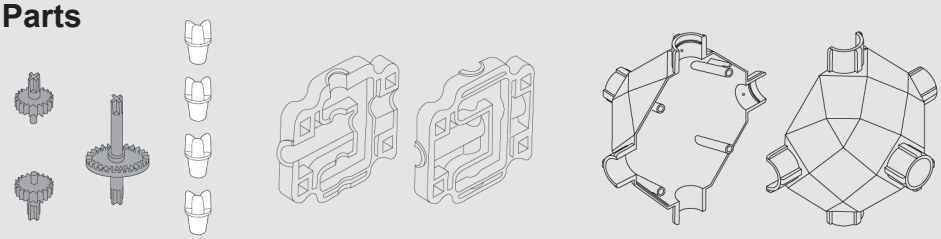




Crown Gear Capsule

- The Crown Gear Capsule delivers the received rotating force to the positive direction or converts it to 90 degrees. The shape of the gear engagement can either make one axis rotate in one direction or two axis rotate in opposite directions.

Parts



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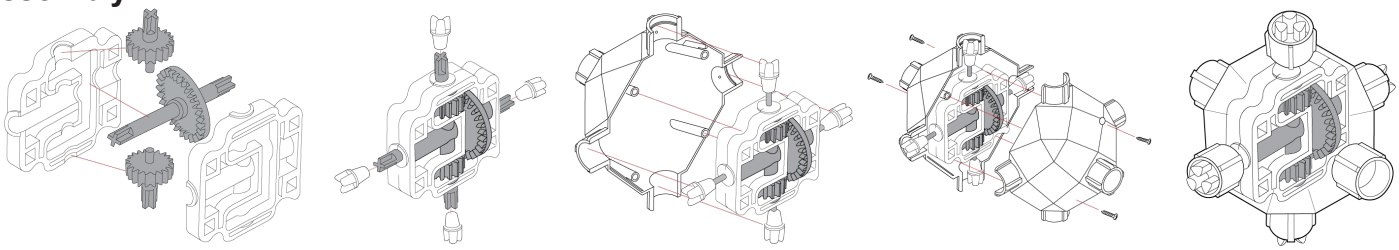
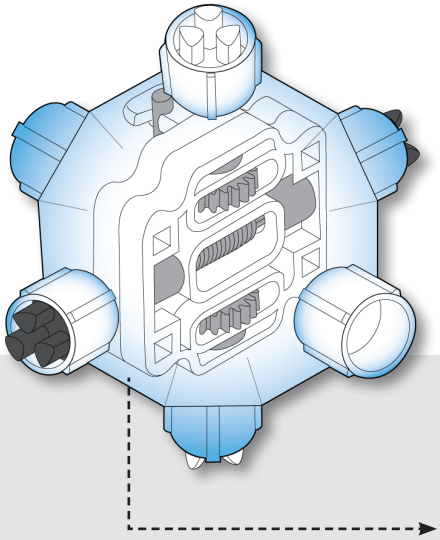
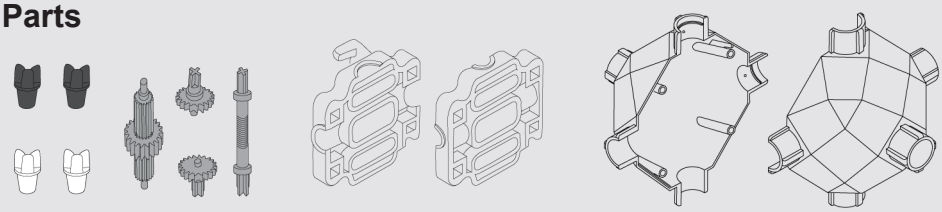




Worm Gear Capsule

- The Worm Gear Capsule combines the functions of the Speed Reduction Capsule and the Crown Gear Capsule in one unit. The gray gear axis delivers the same rotating force received from the motor to the black gear on the opposite side, while the beige gears on both sides convert the rotating direction to 90 degrees, reducing the speed and increasing the power.
- The black gear (output part) of the Motor Capsule and the black gear (input part) of the Worm Gear Capsule should be connected for correct operation.

Parts



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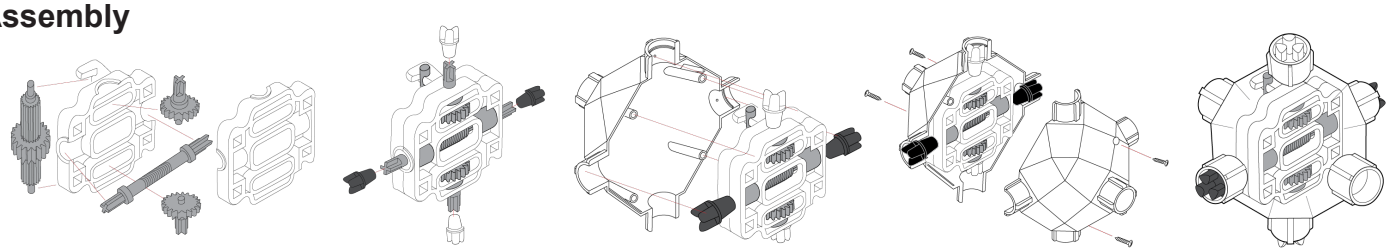
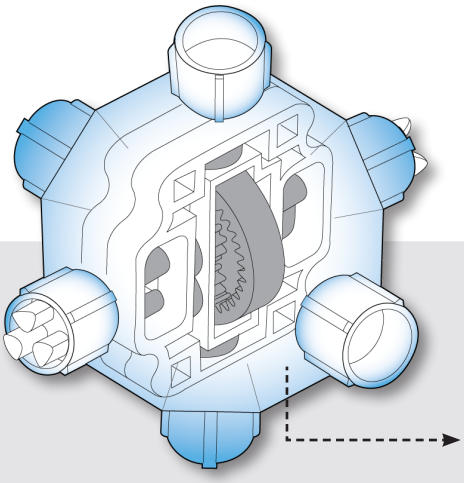


