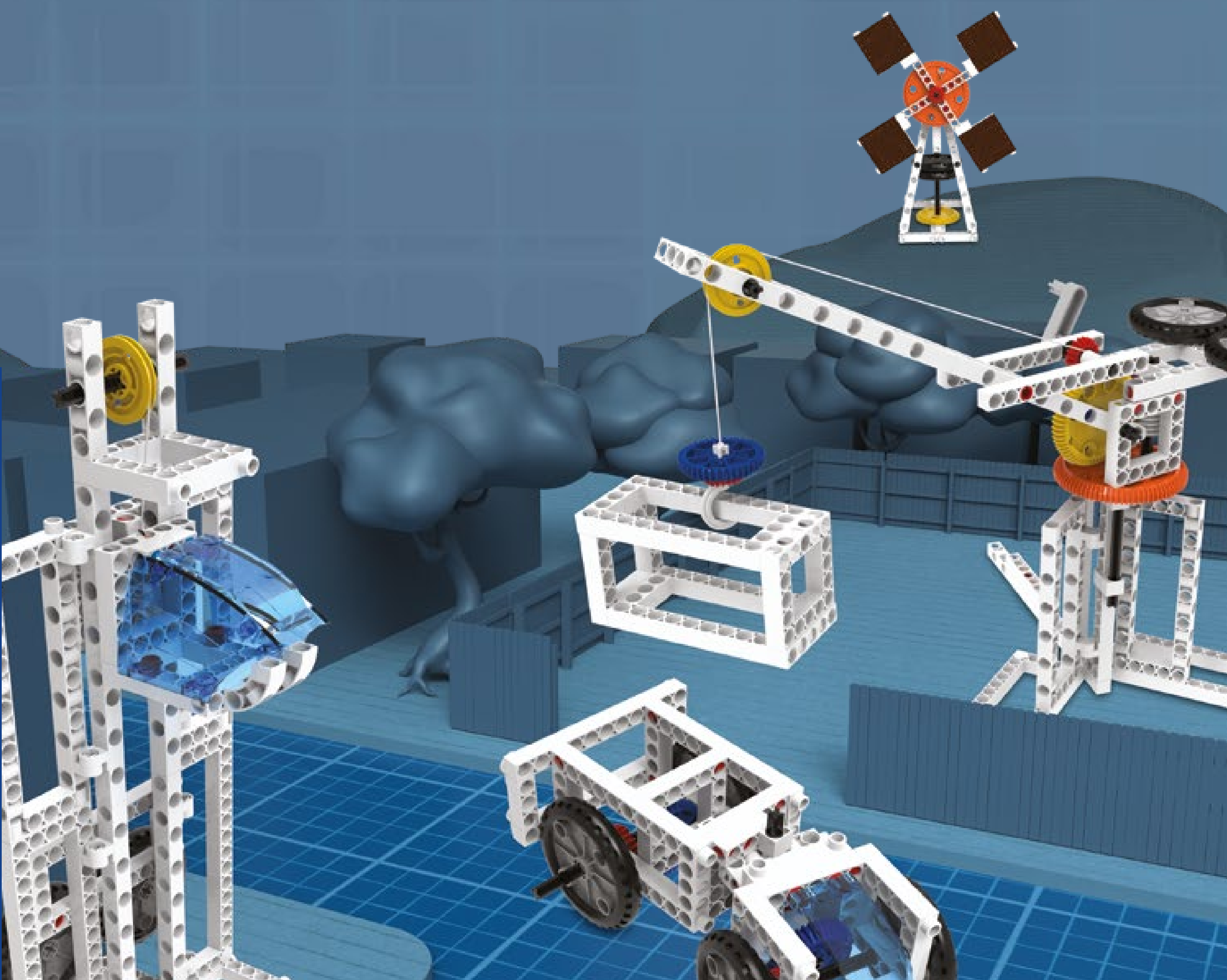
Experiment Manual

Mechanical Engineering

Machines & Vehicles



THAMES & KOSMOS

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››› IMPORTANT INFORMATION

Dear Parents and Adult Supervisors,

Engineering is an extremely exciting and varied field that touches on many aspects of our lives. It can be a lot of fun to figure out the amazing physical phenomena that we encounter every day and to put this understanding to use in machines, vehicles, and other mechanical devices.

This experiment kit will bring your child closer to understanding mechanical engineering and physics. With its wealth of simple models and experiments, your child will gain basic insights into the world of physics and its applications in various machines and vehicles — which will help them to understand and engage more deeply in the lessons taught in school.

The individual experimental models are assembled step by step using a modular construction system. It will require a little practice and patience at first. And your child will be particularly happy to have your help with the models that are identified as "difficult."

Some of the experiments will require items from your household. Discuss with your child beforehand which items may be used. From time to time, some string will have to be measured, cut, or tied with a knot. It will be best if you can offer your help here, too.

We wish you and your child lots of fun experimenting, discovering, and learning!

Safety Information

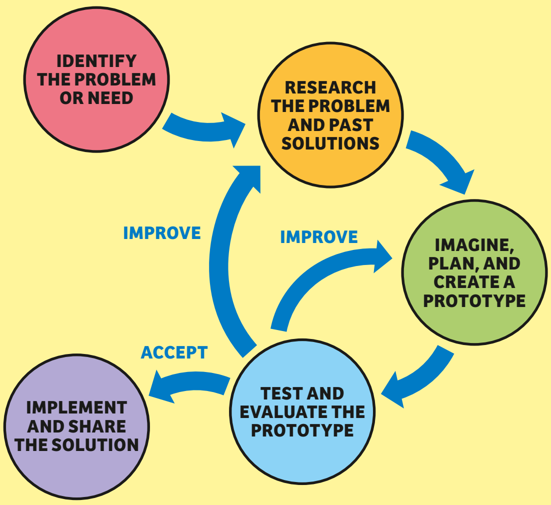
››› **WARNING.** Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled. Strangulation hazard — long cords may become wrapped around the neck.

››› Keep the packaging and instructions as they contain important information.

››› Store the experiment material and assembled models out of the reach of small children.

What Is Engineering Design?

Engineering Design is a general term used to describe a step-by-step process that engineers use to create things — from cars to computers, from airplanes to aerosol cans, from industrial machines to Internet routers, from skyscrapers to skateboards. Engineering design is an iterative process, which means that some or all of the steps can be repeated over and over again to improve the final solution. The engineering design process is not one specific set of steps, but rather can vary depending on the project. One example of the process is illustrated to the right.



You can practice an iterative engineering design process with all of the models that you will be building in this kit.

1. Identify the problem by asking the question: What problem is the machine or device attempting to solve?

2. Build and test the model. How well does the model solve the stated problem? Does it work as well as it needs to? Can it be improved?

3. Imagine, plan, and build a new version of the model. Retest it. Does the new model work better than the previous model?

What Is Mechanical Engineering?

Mechanical Engineering is all about designing and testing machines that move or involve forces. These machines can be anything from cars and airplanes to robots and wind turbines. Mechanical engineers use what they know about physics — like how things move, how forces work, and how energy flows — to build these machines and make sure they work safely and efficiently. They follow the engineering design process to plan, build, test, and continually improve their projects. They must balance factors like cost, time, materials, and quality. It's like being a problem-solving inventor who uses science to create things that help people and make the world better!

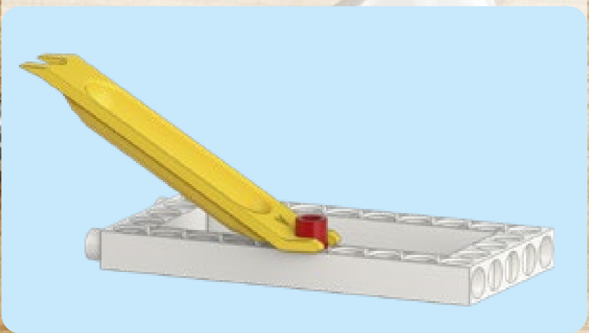
More force with the anchor pin lever

YOU WILL NEED

- 21 1 Square frame
- 8 1 Red anchor pin
- 39 Anchor pin lever

HERE'S HOW

- Firmly press the red anchor pin into one of the frame's holes.
- Try using just your finger to pry the anchor pin loose.
- Now try using the anchor pin lever to pry it out (see picture).



A simple experiment to get you started

A lot of problems can be solved as long as you have the right tools. The anchor pin lever offers you the advantage of a basic principle of physics — the lever principle.

WHAT'S HAPPENING?

If you are only using your fingers, it can be difficult to apply enough force to loosen the anchor pin. It's easier with the anchor pin lever, because it puts the lever principle at your disposal. Starting on page 37, you will be learning about this fundamental principle of physics and how you can put it to use.

READY FOR MORE?
Then come along into the exciting world of mechanical engineering...

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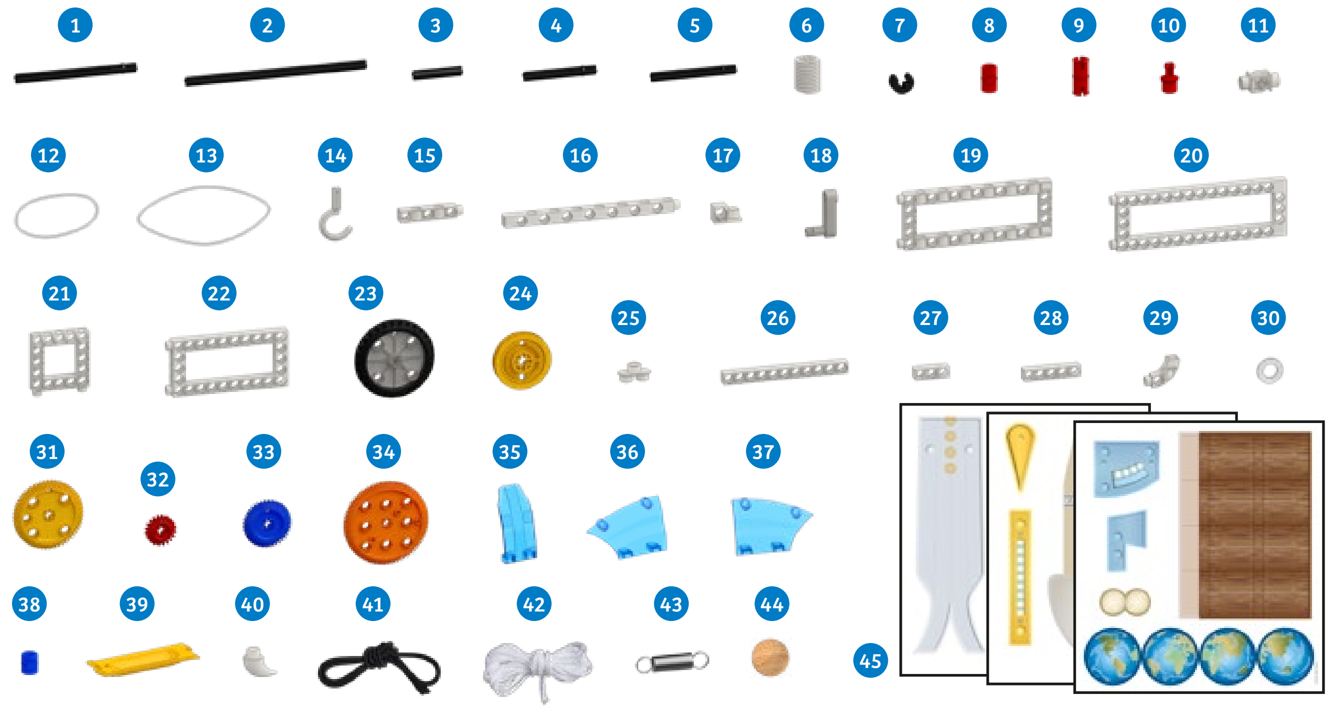
What's inside your experiment kit:



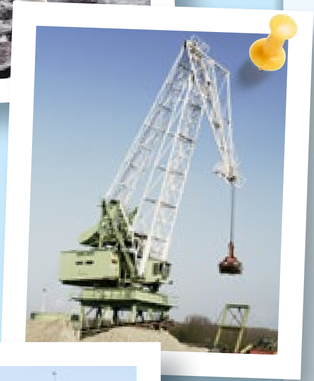
Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
❍	1	Axle, 10 cm	2	703 234
❍	2	Axle, 15 cm, without head	1	703 518
❍	3	Axle, 4 cm, without head	1	715 807
❍	4	Axle, 6 cm	2	703 238
❍	5	Axle, 7 cm	1	723 892
❍	6	Worm screw	1	715 046
❍	7	Axle lock	3	702 813
❍	8	Red anchor pin	30	702 527
❍	9	Joint pin	4	702 524
❍	10	Shaft plug	7	702 525
❍	11	Hinge	10	715 052
❍	12	Rubber band, medium	2	703 241
❍	13	Rubber band, XL	1	715 801
❍	14	Hook	1	706 533
❍	15	5-hole dual rod	2	715 675
❍	16	Long dual rod	4	715 676
❍	17	90-degree converter - X	5	715 051
❍	18	Crank	1	719 237
❍	19	Dual frame	2	715 045
❍	20	Long frame	3	727 602
❍	21	Square frame	6	714 284
❍	22	Short frame	3	715 044
❍	23	Wheel	4	715 049

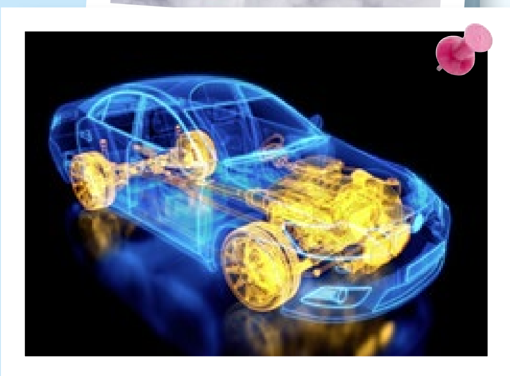
✔	No.	Description	Qty.	Item No.
❍	24	Medium pulley wheel	1	707 010
❍	25	Two-to-one converter	4	714 286
❍	26	11-hole rod	3	714 282
❍	27	3-hole rod	5	715 042
❍	28	5-hole rod	3	714 179
❍	29	Curved rod	2	714 285
❍	30	Washer	6	727 601
❍	31	Large gear wheel, yellow	1	715 047
❍	32	Small gear wheel, red	5	710 062
❍	33	Medium gear wheel, blue	2	716 179
❍	34	Extra-large gear wheel, orange	1	715 048
❍	35	Small body plate	2	715 280
❍	36	Body plate 3	1	714 276
❍	37	Body plate 4	1	714 277
❍	38	Blue anchor pin	2	717 767
❍	39	Anchor pin lever (Part separator tool)	1	702 590
❍	40	Horn	1	715 054
❍	41	Elastic cord	1	703 245
❍	42	String	1	714 240
❍	43	Spiral spring	1	714 475
❍	44	Wooden ball	1	703 243
❍	45	Die-cut sheets (3)	1	729 799