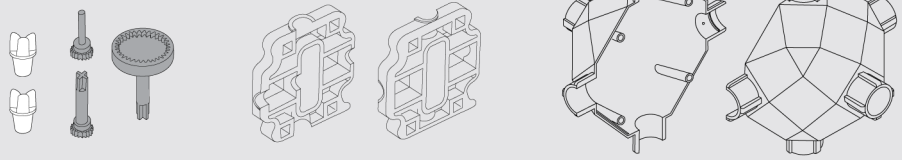
1 Major Components - Capsules



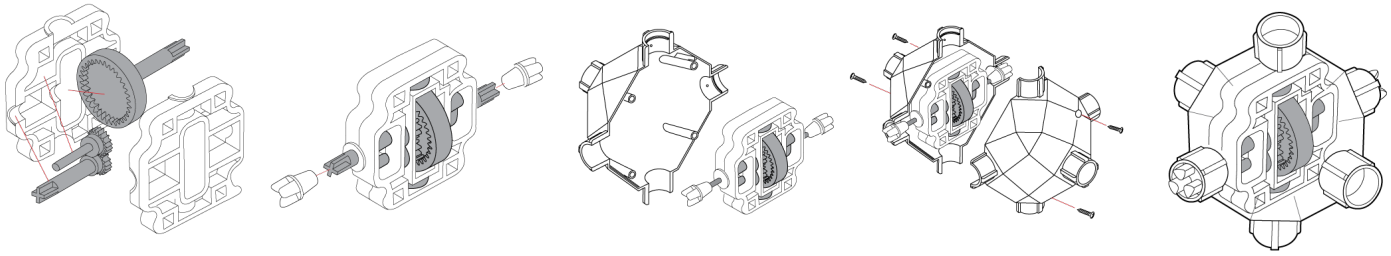
Internal Gear Capsule

- The Internal Gear Capsule increases or decreases the received rotating speed in the positive direction. The rotating speed will be faster by attaching a big gear in the rotating force receiving direction. It will be slower with the small gear.

Parts



Assembly



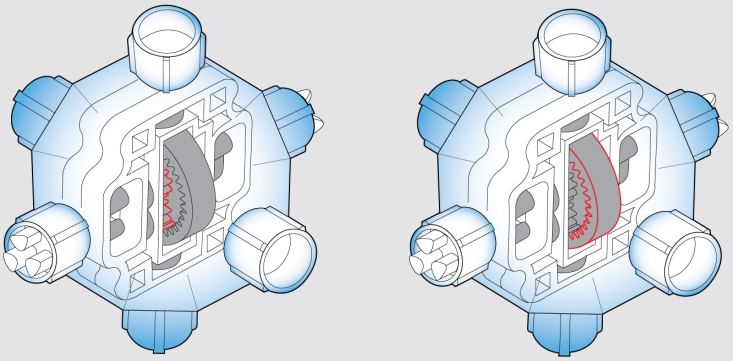
How to Connect Gears

When attaching the small gear:

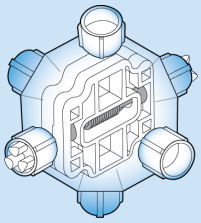
- When the small gear is attached in the direction of the motor, rotating speed will be reduced to 1/3.

When attaching the big gear:

- *When the big gear is attached in the direction of the motor, rotating speed will be increased by three times.*

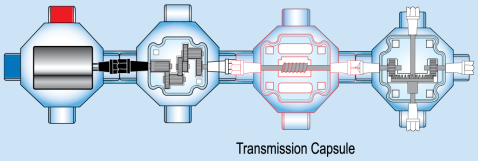


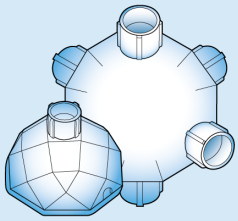
2 Basic Parts



Transmission Capsule

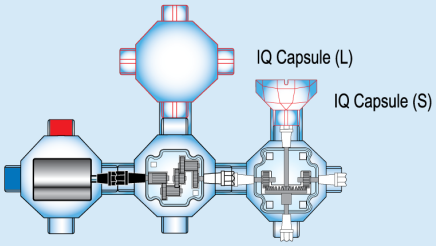
The Transmission Capsule can be used as a connector between different capsules, it delivers the rotating force through the gear without conversion.

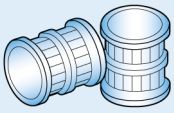




IQ Capsule

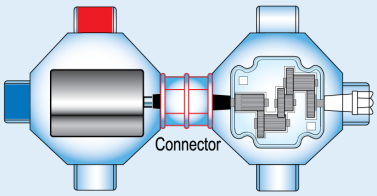
The IQ Capsule is used to connect or pass the lead line or bulbs. It can also help create interesting shapes for the model.

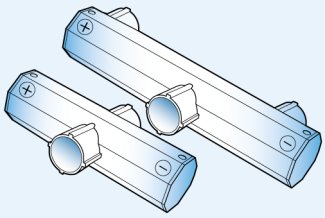




Connector

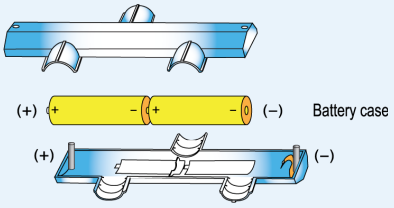
Connectors are used to connect each part.

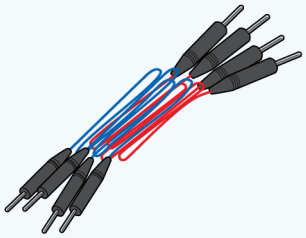




Battery Case

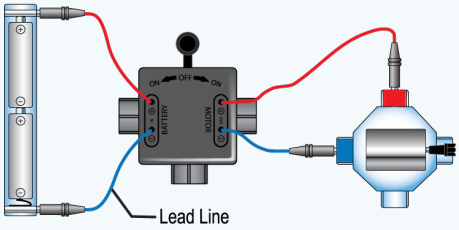
The Battery Case can hold 2 - AA batteries, which supply power to drive the models.

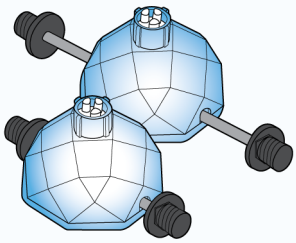




Lead Line

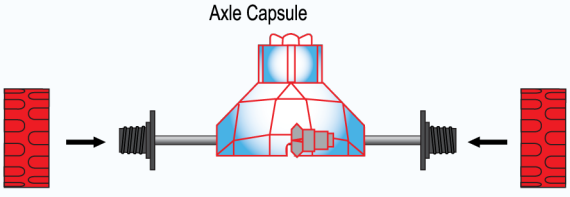
The Lead Line is used to connect the Battery Case, Motor Capsule, and Switch Box to deliver current.

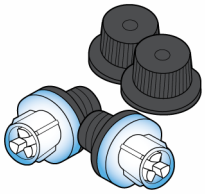




Axle Capsule

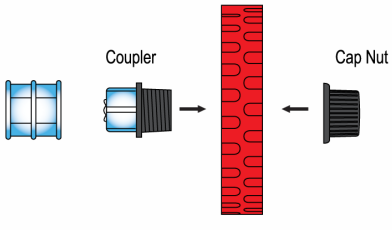
The Axle Capsule is used by connecting to the Axle support. The screw ends of the Axle support allow for attaching wheels and propellers. (These should be attached by pushing firmly, until a “click” sound is heard.)



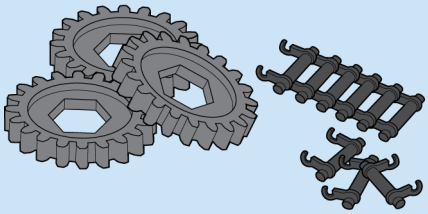


Coupler and Cap Nut

Couplers and Cap Nuts are connected to a wheel or propeller to allow engagement with gear rotation.

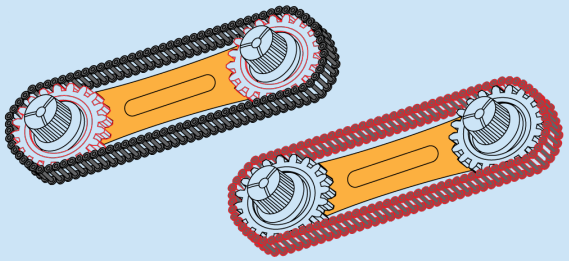


2 Basic Parts



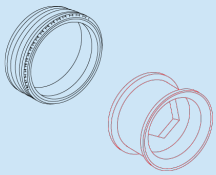
Gear Wheel and Chain

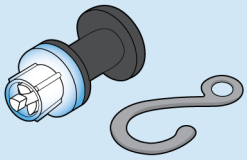
Gear Wheels and Chains are used to deliver power to each other by connecting two gear wheels with a chain.



Cable Tire

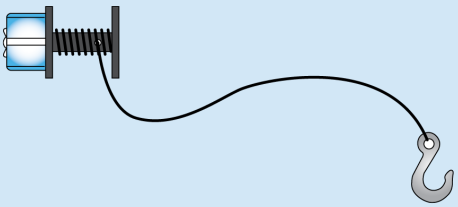
Cable Tires can be attached to small wheels to move a cable car on a thread.

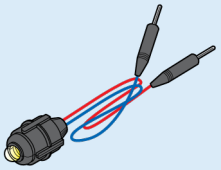




Winding Drum and Hook

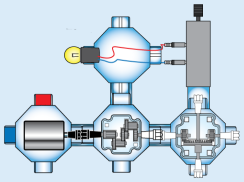
Winding Drum and Hook are used to wind up thread and lift objects up and down by using rotating force.

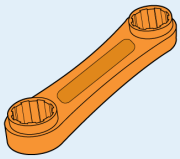




Lamp

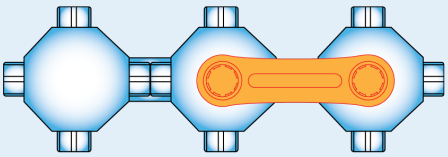
Lamp can be used by connecting both wires to the Switch Box (+ or - polarity is stated).

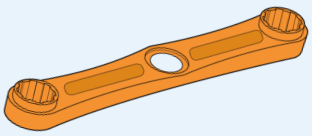




Straight Bar Connector (S)

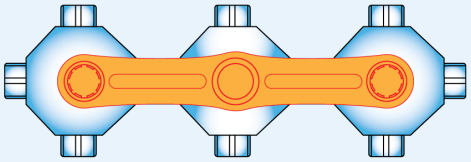
Straight Bar Connectors (S) are used for fixing two capsules horizontally or vertically.

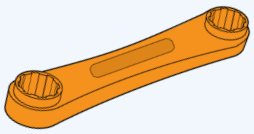




Straight Bar Connector (L)

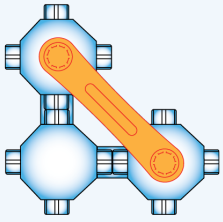
Straight Bar Connectors (L) are used for fixing three capsules horizontally or vertically.

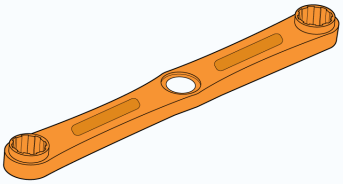




Diagonal Bar Connector (S)

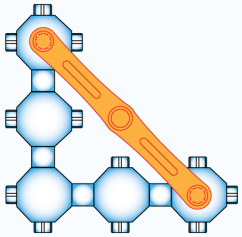
Diagonal Bar Connectors (S) are used to fix two capsules diagonally (45 degrees).





Diagonal Bar Connector (L)

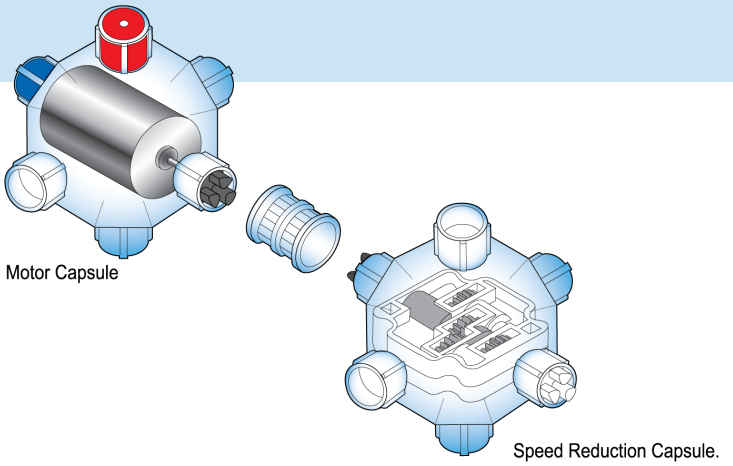
Diagonal Bar Connectors (L) are used to fix three capsules diagonally (45 degrees).