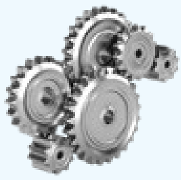
››› TABLE OF CONTENTS

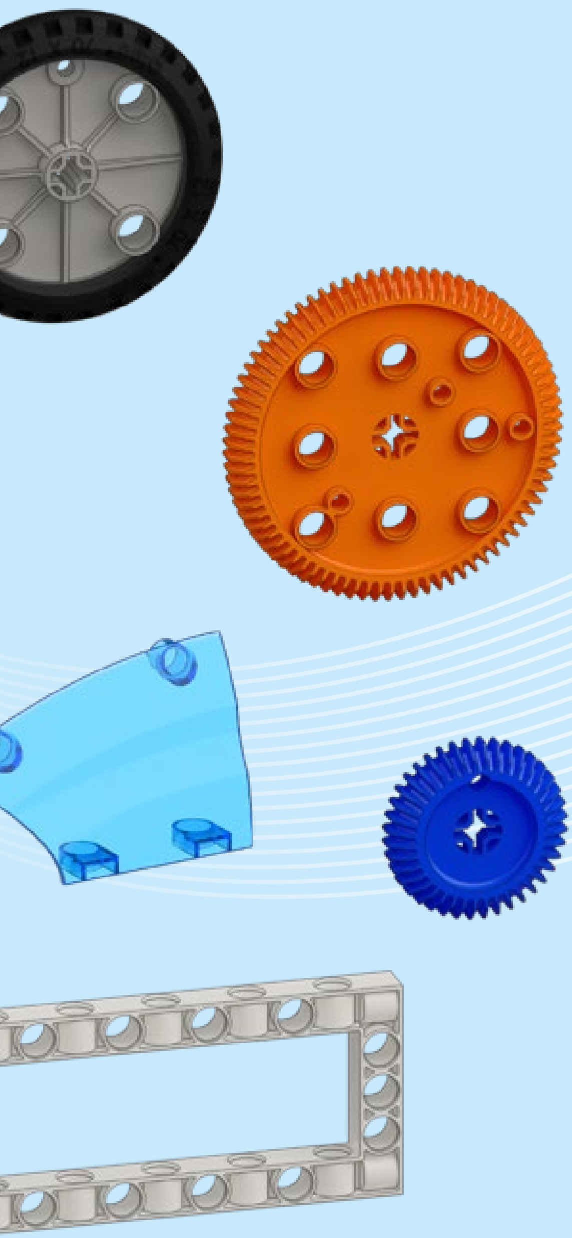
TIP!
You will find additional information in the "Check It Out" sections on Pages 18, 28, 36, 46, 57, and 65



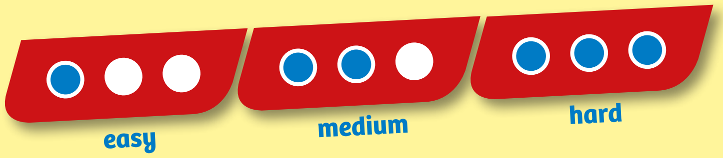




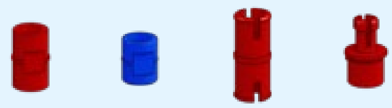


TIP!

Above the assembly instructions for each model, you will find a red bar that tells you how difficult that model will be to assemble:



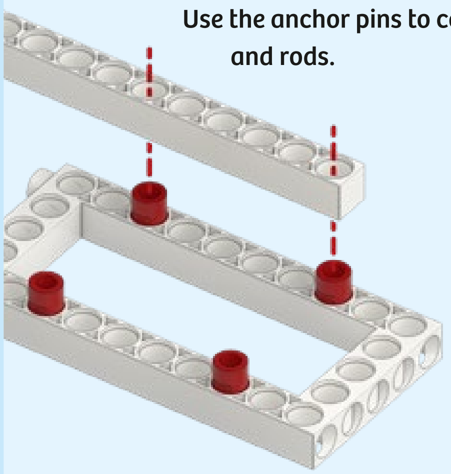
ANCHOR PINS AND CONNECTORS



Take a careful look at the different assembly components. Red anchor pins, blue anchor pins, joint pins, and shaft plugs all look pretty much alike at first glance. But when you assemble the models, it's important to use the right ones. The blue anchor pins are shorter than the red ones.

CONNECTING FRAMES AND RODS

Use the anchor pins to connect frames and rods.



GOOD TO KNOW!

If you are missing any parts, please contact Thames & Kosmos customer service.

Any materials not included in the kit are indicated in *italic script* under the "You will need" heading.

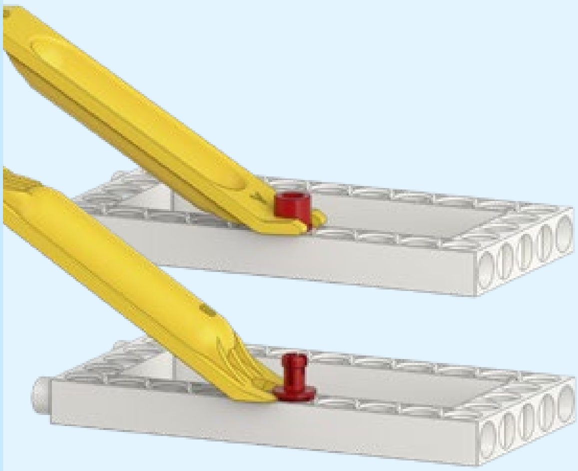
AXLES

Your kit contains axles (also called shafts) of various lengths. When assembling the model, always be sure that you're using the right one. There are axles that look the same all the way from one end to the other, and others that have a "head." Axles with a "head" always have to be installed the correct way around.

AXLE LOCKS

The axle locks are used to keep the axles from slipping. You can also install them after assembly.

THE ANCHOR PIN LEVER

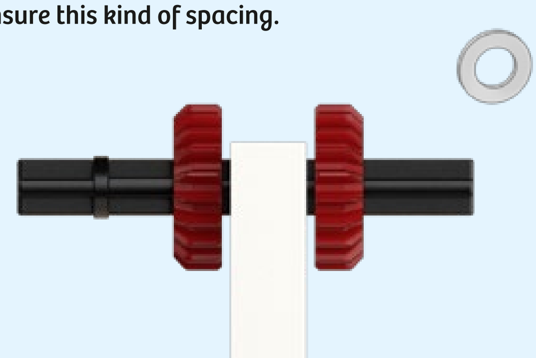


When you want to take your model apart again, you will need the anchor pin lever. You already had a chance to use it a little in the "Experiment to hit the ground running" on page 1.

Use the narrow end of the lever to remove the red anchor pins. You can use the wide end to pry out shaft plugs.

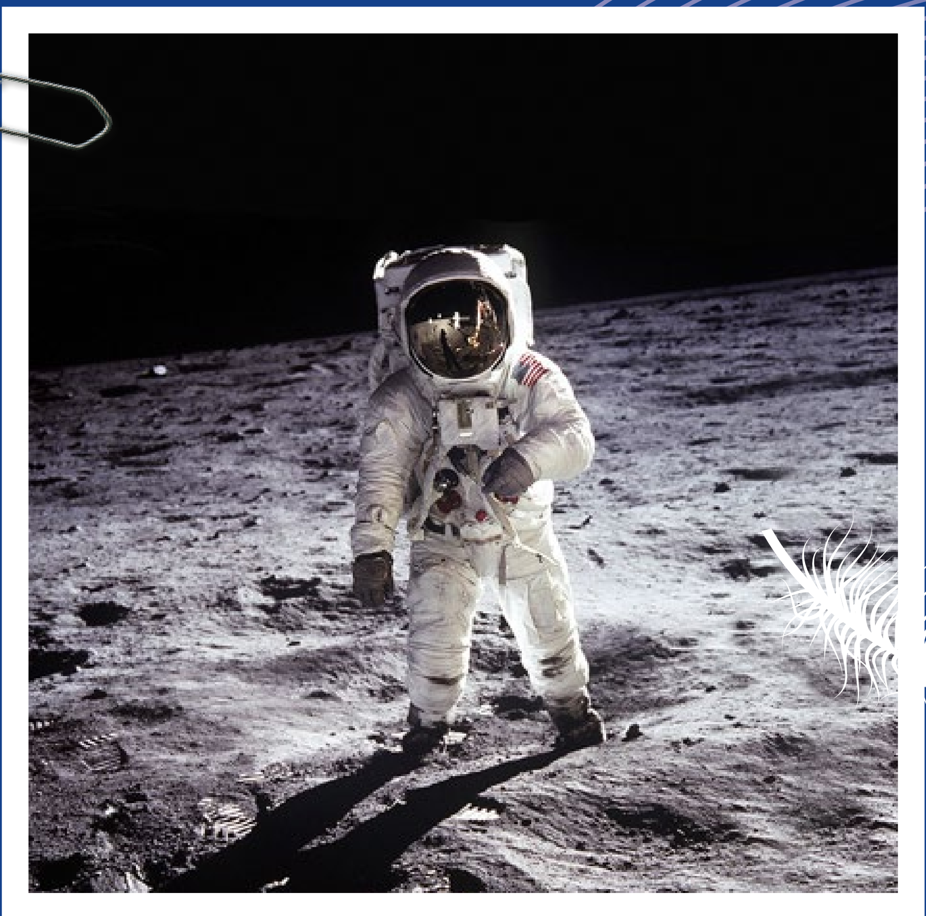
GEAR WHEELS AND PULLEY WHEELS

If gear wheels or pulleys are mounted too tightly against other components, they can be hard to turn. If you leave a gap of about 1 mm between the gear or pulley and an adjacent component, it will turn easily. In some of the models, a washer is used to ensure this kind of spacing.



Forces that Move Our World

Astronauts move weightlessly through space. Back on Earth, though, they will drop with a thud just like an apple falling from a tree. This chapter will explain why that is.



INTRODUCTION

NEWTON'S APPLE AND GRAVITY

Everyone knows that an apple will fall from its tree if you don't pick it first. But where exactly will the apple end up when that happens? And where will it end up if the apple tree is by a cliff? Can you predict it, or will it just fall "any old which way" to the ground and roll off the cliff just by chance?

Amazing though it may seem, it has only been about 300 years since anybody has been able to answer these questions and make a correct prediction. Isaac Newton, who was born in 1643, determined that all objects will move only if a "force" has acted upon them. The interplay of different forces, then, determines the path that the apple will take and where it will end up.

The reason that the apple falls at all is that gravity acts upon it. Gravity primarily acts in the direction of the heaviest object in its surroundings. For us on Earth, that object is the Earth itself! That is why gravity pulls things toward the center of the Earth, or directly downward. This force is also known as weight.

WEIGHT

You can calculate the weight of an object as follows:

Weight [N] = mass [kg] • local gravity [N/kg]

The direction of this force will be toward the center of the Earth.

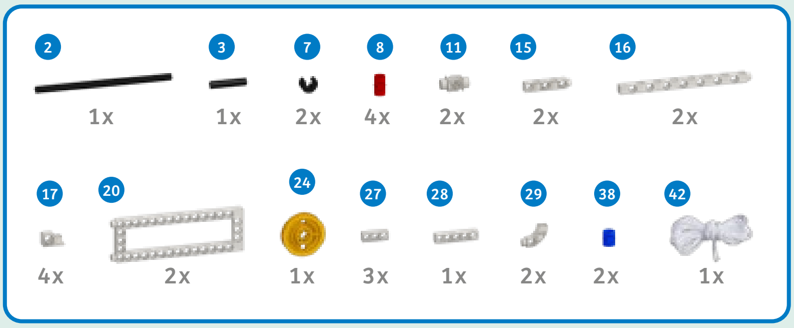
In this equation, the newton [N] is the unit of force, named in honor of the scientist. The kilogram [kg] is the unit for mass. You can easily use a scale to find out how much mass an object has.

DID YOU KNOW …

… that an apple on the Moon weighs less than the same apple on Earth? That is because every planet (or every location) in our Solar System has a different local gravity.

Moon's surface: 1.62 N/kg
Earth's surface: 9.81 N/kg
Jupiter's surface: 24.9 N/kg
Pluto's surface: 0.19 N/kg

TIGHTROPE WALKER



Circus tightrope walkers perform their act high up in the air. Build your own tightrope walker and learn something about gravity and opposing forces in the process.

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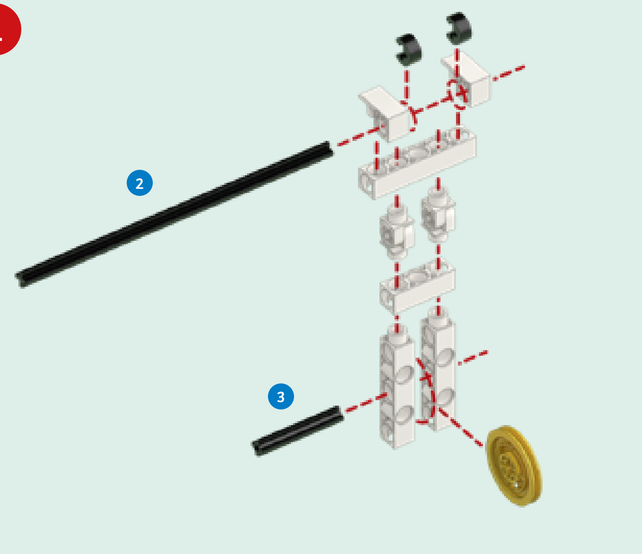

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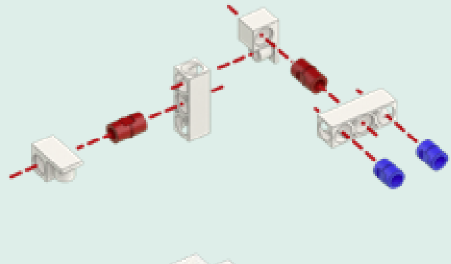

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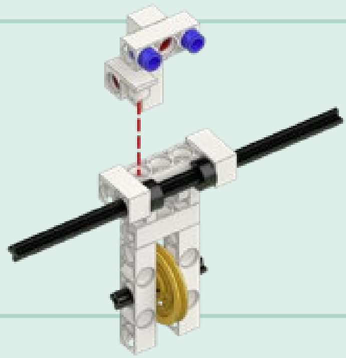