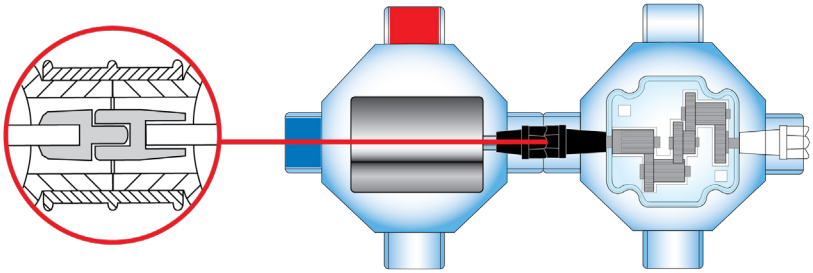


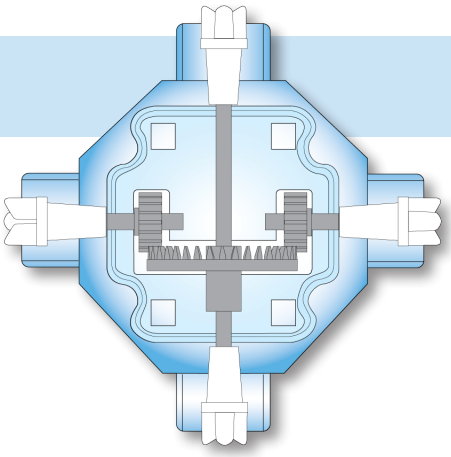
3 Principles of Operation

Connecting Motor Capsule and Speed Reduction Capsule

- Speed Reduction Capsule are designed to have the same number of rotations. In other words, when the motor capsule rotates 23 times, the black gear of the Speed Reduction Capsule also has 23 rotations. While the black gear makes 23 turns, the gray gear on the opposite side is designed to make one turn.
- However, the gear will not move if the gray gear of the Speed Reduction Capsule is connected to the black gear of the Motor Capsule.
- Capsules need to be connected properly through their gears for correct operation.



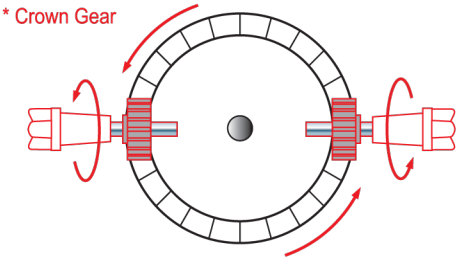


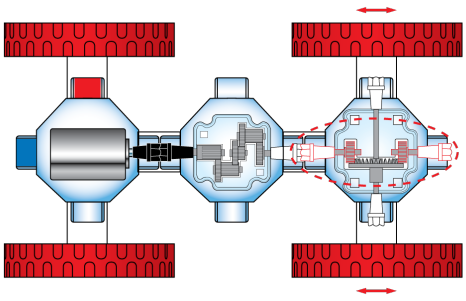


Crown Gear Capsule

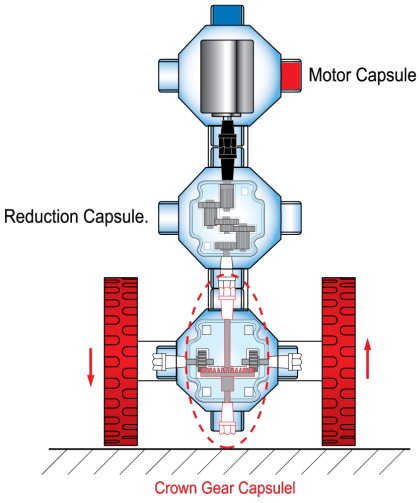
Composition
The Crown Gear Capsule consists of 3 parts (1 big gear and 2 small gears).

Features
The Crown Gear Capsule is designed to create forward movement, reverse movement, and rotate of the product. The different directions can be achieved by connecting the appropriate gears.



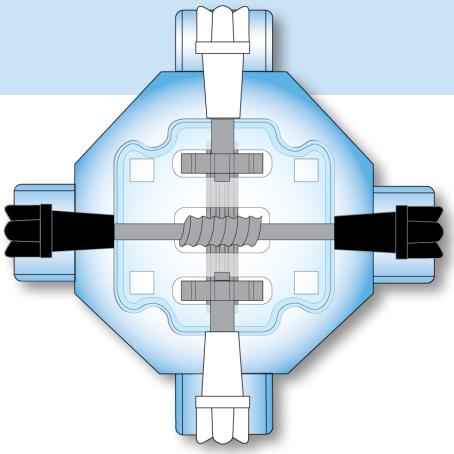


Connecting for Forward/Reverse Movements
By connecting the small gears in the direction of the Speed Reduction Capsule, both ends of the big gear will rotate in the same direction. Therefore, the wheels assembled at both sides of the big gear will rotate in the same direction, creating forward/reverse movement.



Connecting for Rotation
By connecting the big gear in the direction of the Speed Reduction Capsule, and connecting small gears with both sides of the big gear, rotating in different directions, the product repeats rotating without forward/reverse movement.

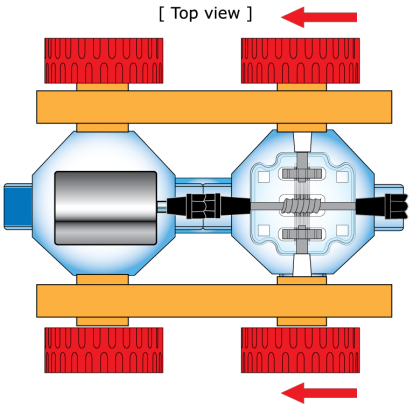
3 Principles of Operation



Worm Gear Capsule

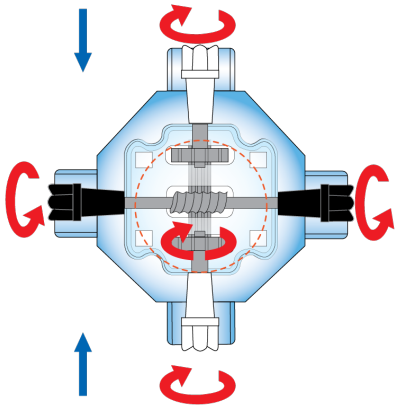
Composition
The Worm Gear Capsule consists of 3 kinds of gears
(Black Gear, Small Gear, and Worm Gear)

Features
The Worm Gear Capsule is designed to contain the characteristics of both the Speed Reduction Capsule, which reduces rotating speed and increases power, and the Crown Gear Capsule, which converts the power delivery direction to 90 degrees.



A capsule containing the combined attributes of the Speed Reduction and Crown Gear Capsules

- Driving a model after connecting the black gears of the Motor Capsule and the Worm Gear Capsule will bring the same effect as connecting the Speed Reduction Capsule, the Crown Gear Capsule, and the Motor Capsule.
- Meanwhile, the black gear on the opposite side of the black gear connected to the motor will deliver the power of the motor without increasing it.



Worm Gear in the center increases the motor power

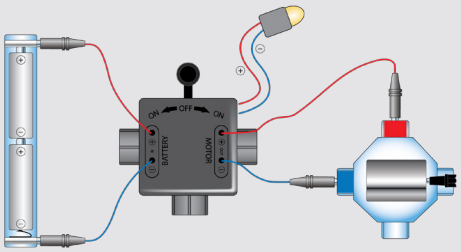
- When the rotating force is delivered to an ordinary gear axle in an overload condition, the motor may stop rotating due to low power.
- However, if the motor rotates through the black gear of the Worm Gear Capsule, it will have higher power. This is because the rotating speed of the two small gears in 90° direction will decrease, and their rotation force will increase.
- Also, the black gear on the opposite side of the black gear connected to the motor will deliver the power without increasing it, resulting in the possible stoppage of rotation in case of an overload around the connecting area.

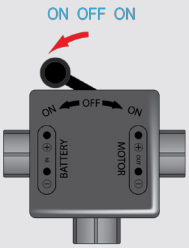
Unlike the Speed Reduction capsule, the Worm Gear Capsule has 2 black gears that can be connected with the motor. Therefore the black gear of Worm Gear Capsule can be connected with the black gear of the Motor Capsule regardless of its direction.

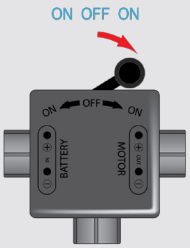
How to connect the Switch Box

- Connect the Battery (IN) of the Switch Box with the ‘Battery Case’.
- Connect the Motor (OUT) of the Switch box with the ‘Motor Capsule’.
- Connect the lamp with ‘Lamp (OUT)’ in the back of the Switch Box.

The product will move forward and backward by moving the red handle on the Switch Box to the right and left.







4 Applications

Propeller (Fans and Ventilator)

Study Area:
Variables that affect propellers
Differences between fans and ventilators

Points of Investigation:
Learn about the angle of a fan propeller (3rd Law of Motion)
- Adjust the angle of the wings on the propeller to learn about the strength of the wind generated.
- What are some of the propeller-driven products around us?

What is the difference between a Fan and a Ventilator?
- Change the direction of the connected switch and operate. What happens to the air flow?
- Explain the directional change of the propeller's rotation by using the + and - direction of the electrodes.

STEM Challenge
Build a better fan to cool the house. Build it with the worm gear or without?

Use the Design Process to Solve a Problem

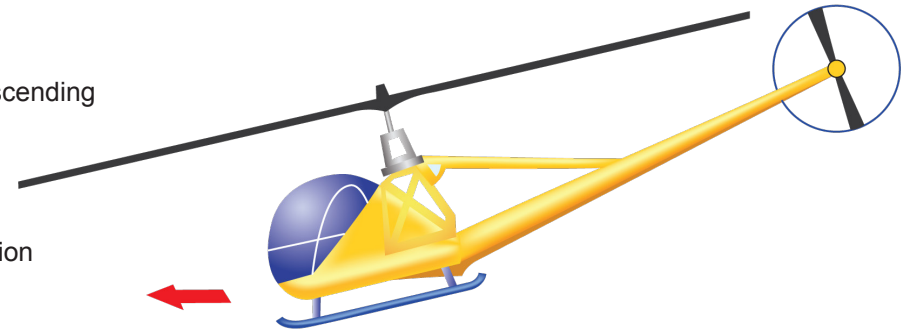
1. **STEM Practice - Possible problems to solve**
   - ventilate a greenhouse
   - cool zoo animals on a hot day
   - keep audience cool at a school graduation
2. **Investigate possible solutions**
3. **Decide the type of functions of your prototype. How will it solve the problem?**
4. **Construct the prototype with capsules and parts.**
5. **Test if the prototype can complete your chosen function.**
6. **Investigate ways to improve your prototype.**

Helicopter

How can a helicopter fly?
- As a helicopter propeller rotates, the movement creates lift – air has to travel further and therefore faster over the wing, than below it. This causes the pressure below the wing to be higher, than on top, which then causes the helicopter to ascend. (Newton's 3rd Law)
- The aforementioned lift applies only to ascending and is unable to adjust direction. This is the reason why helicopters need a Tail Rotor (often called tail propeller).

Main Rotor
- generates lift for vertical ascending and descending
- angle of attack
- speed of rotation

Tail Rotor
- prevents body rotation and maintains direction



Origin
- Dragonflies: the observation of Dragonfly flight inspired the development of the helicopter.
- Origin of Propeller: A propeller is on the list of inventions of Leonardo da Vinci. Though, even earlier in history, there is record of a hydraulic turbine that utilizes a spiral curve in ancient Egypt.

4 Applications

Power Transmission (Car)

Study Area:
Variables that affect velocity and acceleration
Laws of Motion

Points of Investigation:
Learn about Acceleration (2nd Law of Motion)
- Check the speed at the starting point, and in the middle.
- Identify other things around us that we can use to learn about acceleration.

Learn about the Law of Inertia (1st Law of Motion)
- Why does my body lean forward when I am in a car and the driver suddenly brakes?

Have a Car Race
- Let a friend use the big battery case and the other friend use the small battery case, and check whose car runs faster.
- Why did one make a later finish?

STEM Challenge

Cleveland, Ohio needs snowplows:
Build a snowplow that can move the most snow.
We will use blocks as the mass we move.

- Try moving snow with a plow built with the worm gear and without?
- Which snowplow stalls and which snowplow does not?
- What is the maximum mass your snowplow can move without stalling?
- Does your snowplow work better with tread on the wheels or without?
- What advantage does the tread give your snowplow? *(Increases friction between the ground and the plow).*
- How steep of a hill can your plow climb without the tread? With tread?

Use books and a ramp to measure this.
You can use a spring scale to measure the pulling force of your plow (this will also be the pushing force). The work in is always going to be more than the work out.

Use the Design Process to Solve a Problem

1. **STEM Practice - Possible problems to solve**
   - Build a new car ride at the amusement park
   - Build a snow plow
2. **Investigate possible solutions**
3. **Decide the type of functions of your prototype. How will it solve the problem?**
4. **Construct the prototype with capsules and parts**
5. **Test if the prototype can complete your chosen function**
6. **Investigate ways to improve your prototype**

Speed

What does Speed mean?
Speed means the distance moved within the time given

m/h - distance moved per hour (unit: miles)

How to read: m/h 80m/h = moves 80 miles per hour

How to calculate the speed:
Total distance traveled/total time traveled

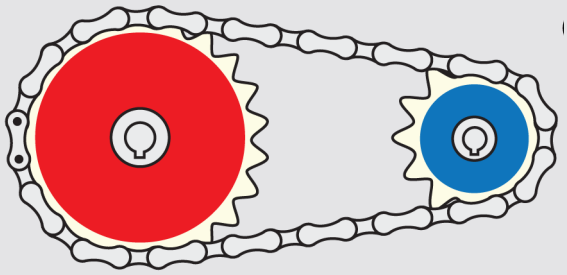
Speed of different objects:

Boeing 747	578 m/h	
Sports car	150 m/h	
Cheetah	62 m/h	
Shark	25 m/h	
Marathon Runner	12 m/h	

Power Transmission with a Chain (Motorcycle)

Study Area:
Learn how to use the power transmission chain.