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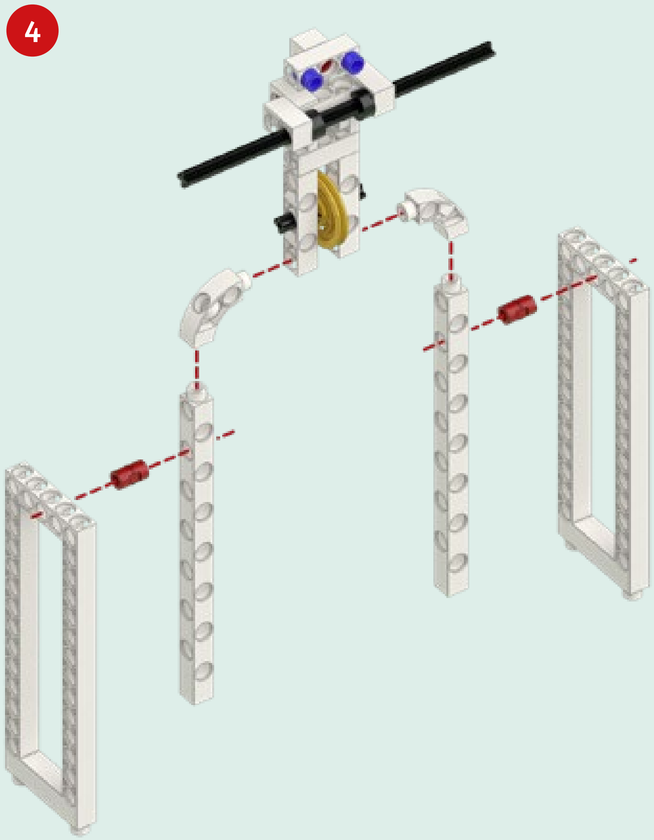

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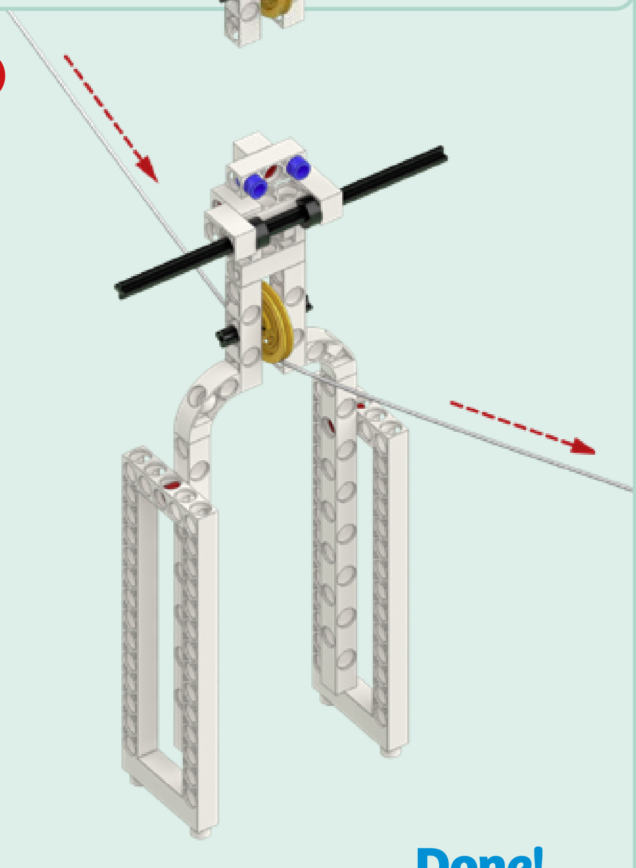


Done!

EXPERIMENT 1

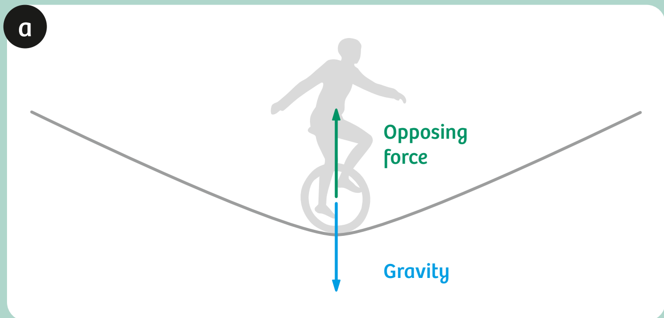
Balancing tightrope walker

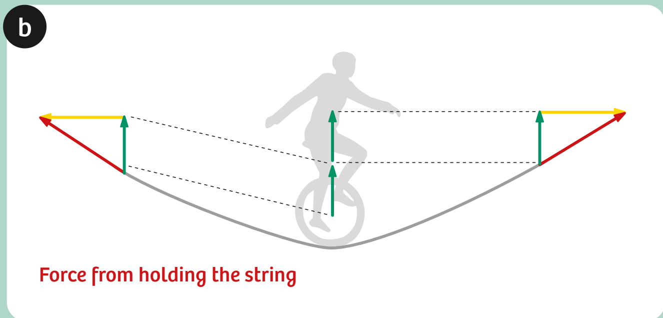
YOU WILL NEED

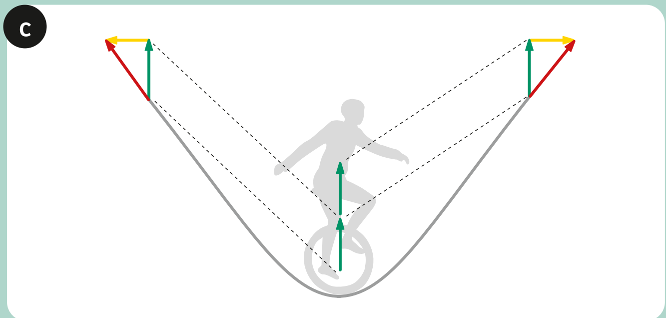
- Assembled tightrope walker
- String

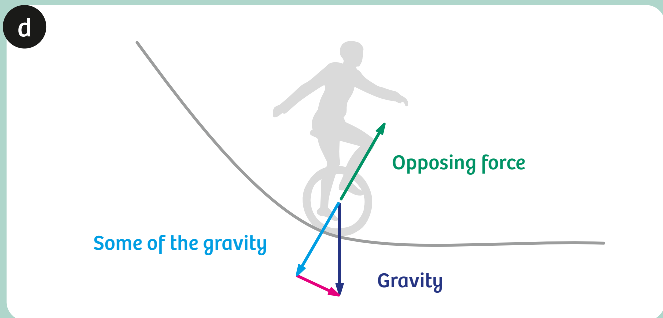
HERE'S HOW

- Hold the string tightly in your hands and pull it up in the air with the tightrope walker on it.
- Hold your hands at different heights and watch how the tightrope walker moves.





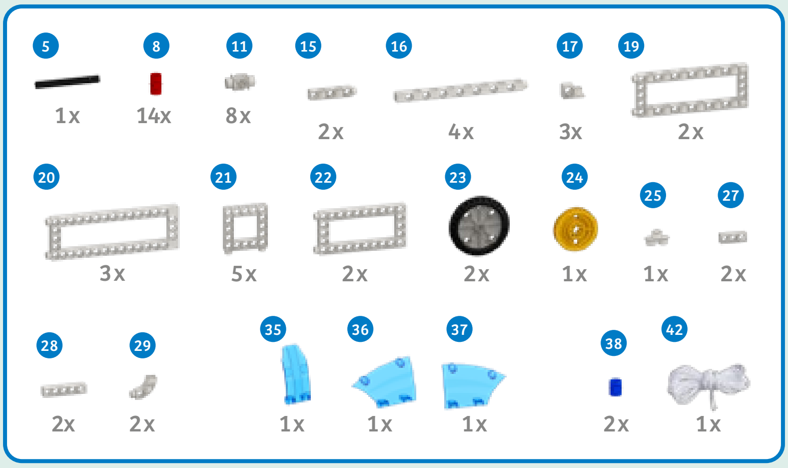




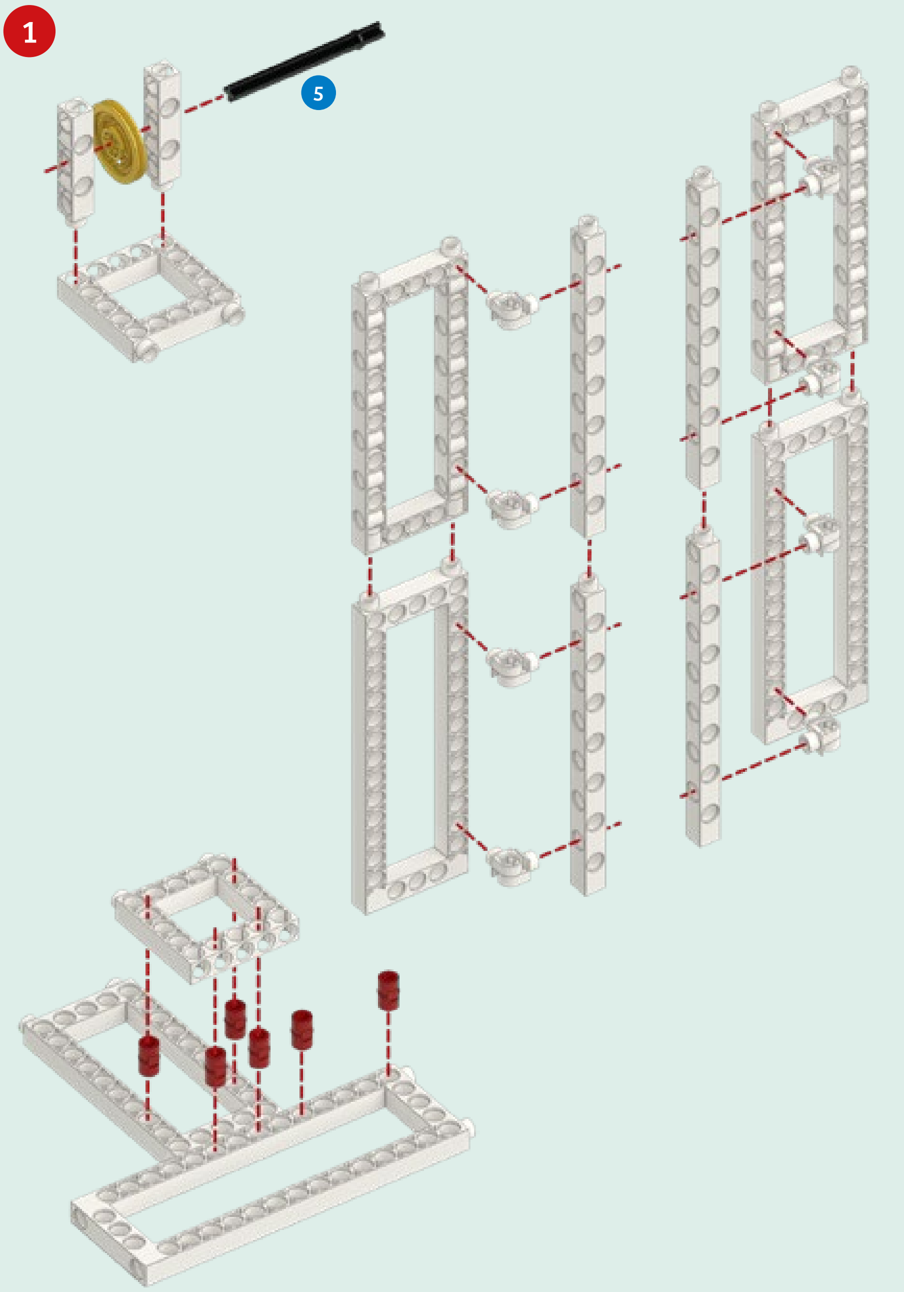
WHAT'S HAPPENING?

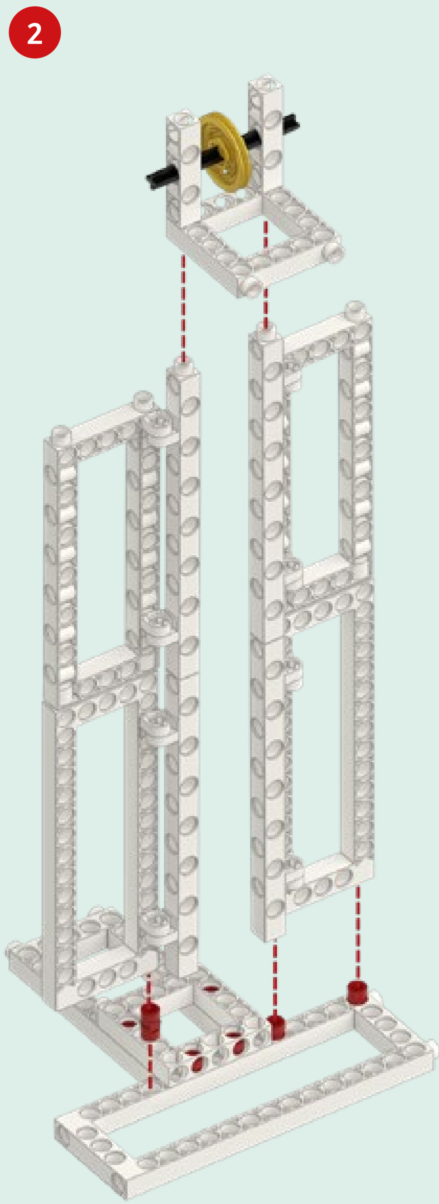
Gravity acts on the tightrope walker and pushes him straight down (a). When you pull on the string with your hands, it exerts an equally great opposing force (b). But in fact, only a portion of the force that you exert when you pull is holding the tightrope walker up in the air! The rest of the force is keeping the string tight (c). If the string is held at a slant, then the force of gravity also gets divided up. A portion of it continues to push down on the string. The other portion, for which there is no opposing force, moves the tightrope walker forward (d). You will learn more about this in the section about inclined planes.

ELEVATOR



Force and opposing force are redirected in such a way that they cancel each other out.





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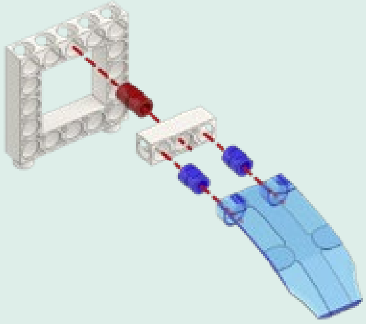

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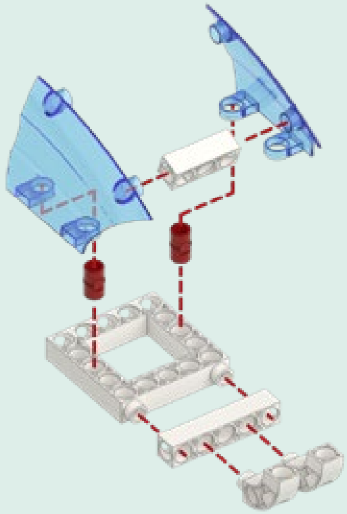

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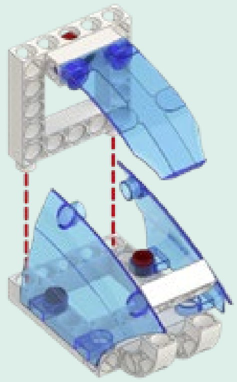

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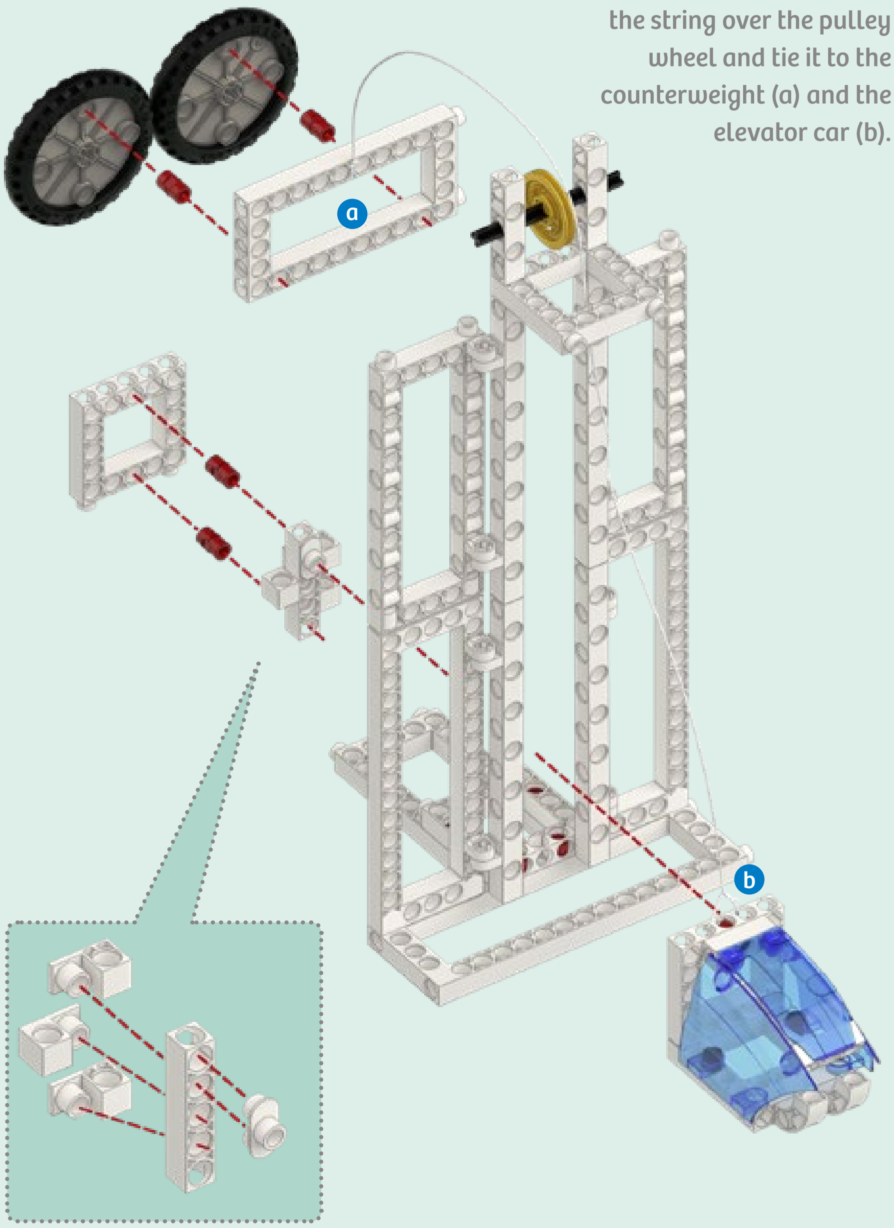
Here, use a piece of string about 30 cm in length. Guide the string over the pulley wheel and tie it to the counterweight (a) and the elevator car (b).



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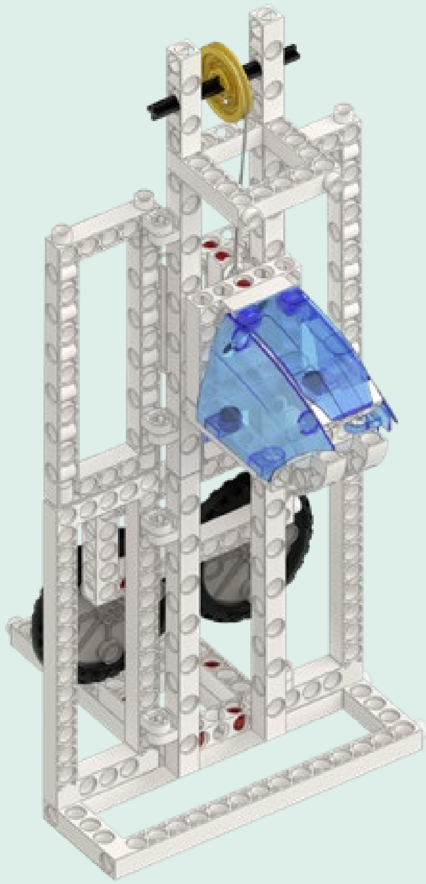


Done!

EXPERIMENT 2

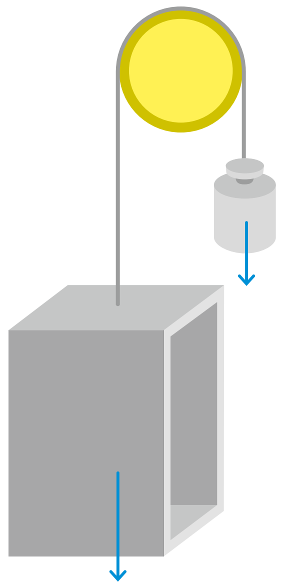
Riding the elevator

YOU WILL NEED

- Assembled elevator

HERE'S HOW

- Move the elevator up and down. Do you need to apply much force?
- Will the elevator remain stopped at a height of your choosing?



WHAT'S HAPPENING?

Forces can be redirected in ways that allow you to avoid having to pull upward in order to exert an upward force! Engineers take advantage of that fact when building elevators. By using pulleys, the weight of the elevator car and that of a counterweight cancel each other out. When that happens, they are in an "equilibrium of forces."

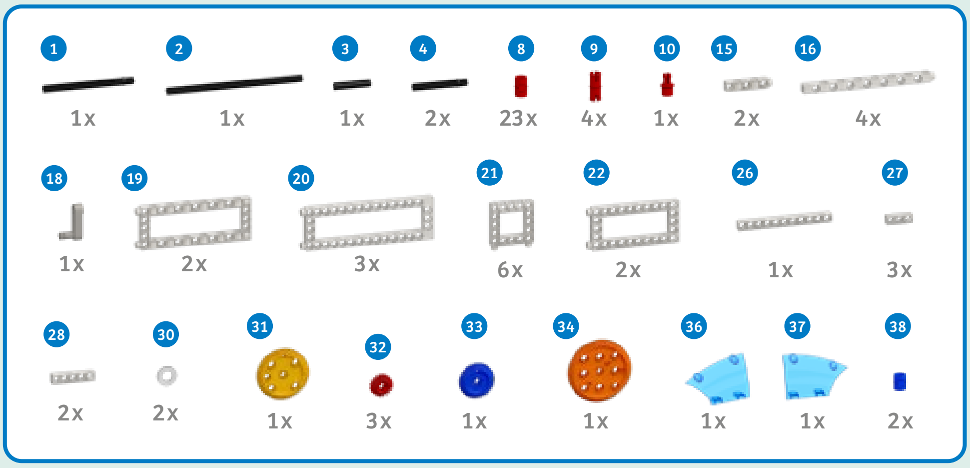
The weight of the elevator [N] – the weight of the counterweight = 0

The upshot is that the elevator can be raised and lowered without much expenditure of force, and will stay standing at a certain height all by itself. See for yourself!

TIP!
If you suspend other counterweights from the elevator, you can simulate a sort of artificial gravity for the elevator car. This is how you calculate the artificial local gravity:

$$\text{artificial local gravity [N/kg]} = \frac{\text{elevator mass [kg]} - \text{counterweight mass [kg]}}{\text{elevator mass [kg]}} \cdot \text{local gravity [N/kg]}$$

ASTRONAUT TRAINING



Astronauts train in cabins like this for their voyages into space.

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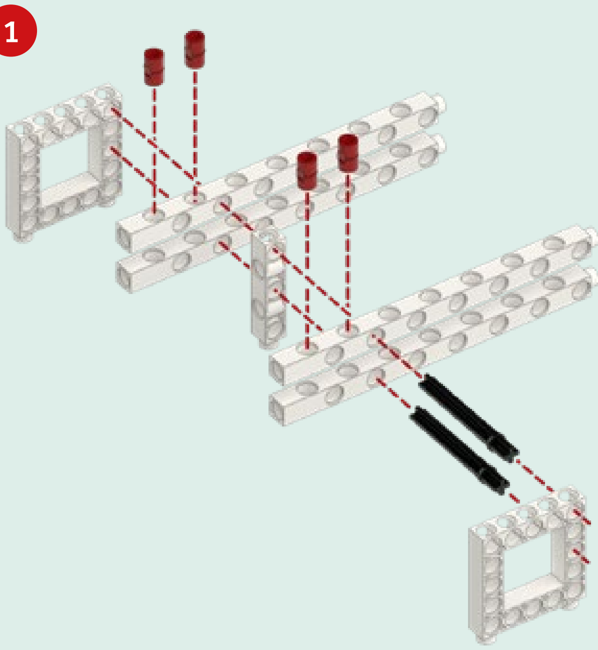

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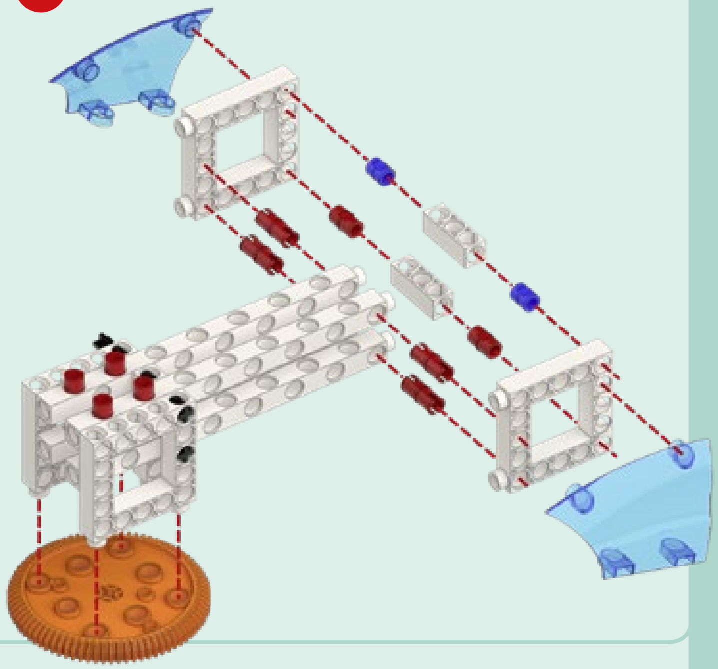

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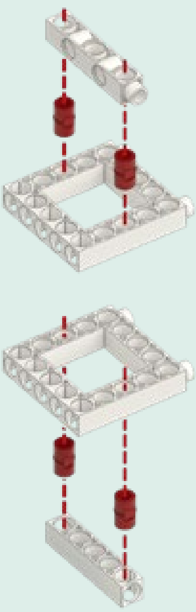

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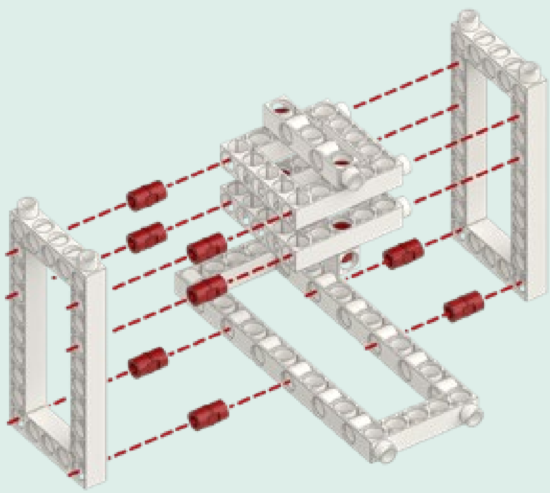

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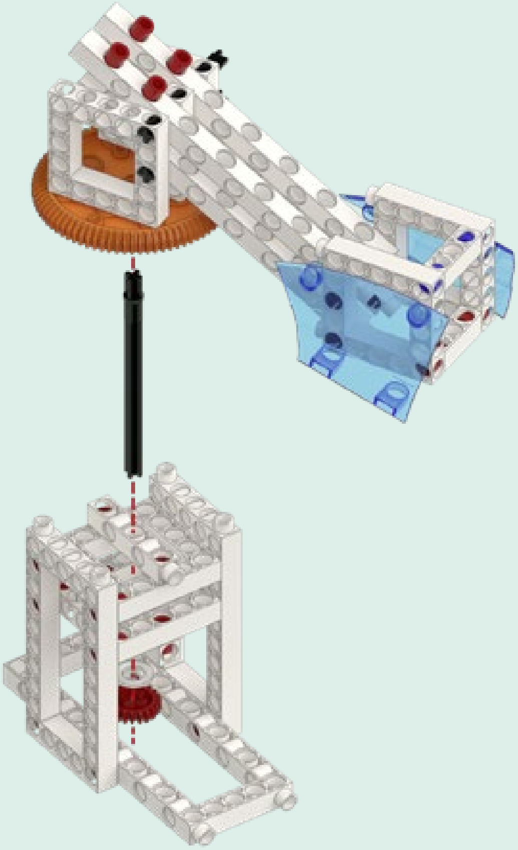

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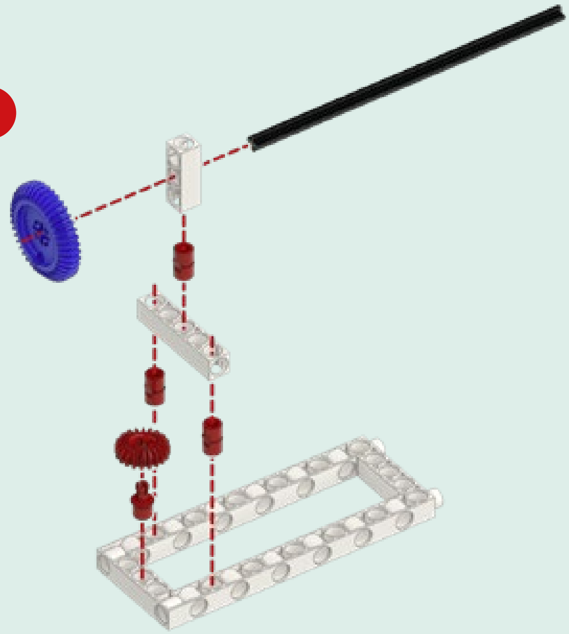