Points of Investigation:
Find the differences between Chain and Gear power
- Chains can transmit the power even if the two axes are separated by distance.
- Bicycles, motorcycles, and tanks move using chains. What else?
- How do gear size differences affect the transmission of power?



Differences between Chain and Belt
- A belt transmits power by using frictional force, whereas a chain is used when the two axes have comparable distance and a sure way of power transmission is needed.
- Conveyors, as the ones at the airport, are moved by a belt.

Use the Design Process to Solve a Problem

1. **STEM Practice - Possible problems to solve**
2. **Investigate possible solutions**
3. **Decide the type of functions of your prototype. How will it solve the problem?**
4. **Construct the prototype with capsules and parts**
5. **Test if the prototype can complete your chosen function**
6. **Investigate ways to improve your prototype**

Gravity (Cable Car)

Study Area:
How does Gravity affect hanging objects?

Points of Investigation:
What is Gravity?
- Gravity is an attractive force between two objects. All objects are influenced by Gravity

Why are the cables (on a cable car) not tense?
- Hang a heavy mass in the middle of a rope, and pull the end of the rope to make it straight. Is it possible?
- The cable is not in a straight line but a little bent. The mass pulls on the rope while the earth pulls on the mass.

Use the Design Process to Solve a Problem

1. **STEM Challenge - Possible problems to solve**
   - Carry a GoPro across the top of a gym to videotape during a school pep rally
2. **Investigate possible solutions**
3. **Decide the type of functions of your prototype. How will it solve the problem?**
4. **Construct the prototype with capsules and parts**
5. **Test if the prototype can complete your chosen function**
6. **Investigate ways to improve your prototype**

STEM Challenge

Your school wants to video everyone from above during a school assembly.

Make a pulley car to carry a camera (a GoPro camera would attach easily) across the top of the gymnasium using pulleys and string.

Can you devise a method to make the pulley car turn off or change directions? What does the chain drive between the gears allow your device to do?

5 STEM Challenges

Science, Technology, Engineering & Math Challenges

1. Tire Tow Challenge

A local lake has had several tires thrown in it and they are too large for a person to pull from the water manually. Design and build a machine that can use a hook to pull them out. Create a pull-off bracket system - the group whose machine can pull the tire out successfully in the shortest amount of time wins.

A second challenge is to build a machine that can also pull the heaviest tire out.
You must document your design (include the components used, and why you used it.)
Measure the pulling force of your machine using a spring scale and your method for measuring it. Do multiple trials and predict the mass of the tire that your machine can pull using Newtons second law of motion:
Force = mass x acceleration.

- How can you measure the angle of your towing line with hook?
- How does the angle affect your force?
- Does the mass of the hook and line affect your pulling force?
- What is impulse and how does it affect your design?

Helpful equation: Impulse = Force applied x change in time it is applied.

- How does pulling the tire quickly versus pulling it slowly affect your machine?
- Is safety a factor?
- The power of your machine is work/change in time. How much power does your machine have? What can you change in your design to increase power?

2. Tug of War Challenge

Design and build a robot machine to win a tug of war.

3. Cave Explorer Challenge

Build a robot that can explore a dark cave.

4. Sky Diving Challenge

Design and build a machine to simulate a sky-diving experience. Use a piece of paper or a balloon as your sky diver.

- What is the mass of your sky diver?
- What is the maximum weight your fan can support?
- Can you calculate the force of the air your fan is exerting?
- Draw a force diagram for your sky diver.

5. Snail Race Challenge

Build a car that can “win” a race by crossing the finish line last – a snail race.

6. Biomimicry Challenge

Biomimicry looks to nature to solve human engineering problems.
For instance, how can an ant lift 1000 times their own weight? How are they built that can allow then to do that and can you design and build a machine that can do the same?

- How are individual pieces of the IQ key and their designs (shapes) inspired by nature? Challenge students to build an IQ Key machine that accomplishes a task using biomimicry as inspiration.
- Research other examples of biomimicry online.

7. Playground Challenge

Design and build a playground ride.

- What simple machines do you use to build your ride?
- How do you make your ride safe for children?

8. Quality Test Challenge

An athletic shoe company needs a machine that they can use to test shoes for quality by kicking a ball. Design a prototype machine that can kick a small ball.

- How much power does your machine have?
- How often can it kick a new ball?
- What is the kinetic energy of the ball?
- How much work can the machine do to a ball?

9. Car Chase Challenge

Catch a thief car chase challenge: the teachers creates a machine that moves at a constant rate, but is slower than the maximum speed possible using the IQ key system (replacing one of the batteries with a dead battery will accomplish that). Challenge student to measure the velocity of your car and to then design and build a car that can catch your car.

10. Submarine Challenge

In 1954, The Chicago Museum of Science and Industry dared to move a German U-505 submarine that was captured in WWII across the great lakes and from Lake Michigan to the museum for display.

Moving the 770 ton submarine across land was an incredible feat. How did they do it?
Assign teams to research how it was done and to design and build machines that can lift a submarine out of water and then move it to a museum.

Keep an engineering log of the physical quantities you measure using your prototype to move the submarine. The teacher should provide a miniature toy submarine for you to make measurements that you need to test your prototype, but you cannot test your machine on the submarine directly until all groups are ready to move it.

Physical Quantities to Measure Using IQ Key Machines

- Force = Mass x Acceleration
  Force x Distance = Change in Potential Energy
  Force x Distance = Change in Kinetic Energy

- Acceleration = Change in Velocity (Velocity final – Velocity initial)

- Kinetic Energy = 0.5 x Mass x Velocity^2

- Gravitation potential energy = Mass x Gravity x Position above Center of Earth (frequently referred to as height)

- Work = Force x Distance
  Work = Change in Potential Energy (PE final - PE initial)
  Work = Change in Kinetic Energy (KE final - KE initial)

- Power is the rate at which an energy conversion occurs.
  Power = Work / Change in Time.
  How much work are their machines doing?

- Impulse = Force applied x Change in Time

6 Competitions

Rube Goldberg Competitions

Use several IQ Perfects and ordinary household materials to build a complex machine to do a simple task and enter it in the Rube Goldberg contest. Students should brainstorm how many steps their machine has and each simple machine should be used at least once. An inclined plane, a pulley, a screw, a wheel and axle (gear system), a wedge, and a lever.