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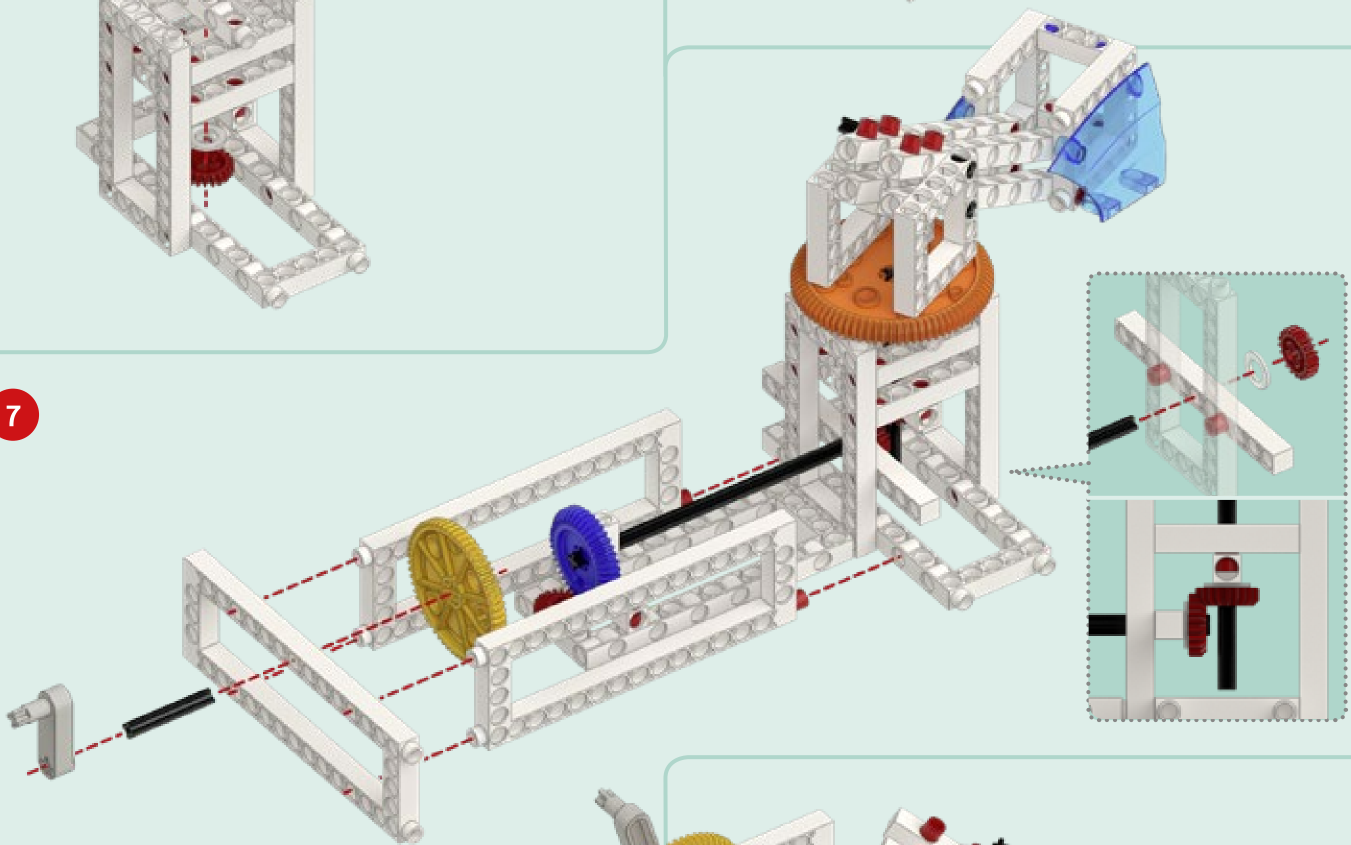

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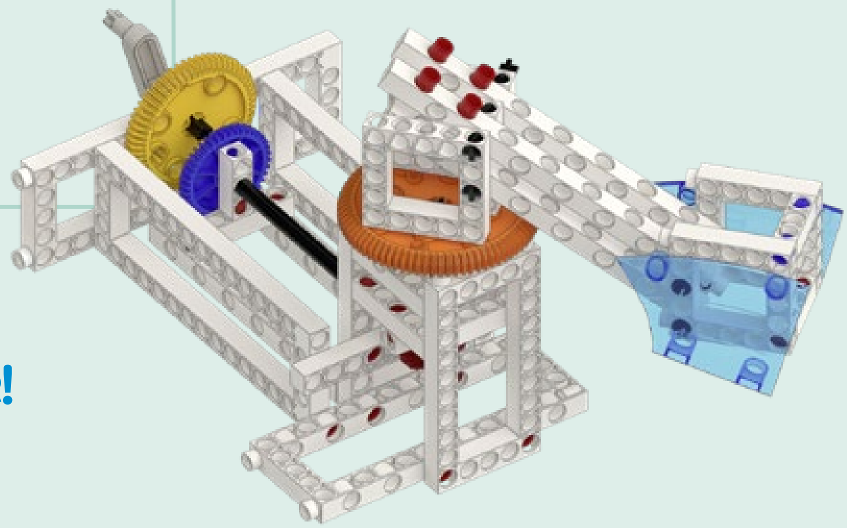


Done!

EXPERIMENT 3

Rocket launch simulation

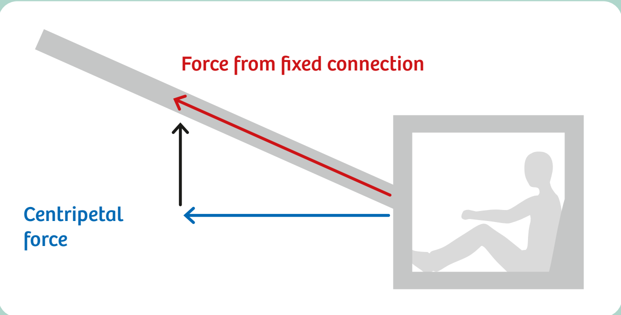
NASA Training Station

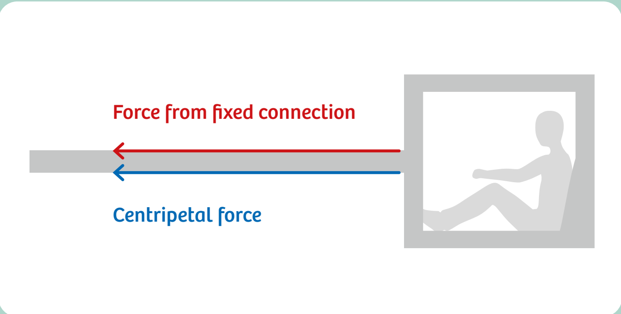
YOU WILL NEED

- Assembled astronaut training station

HERE'S HOW

- Turn the crank and keep your eye on the cabin.
- Gradually increase the speed. How does the cabin's position change?

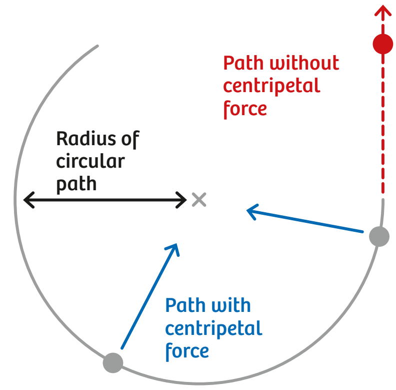




TEST RUN FOR EVERYONE

Astronauts use a cabin spinning quickly around a suspension mount to simulate the strong forces of a rocket launch. You can experience this kind of effect yourself by sitting in a quickly-accelerating car. Of course, the effect is much stronger in a rocket.

The force that presses an astronaut into his or her seat in those training stations is called centripetal force. It always occurs when you spin an object quickly around an axis. Without some sort of force, an object would naturally move in a straight line and not on a curved path. So you have to apply centripetal force to keep an object in a circular orbit.



WHAT'S HAPPENING?

The cabin lifts up when it spins quickly. That is an indirect way of making the centripetal force visible. The faster you spin, the higher the cabin rises and the greater the centripetal force has to be.

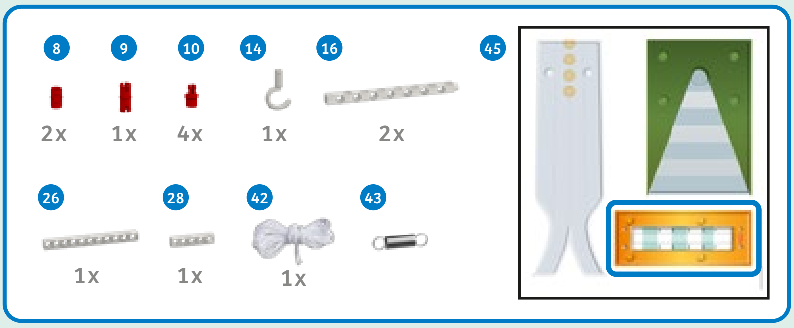
TIP!

The exact formula for the centripetal force of a mass is

$$\text{centripetal force [N]} = \frac{\text{mass [kg]} \cdot \text{rotational speed [m/s]} \cdot \text{rotational speed [m/s]}}{\text{radius of the circular path}}$$

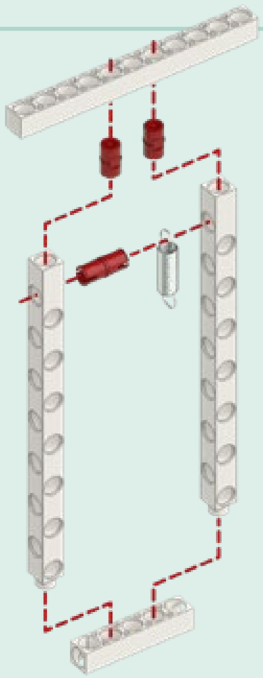
with its direction being toward the center of the circle.

FORCE METER



Use this instrument to measure forces.

1



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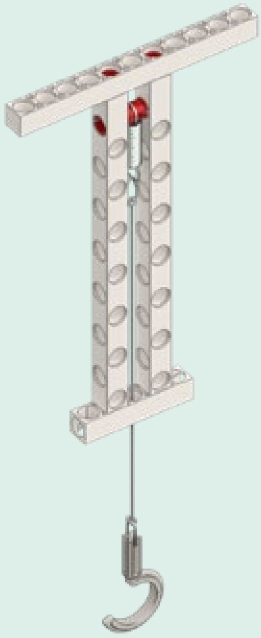
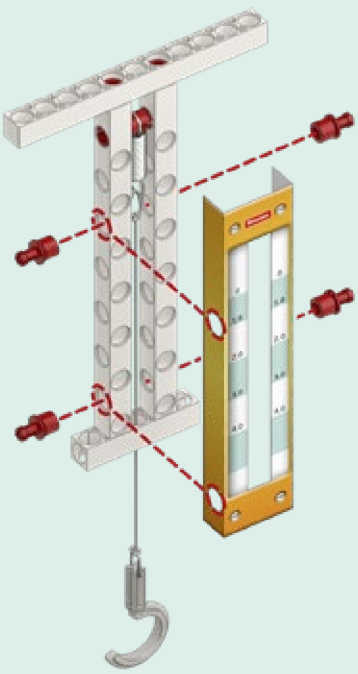


Here, use a piece of string about 20 cm in length. Tie the lower end to the hook. At the top end, tie a loop and hang it on the spring.

3



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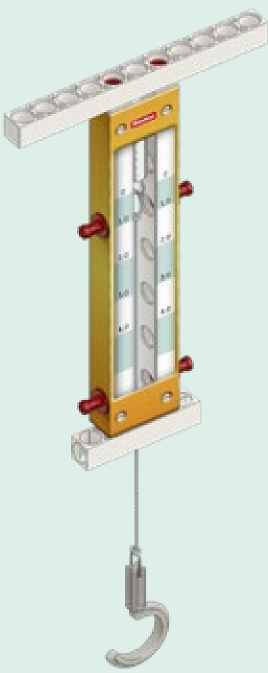


Done!

EXPERIMENT 4

Measuring forces

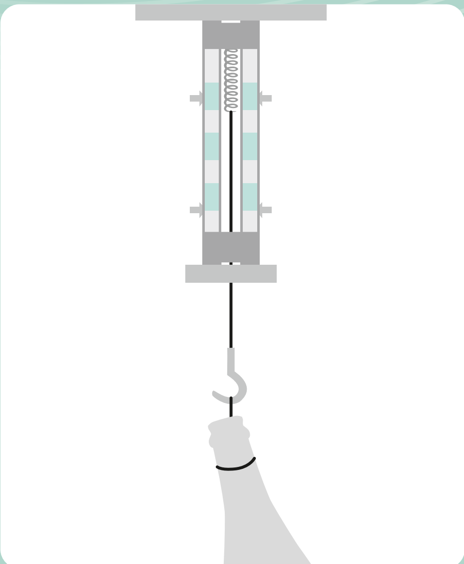
YOU WILL NEED

› **Assembled force meter**

HERE'S HOW

› Pull on the force meter's hook and look at the reading on the scale.

› Suspend various objects from the hook in order to determine their weights.



WHAT'S HAPPENING?

You can use the force meter to measure all kinds of forces and — most important of all — you can use it to compare different forces. In later experiments, you will using the force meter over and over again.

Your force meter uses the force of a stretched spring as its comparison force. You can determine the force by applying the following formula, called "Hooke's law":

tension force [N] = spring constant [N/m] • the distance the spring is stretched [m]

In other words: The more the spring is stretched, the greater the measured force.

DID YOU KNOW ...

...that for natural scientists, and especially physicists, it's very import to have extremely precise measuring instruments? Researchers will tinker for years on new ways to achieve even more precise measurements. One example: Instruments that have been established for some time now are capable of distinguishing events that follow each other by a mere 0.000,000,000,000,001 second (one femtosecond)!

TIP!

For a fairly exact measurement value, you can assume a spring constant of about 2.5 [N/cm], or 250 [N/m]. Or, you can determine the spring constant of your force meter yourself:
Fasten the string of your force meter to a household scale with a weight or a piece of tape. Write down the weight indicated on the scale. Then lift up on the force meter so that it stretches by exactly 1 cm. Write down the new "weight."

$$\text{spring constant [N]} = \frac{\text{weight [kg]} - \text{new weight [kg]}}{\text{distance stretched [m]}} \cdot \text{local gravity [N/kg]}$$

Now you will be able to take direct measurements of the weights of different objects weighing different amounts.

CHECK IT OUT

The conquest of space

In order for astronauts to get into space, they require a launch rocket, plus a space shuttle or space capsule to be able to return to Earth. When the launch rocket takes off, the force exerted on the astronauts in the accelerating vehicle is about three times the force of gravity. This kind of force is called “three g” (with g being the symbol for acceleration due to gravity at the Earth’s surface).

MILESTONES OF SPACE TRAVEL

The first man-made satellite (an object that circles the Earth on a fixed orbit) in space was Sputnik, which transmitted the first messages from space to Earth in 1957.

The first living creature in Earth’s orbit was a female dog named Laika. She was carried into space by a Russian rocket in 1957, but unfortunately she died just a few hours later.

Four years after that, the Soviet cosmonaut Yuri Gagarin became the first person to return safely to Earth after a brief flight into space.

In 1969, the first Moon landing was broadcast worldwide on television. As he stepped onto the Moon’s surface, Neil Armstrong spoke the following famous words: “That’s one small step for [a] man, one giant leap for mankind.”

DID YOU KNOW ...

...that the local gravity becomes weaker and weaker as you increase the distance away from the Earth’s surface? In order to get far enough away to avoid getting pulled back to Earth or into Earth’s orbit by gravity, you need to travel at a certain speed known as the escape velocity — which is around 40,000 kilometers per hour!

At the Construction Site

Can you imagine a big construction site without a crane? Thousands of years ago, the ancient Egyptians had to engineer their pyramids without that kind of equipment. Here's where you will learn about how they managed to do it, and how you can use physics to help you move heavy objects with ease.

Construction work

Builders and engineers have come up with many inventions to save force while performing a given amount of "work." Just don't interpret that in terms of the kind of work your parents might talk about though!

In physics, work means moving an object in the direction (or against the direction) of a force. So if you hold a bottle of water straight in front of you, you are not actually performing work even though gravity is acting on the bottle and it may become difficult to keep your arm stretched out after a while. But if you lift the bottle up, then you are performing work, because you are moving the bottle against the force of gravity.

To perform a certain amount of work, it makes no difference how much force you apply and how far you move the object as long as both together (force times distance) yield the desired amount of work. That means that you can choose between applying more force and covering more distance.

The builder's trick, then, is to figure out how to reduce the amount of force required to do the work of moving heavy building materials.

WORK

The amount of work you accomplish can be calculated as follows:

work [J] = force [N] • distance [m]

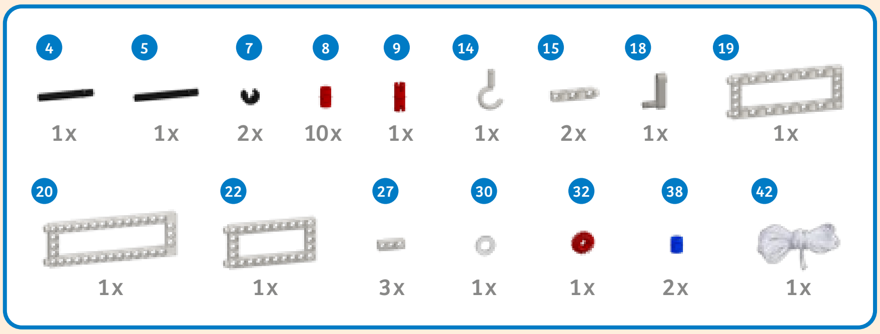
In the example with the bottle, let's take gravity as the force, and the distance is the difference in height when you lift the bottle.

work performed on the bottle [J] =
mass [N] • local gravity [N/kg] • difference in height [m]

DID YOU KNOW ...

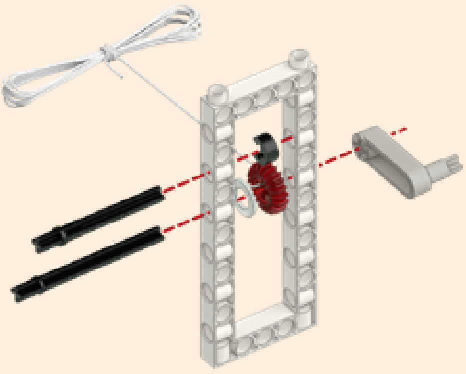
... that the unit of work, called the joule (pronounced like "jewel"), is named after a famous English physicist named James P. Joule (1818-1889)?

HOIST



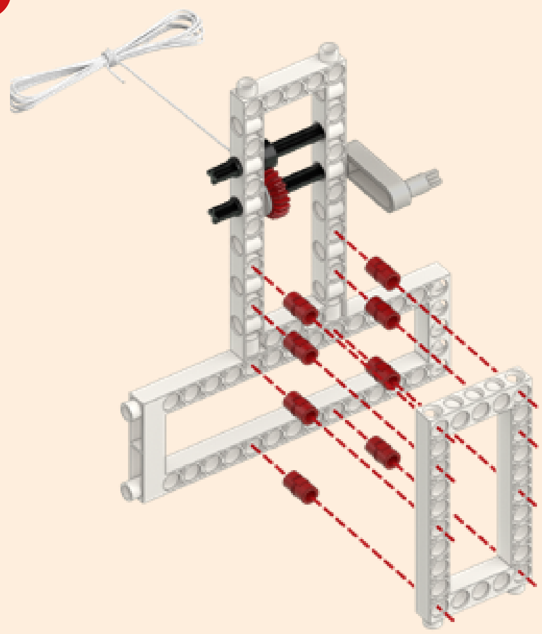
The hoist offers a way to reduce the amount of force needed when lifting objects. It was known and used in ancient times.

1



Pass the end of the string through the gear wheel before inserting the axle, and tie it tight.

2



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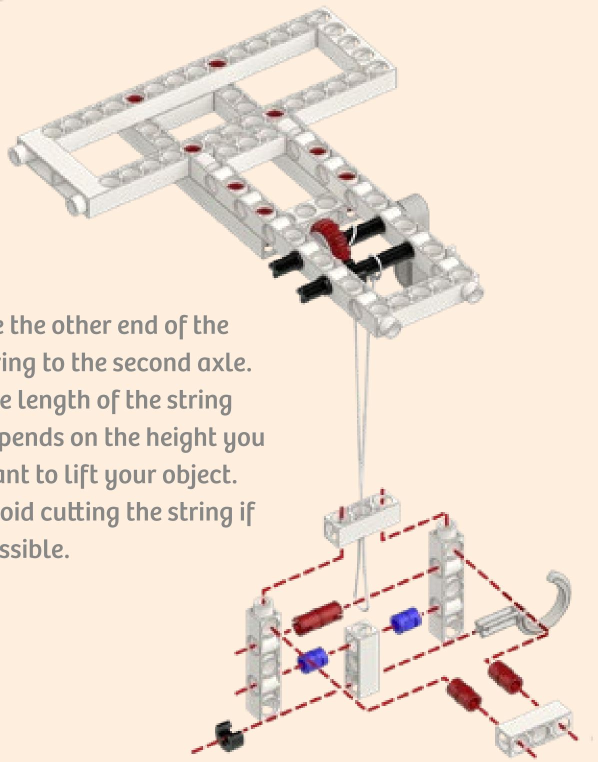
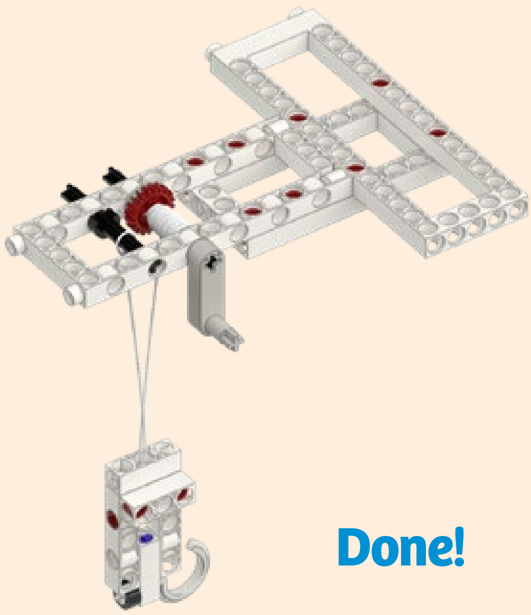


Tie the other end of the string to the second axle. The length of the string depends on the height you want to lift your object. Avoid cutting the string if possible.

4



Done!

EXPERIMENT 5

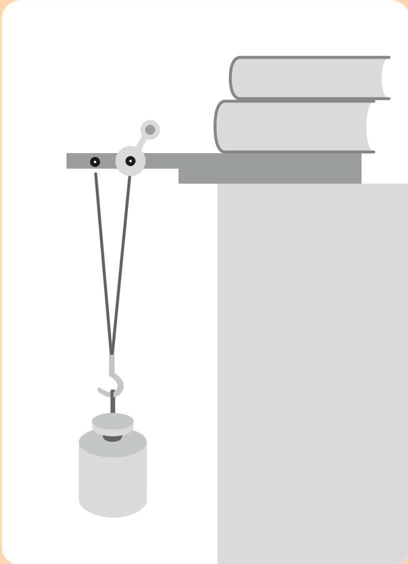
Hoist in operation

YOU WILL NEED

- **Assembled hoist**
- *Books to anchor down the hoist*
- *Any load, such as a small bottle*

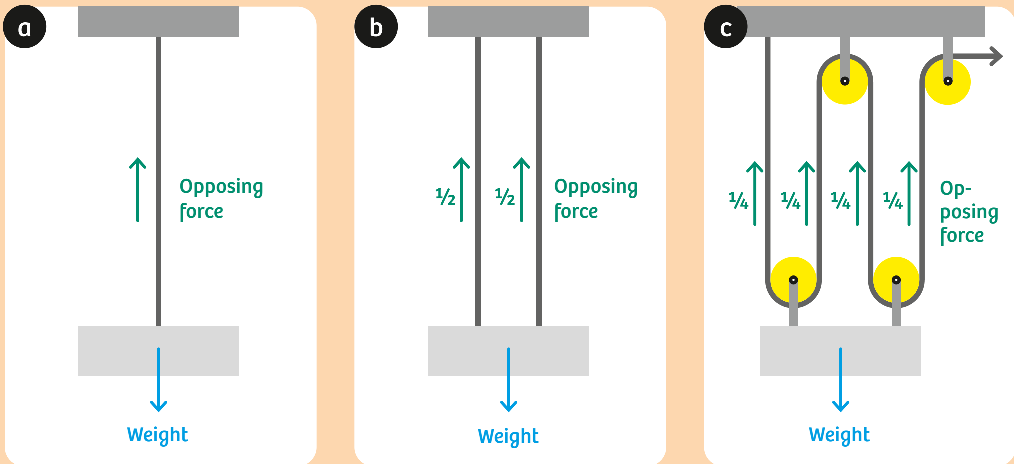
HERE'S HOW

- Place the hoist on a table or book case, and weigh it down with a few books.
- Hang an object from the hook.
- Turn the crank to lift the object.



TIP!
Use the force meter from the last section to measure the force more precisely.

TIP!
Try modifying the hoist to distribute the force across four strings.



WHAT'S HAPPENING?

As the object is slowly lifted, you will be astonished how easy it is! If you suspend the load from just one string, you have to work against the entire weight on that one string (a). But if you use more than one string (b), the required opposing force is divided among them!

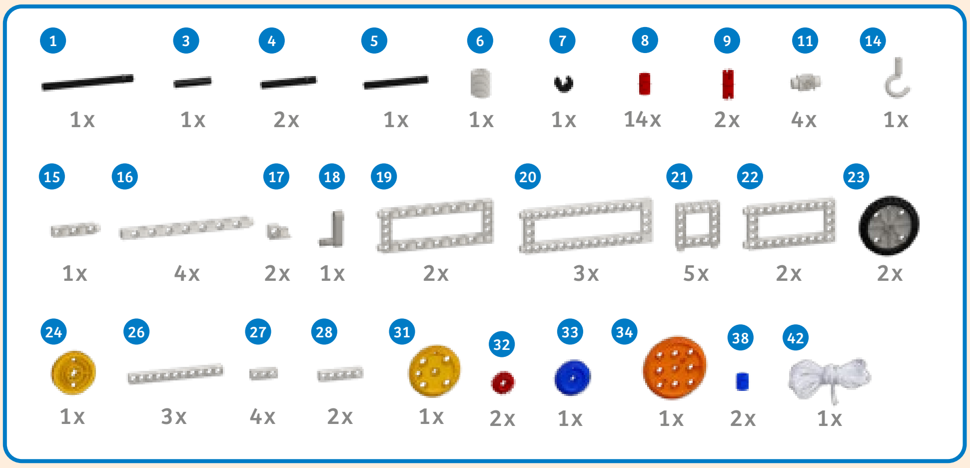
$$\text{opposing force per string [N]} = \frac{\text{opposing force of the load [N]}}{\text{number of strings}}$$

The trick is to tie the strings to the hoist and the load in such a way that you can use just a single continuous string. But someone will have to hold the end of the string to keep it from unrolling and to apply the same portion of opposing force as one of the string sections. In the case of your hoist, that someone is you holding or turning the crank. This allows you to lift even heavy loads with relatively little force (c).

Of course, there's just one catch. The length of the string that you pull to lift the load will have to increase along with the larger number of pulley wheels and string sections. Remember:

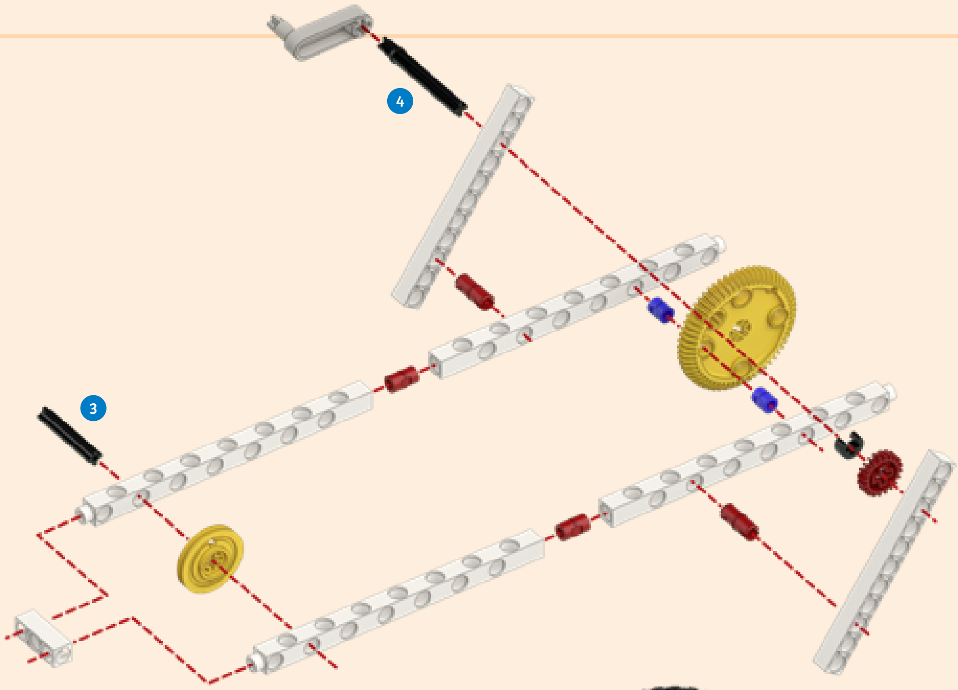
$$\text{work [j]} = \text{force [N]} \cdot \text{distance [m]}$$

CRANE



Those big boom cranes you see at construction sites are the result of centuries of trial-and-error improvements — in other words, engineering design!