Examples: http://rubegoldberg.com/

Invention Competitions

State Science Days

7 Mechanical Advantage & Efficiency

Measure Mechanical Advantage and Mechanical Efficiency Using the IQ Key

1. **How do you determine the electrical energy supplied from the 2 AA batteries used with the IQ Key?**
   - 1.5 volts means 2.40 x 10-19 J of energy supplied. Two batteries will double this. This is the work (change in potential energy to kinetic energy) into the motor. It is possible to use the energy in and measure the energy out by measuring the mass and speed of an IQ Key car.
   - This can be done with a pan balance, stop watch, and meter stick. A Vernier motion detector would simplify this for teachers.
   - KE = 0.5 x mass x v2. The PE will be more than the KE due to internal losses to friction. Since mechanical efficiency is work out/work in x 100, KE/PE x 100 tells you what the mechanical efficiency is.

2. **Measure mechanical advantage of the screw in the Worm Gear Capsule:**
   MA = diameter of screw times 3.14 divided by the distance between two threads (the lead). MA=3.14 d/l
   - Determine a method to measure and calculate this.

3. **MA advantage of the Worm Gear**:
   - Count the number of teeth on the worm gear. You might want to mark one of the teeth with a bit of marker to keep track of which teeth you have counted. Or, you can turn the reduction axle (which will turn the worm) and count turns until you have rotated the worm gear once. The number of teeth on the worm wheel tells you the reduction ratio.
   - If 23 turns of the worm turns the worm wheel once (23 teeth on the worm wheel) then it is 1:23. The mechanical advantage of the gear set is then the inverse of the reduction ratio - 23.
   - The gear transmits torque force. (You must determine how many turns of the worm turns the worm wheel once to find the MA of the IQ Key Worm Gear Capsule.)

4. **Measure torque: Turning force of the motor shaft.**
   - Attach the propeller directly onto the motor shaft and connect the batteries. Turn it on so that the propeller is moving. Notice that it is moving very fast and pushing a lot of air.
   - However, you can stall it easily by inserting a piece of paper. You can quantify this turning force by using a Vernier or Pasco force sensor to stall the propeller.
   - Now attach the worm gear to the motor shaft before the propeller. The worm gear increases torque by slowing down the motor shaft.
   - Attach the propeller to one of the side shafts. Turn it on. Observe that the propeller moves much slower and moves very little air. Insert the piece of paper. Does it stall?

- Use the force sensor to quantify the new torque. Gears are used to change speed and torque. The motor shaft before the worm ear must turn 23 times before the motor shaft attached to the propeller turns once. Notice that the machine slows down but gains torque and therefore will not stall.
- Cars and bicycles use gears to increase torque to go up steep hills without stalling.

5. Mechanical advantage of an inclined plane:

- Use an IQ Perfect crane to determine the mechanical advantage of an inclined plane.
- Use IQ Key parts to build a crane. What mass can your crane pick up?
- Now position an inclined plane and use the crane to pull the mass sideways up the ramp. What mass can it lift the same height by pulling it horizontally and vertically at the same time?
- The mechanical advantage of your inclined plane is the length you pull it horizontally divided by the total height. Since work equals force x distance if you increase the distance it will take less force to do the same work. However, since some energy will always be lost to friction the work in must still be greater than the work out.
- You can measure the pulling force (input) of your crane using a spring scale at the exact angle of your incline plane. Determine the vertical force of your mass using mass x gravity. The amount of mass the crane can actually pull will always be less than it ideally pulls.

6. Mechanical advantage of a lever using the IQ Key:

- Make a vehicle that will supply an input force.
- You are going to need one of the long arms to use later, so whatever machine you build, make sure to save one of them to use as a lever arm. If you do use all the long arms, find something else to use as a lever, for example, a ruler with a hole cut through it.
- Measure the input of your vehicle using a spring scale. You can increase the input force of your machine by using a lever.
- Slide the long arm through the middle on a ring stand. Your lever should be able to rotate freely.
- Attach your car with string to one end of the arm.
- Attach the spring scale to the other end. Make sure the attachment point of your car is the same as the attachment distance of your spring scale. What is the output force of your car now? Done properly it should be almost the same (small losses because efficiency is never 100% - have students calculate this by measuring the pulling power of the vehicle directly first). Work out/work in x 100. The direction of the pull is changed.
- Now change the distance that the car is attached at. Make it closer to the pivot point. You should have a short arm and a long arm now. (The long arm is on the spring scale side) What is the output force now? Is it greater?
- Calculate the mechanical advantage of your lever arm.
- Calculate the mechanical efficiency - The work out/work in x 100. W = Fd. The car has to travel twice as far now to generate the greater force so the work done is still greater although you have increased the force applied.
- What happens if you make the spring scale the short lever arm? Change the fulcrum to the end and attach the car and spring scale. (a 2nd class lever)

7. Wheel and Axle:

- Build a hoist but instead of using part #26 uses the large wheel without tread. Use a rubber band to attach the string.
- How long does it take to lift the gear? Now attach the smaller wheel without tread.
- Attach the string and measure how fast it lifts the gear. Is one faster?
- Can one lift heavier masses? Use a mass set to test this.
- Calculate the mechanical advantage of both your wheel and axle set ups.
- Use a spring scale to measure the maximum pulling force of your wheel and axle. Determine the maximum mass it can lift. Use the spring scale after you have found the maximum to measure the masses puling force. Is one smaller? The work in is always greater than the work out.

8 Sample Lesson Plan

Materials

- IQ Key - for example the Perfect 600
- paper lunch bag
- packing peanuts to fill bag
- Internet access for research and presentations

Goals and Objectives

- Learn about engineering and its applications.
- Design, build, and refine a device that uses energy.
- Observe energy demonstrations.
- Learn about energy conversion, circuits and using machines and energy for problem solving.

Activities

1. What is energy demonstration:

- Use a paper lunch bag full of packing peanuts and an IQ Key machine to guide students while they create a working definition for energy.

- Set up the peanuts on a lab table. Prior to the demonstration build a machine that allows the hook to function, but also allows the machine to roll (e.g. like design 11 in the Perfect 600 guide, but other models or designs will work as well).

- If you ask the class what energy is – many will be able to recite – “energy is the ability to do work” without really knowing what that looks like or what it means.