1



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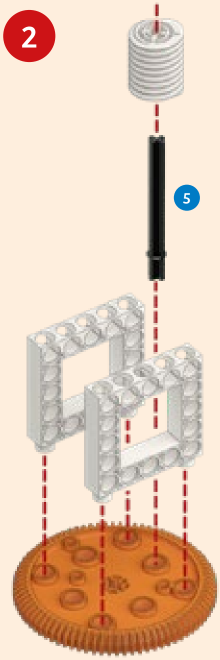

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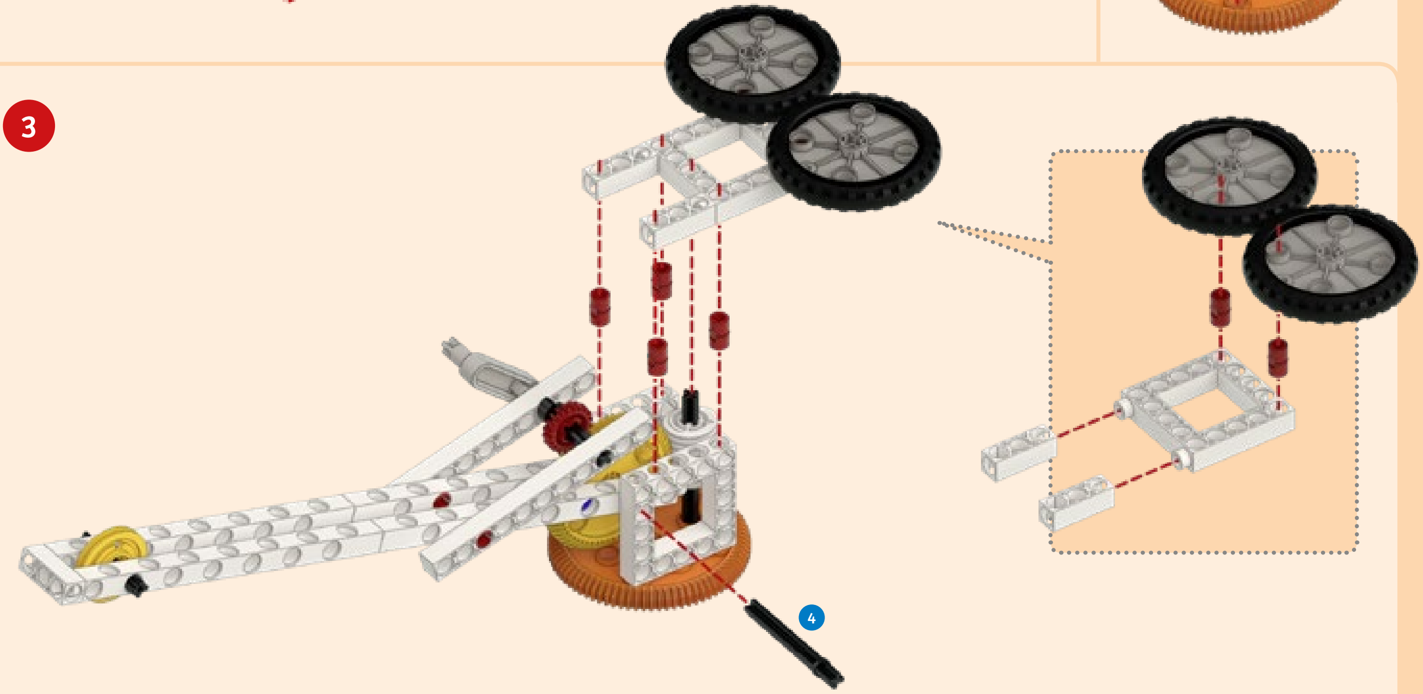

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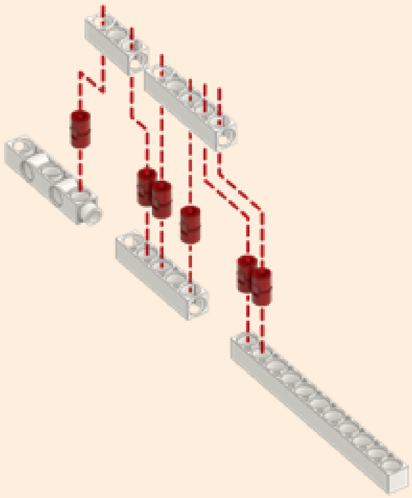

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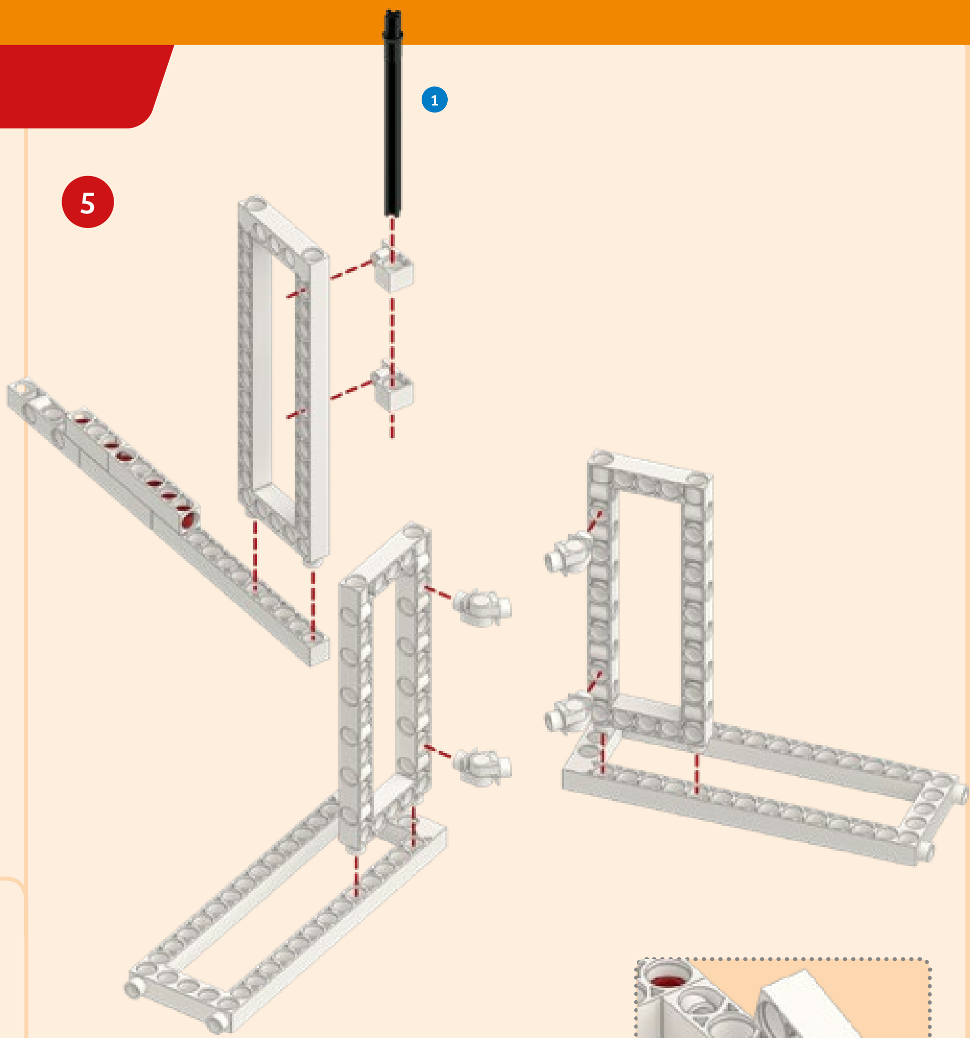

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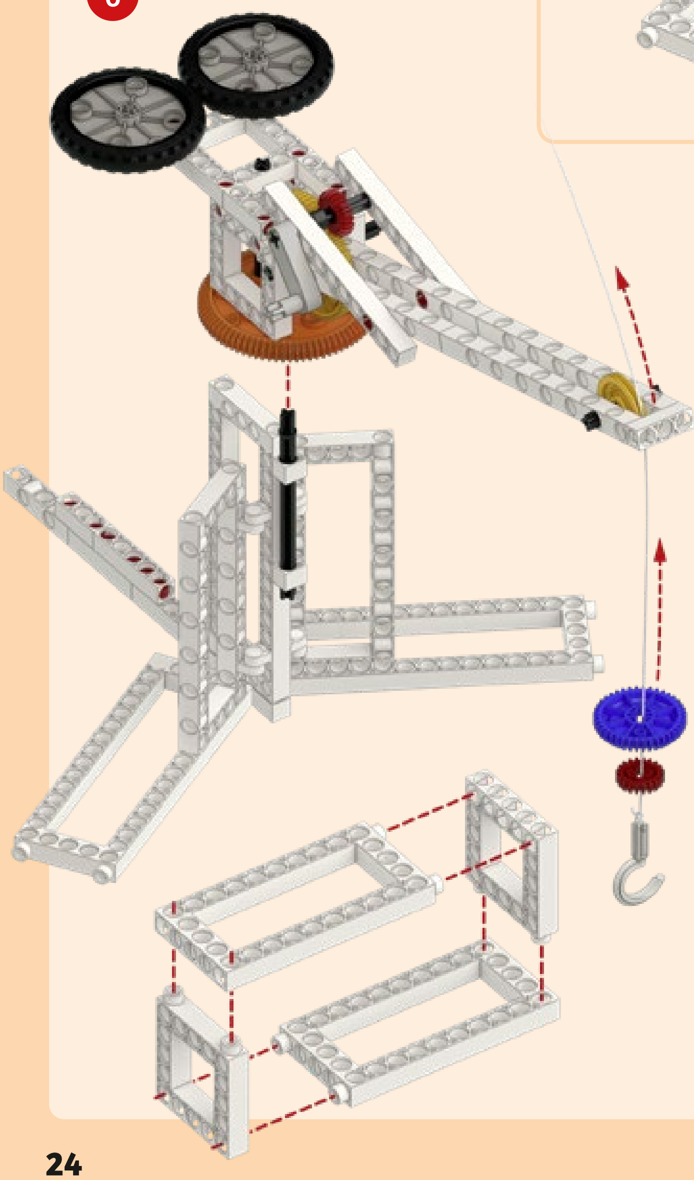

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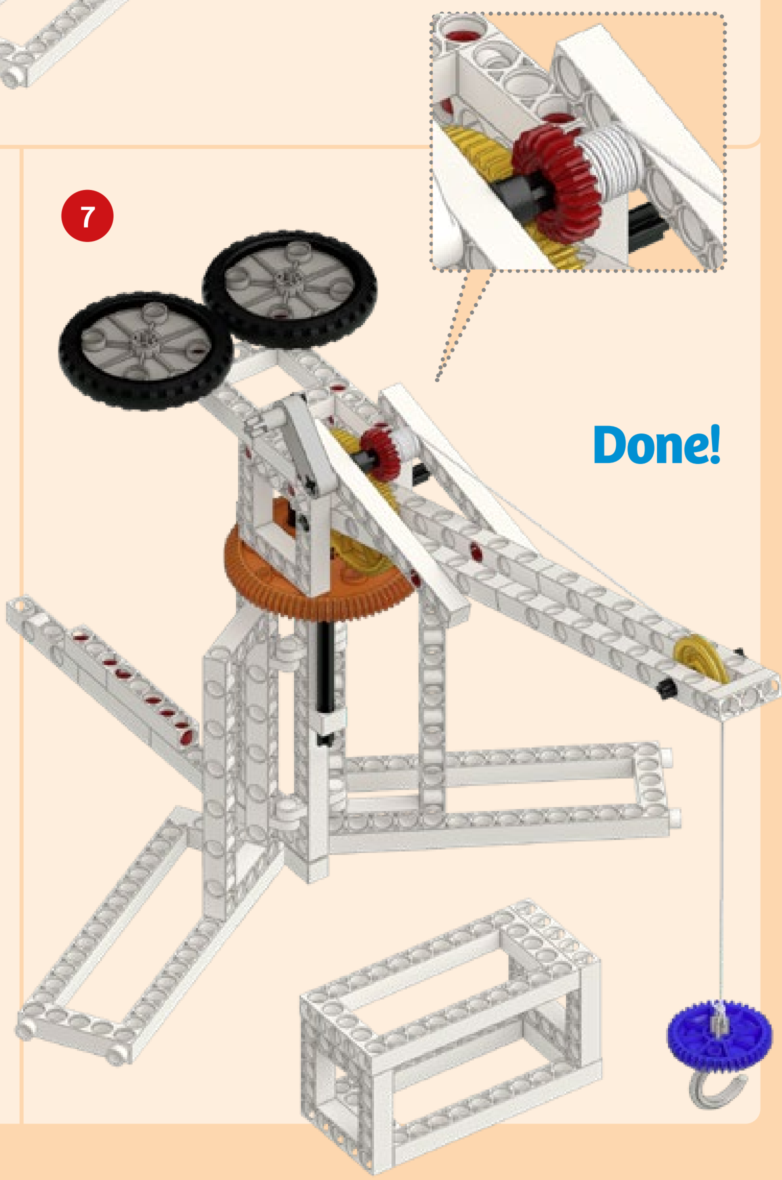


Done!

EXPERIMENT 6

Moving boxes with the crane

YOU WILL NEED

- Assembled crane
- Assembled box

HERE'S HOW

- Use your thumbs to turn the screw and adjust the crane arm upward.
- Operate the crank to lower the crane's hook, and then block the winch's gear wheel with the larger gear wheel to keep it fixed at a given height.
- Place the box in a location where it will be needed for further construction work.

WHAT'S HAPPENING?