- Ask them how you can use the IQ Key to change the bag of peanuts. Students should lead you through using the machine to push the peanuts, pull the peanuts, and lift the peanuts. They may even prompt you to drop the IQ Key machine on the peanuts.
  The push and pull transfers kinetic energy to the peanuts from the moving machine – also kinetic energy. The transfer is the force applied by the IQ Key machine for whatever distance it pushes or pulls it. That’s work.

  Work = Force x Distance

- Lifting the peanuts with the hook is kinetic energy transforming into potential energy and once again work transfers the energy from the IQ Key to the peanuts. Dropping the machine is potential energy transforming into kinetic energy, also transferred from the IQ Key to the peanuts through work. Work is a change in energy - and energy is the ability to do work. Work is a change in the peanuts and a change in the peanuts means work was done.

2. Energy bar diagrams:
A common way to represent energy changes is with energy bar diagrams (see example to the right).

The bar diagram on the left is for before the system changes, the center circle is the system, and anything outside of the circle is the surroundings, and the bar diagram to the right is the system after it changes. Observe that internal energy is only in the after the system changes diagram.

- Students will struggle initially to define their systems in order to describe the energy changes. The IQ Key is many simple machines (remember: tools that make work easier) working together to do a big or complex work. The transparent pieces allow students to see the individual simple machines doing their small bit of the energy transfer through a variety of transformations.

- Start with a small and easy to describe energy transformation and transfer. Have students define the system as the entire IQ Key machine and nothing else. Draw a quick representation of the machine in the circle or just write its name.

- Start with the machine not turned on. What energy does the system have right now?
  It is not raised above the table so draw no bars for gravitational energy. It is not compressed or stretched in any way so no elastic potential energy. It is not moving so no kinetic energy.

- What about chemical energy? What are the batteries?
  Draw four bars vertically to represent the chemical potential energy (each horizontal line represents one bar) in the 'initial' diagram. Now turn on the switch - the machine is now moving.
  It now has kinetic energy: draw one bar vertically to represent the kinetic energy in the 'final' diagram.

- Where did that bar come from? It came from the chemical energy.
  The chemical energy is now a smaller bar by a little over the first horizontal line.

- Batteries run out of energy don't they? Why is the kinetic energy account smaller than the amount of energy lost by the battery? This is because the remainder is in the internal energy account.

- Some energy is always lost to heat into the surroundings during every energy transformation and transfer. An arrow directed out of the system circle should be drawn and labeled heat. Just a small one – the bar on the arrow should be the same size as the bar under your internal energy column.

- Do a new bar diagram making the peanuts your system. The IQ Key machine is now part of the surroundings.
  Any energy in the 'initial' state? Have the IQ Key move the bag by pushing it – it is doing work to the system.
  Draw an arrow directed inward towards the system and label it 'work' and give it some bars. The after diagram should have kinetic energy bars nearly equal to the work done (but not the same! remember: some is always lost to heat).

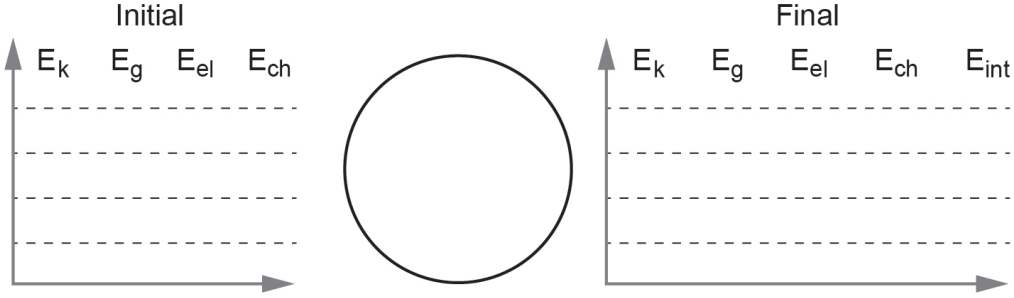
3. Observe one of the gears or drive shafts in the IQ Key. They are each doing work to each other through a series of energy transfers until the more complex machine does work on a larger scale. How many different energy transformations can you name inside the machine you built?

4. How many different transfers are in a machine you built?
Why do engineers make drawings before they build?
Why do they make prototypes?

- What kind of machine do you want to build with the IQ Key system? Older students can quantify the energy transfers using mathematics.

- If you have enough IQ Key sets for teams, ask students to design and build a machine to solve a problem of their choosing. They will demonstrate to the class how their machine works in a technology exposition. They should explain the problem their machine solves and the scientific knowledge used to solve it.

Energy Flow Diagram



E_k = kinetic energy, E_g = gravitational potential energy, E_{el} = elastic energy, E_{ch} = chemical energy, and E_{int} = internal energy

8 Sample Lesson Plan

Discussion and Real Life Applications

1. Discuss the three ways in which energy moves from a system to the surrounding (Heat, Radiant, and Work).

2. Ask students to research and present how simple machines work, such as screws, wedges, levers, wheels, pulleys, and gears. Can your students identify these simple machines in the construction of a complex machine?

3. Have students list the green energy machines they know and how we are using them to benefit society. Windmills and solar panels are becoming very common.

4. Students can research Leonardo da Vinci – a famous artist and inventor of many machines.

5. How does the IQ Key motor work? How about the other capsules? Have students write their own explanation before comparing to pages 4-6.

6. How are motors used to generate electricity? What makes that motor turn its axle? (Not a battery like an IQ Key such as the Perfect 600)

Assessment

Use general participation in activities and discussion, vocabulary, and presentations as a base for assesment.

Vocabulary to use for lessons and assessment:

- Kinetic energy
- potential energy
- energy transformations
- energy transfer
- work
- radiant
- heat
- system and surroundings
- simple machines
- engineering design process
- interdependence of science and technology

Next Generation Science Standards

Students who demstrate understanding of the activities in the Sample Lesson can:

4-PS3-1.
- Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-2.
- Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

Standards Key

4 = 4th Grade
MS = Middle School
HS = High School
PS = Physical Science

4-PS3-4.
- Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

MS-PS3-1.
- Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

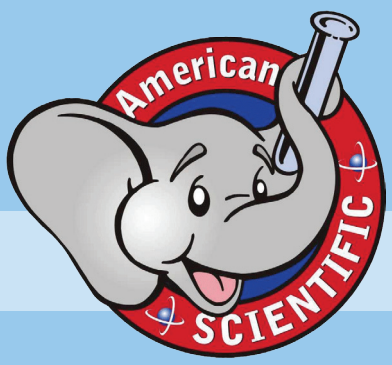
MS-PS3-2.
- Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.

MS-PS3-5.
- Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object

HS-PS3-1
- Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-2.
- Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS3-3.
- Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.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