Here, too, force is saved by increasing distance. That's because the crane's rope that you hang the load from is wound around the axle connected to the crank. A single turn will only wind up a little bit of rope (and only raise the box a short distance), while your hand has to cover a longer distance as it winds the crank. That correspondingly reduces the force required to lift the object. Remember:

work [j] = force [N] • distance [m]

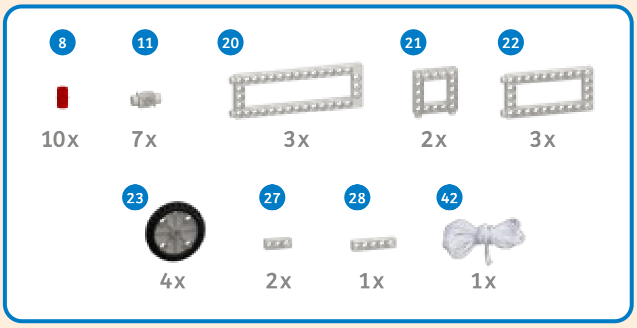
On top of that, your crane model has another feature that lets you trade distance for force. Can you find it?*

DID YOU KNOW ...

... that the first cranes looked completely different from those of today? They were made of wood, and sometimes contained human-powered running wheels.

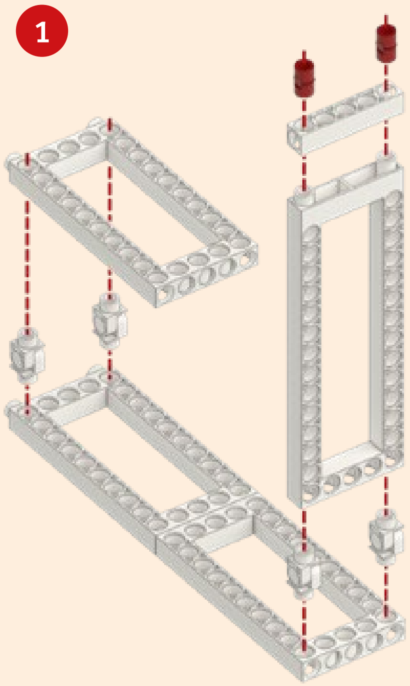
*Your fingers turning the screw cover a lot of distance in order to raise the crane's arm (and the box at the end of it) just a little way.

INCLINED PLANE



In ancient Egypt during the days of the Pharaohs, the crane had not yet been invented. How, then, did they manage to build all those gigantic wonders of the world, such as the pyramids of Giza? They had another trick up their sleeve: the inclined plane.

1



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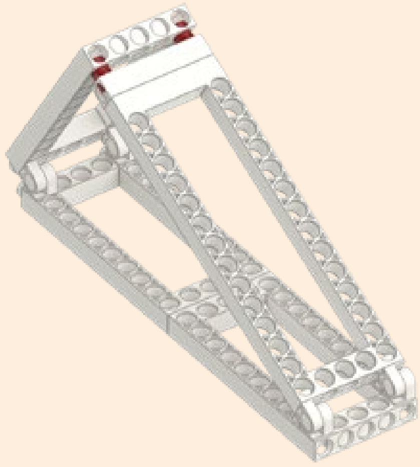

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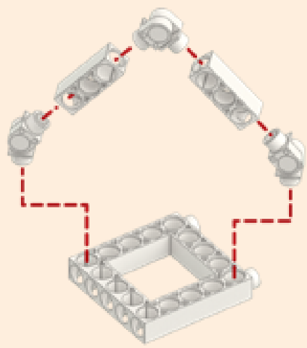
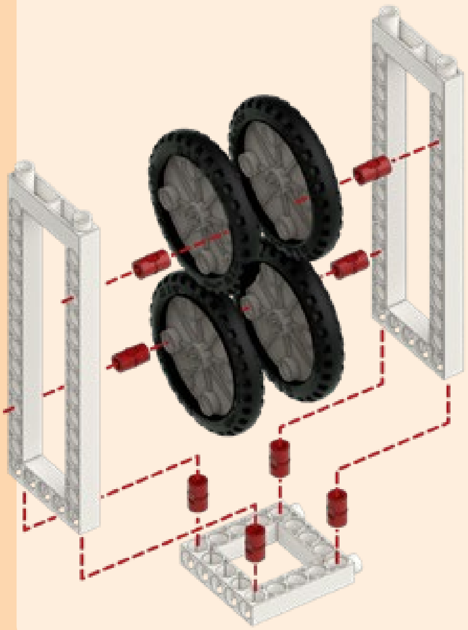


4

This frame with the four heavy wheels inside it represents a “heavy block of stone.”



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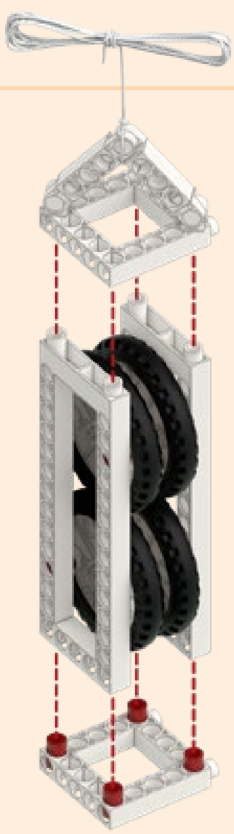

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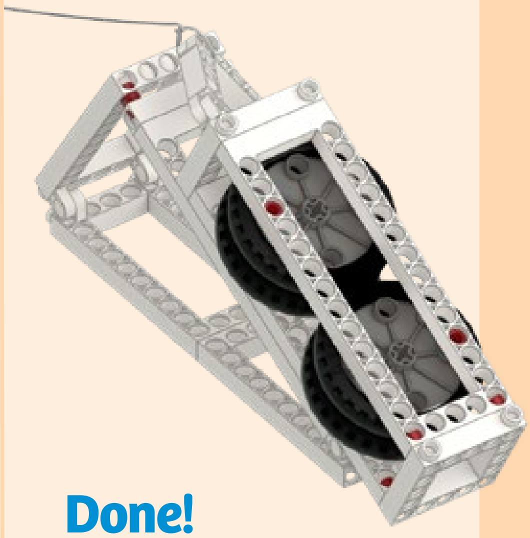


Done!

EXPERIMENT 7

Piling up stones for the Pharaoh

YOU WILL NEED

- **Assembled framework**
- **"Heavy block of stone" with string attached**
- *Large, thin book*

HERE'S HOW

- Set the framework in front of you with the flatter side up. Place a book on top of it. That gives you your "inclined plane."
- Pull the "block of stone" up the inclined plane by the string.
- Repeat the experiment with the steeper side of the framework on top.

WHAT'S HAPPENING?

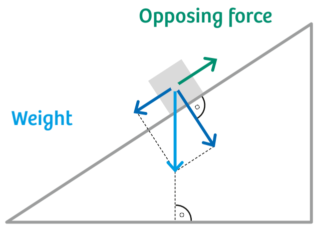
The weight is distributed across the inclined plane. A portion of the weight acts to make the block of stone slide down the ramp, but a portion of it also presses it against the ramp.

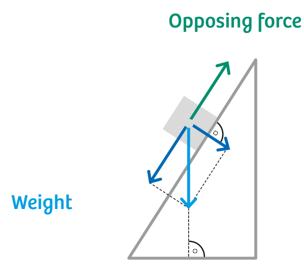
By setting a more or less equal opposing force against the portion of the force that would make the stone slide down the ramp, you can stop the stone or even pull it up. The steeper the ramp, the greater this portion of force. With a vertical "ramp," it is equal to the original weight of the block of stone.

Here, too, the distance covered on the ramp is longer than the actual difference in height, so it saves force. Remember:

work [j] = force [N] • distance [m]

With the model and the force meter from the first section, you can investigate this a little more closely.





CHECK IT OUT

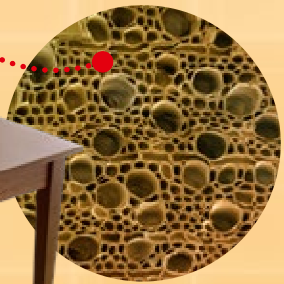
Unavoidable work due to friction

The greatest cause of work in everyday life is friction. This is a force that works against the direction of movement of an object (which is why it always gives rise to work in terms of physics), and becomes greater as the force of contact increase. It is almost impossible to completely avoid friction, but you can reduce it by quite a bit.

REDUCING FRICTION

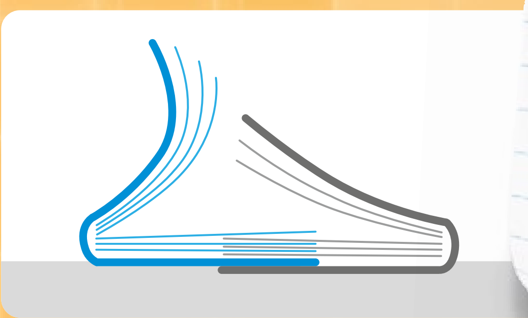
Even the ancient Egyptians knew how to reduce the friction under blocks of stone by laying wooden rollers beneath them. The friction of a rolling object ("rolling friction") is a lot less than that of a sliding object ("sliding friction" or "kinetic friction"). Today, wherever wheels are required to move as free of friction as possible around a fixed axle, ball bearings are used for this purpose.

You can achieve very low friction through the use of cushions of air instead of rollers or wheels. Hovercraft can float contact-free over any surface that is more or less flat. The friction acting on the layer of air separating the craft from the ground is very low.



DID YOU KNOW ...

...that if you look at a flat table surface under a microscope, it doesn't look so flat at all? There are tons of uneven spots that look like canyons and mountains. When two surfaces meet, these microscopic uneven spots will catch against one another. That is the cause of friction.



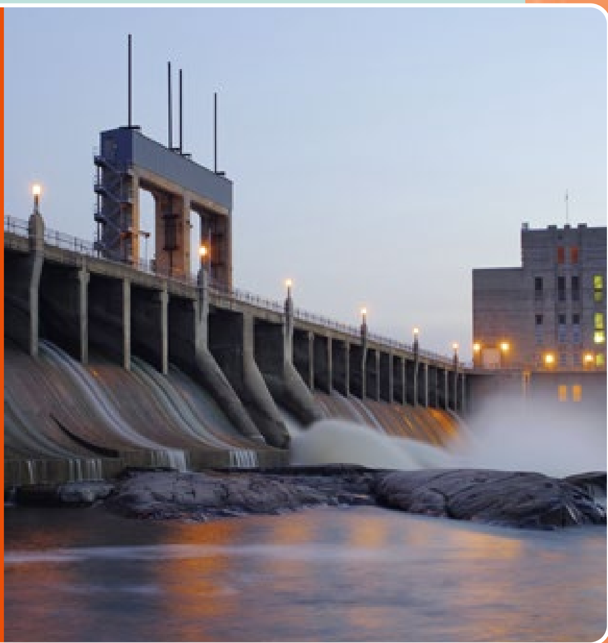
TESTING FRICTION YOURSELF

Test the force of friction for yourself: Take two books of about equal thickness and interleave them (see picture). Then try to pull the books apart. The friction will be even greater if you place a weight on the pages. Friction is greatest when the individual paper pages have not yet begun to move, and are still firmly interlocked and stuck together. This is known as "static friction."

Storing and Converting Energy

Before the roller coaster cars can go racing through their curves and loops, they have to be pulled up the tracks. That equals stored energy to be released during the wild ride downward. You will be astonished at all the ways that energy is stored and converted in your everyday life. The conversion and storage of energy play an important role in technology and mechanical engineering, too.

Power plants — like the hydroelectric power plant shown here — supply energy for use in your home, so the lights will come on when you press the switch.



Energy changes

Energy is something that's hard to grasp, but that every object has in one form or another. An object at a height of 5 meters, for example, has a lot more potential energy than one on the ground. A speedy bicyclist has more kinetic energy (literally, "movement" energy) than a slow one. And a stretched rubber band has more potential tension energy than one that isn't stretched. The nice thing about all these forms of energy is that you can convert one into another.

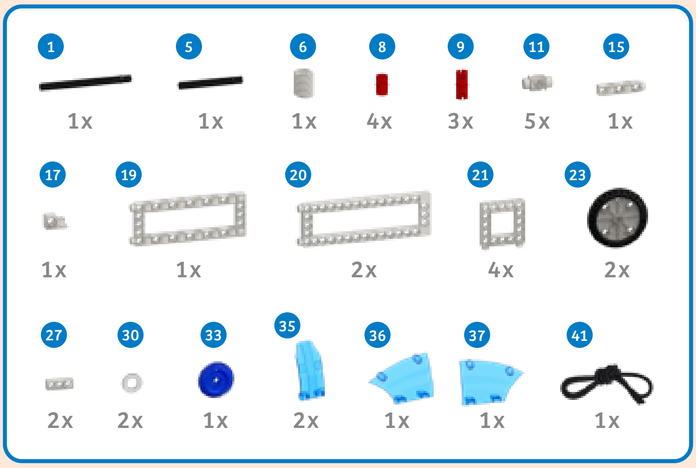
ENERGY-CHARGED BALL

Before you drop a rubber ball, it just has potential energy. As it falls, it goes faster and faster until it hits the ground. As it gains kinetic energy, it loses potential energy. When it hits the ground, the ball spreads and squashes (its kinetic energy becomes potential tension energy) and then it bounces back up (its tension energy becomes kinetic energy again).

You can store energy by converting it into an easy-to-handle form (for example, the kind of potential energy you get by placing an object at a height — see page 46).

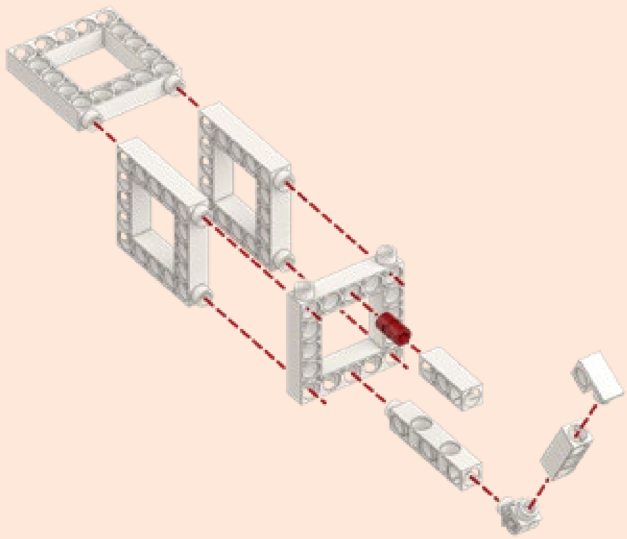
Energy is never lost, it only changes into another form of energy. That is known as conservation of energy. Sometimes, though, it can be hard to know what form the energy is converted into.

ROCKET CAR



Ever since cars have existed, people have tried to set new speed records. The fastest vehicle on wheels (with jet propulsion) holds the record (set in 1997) of over 1228 kilometers per hour!

1



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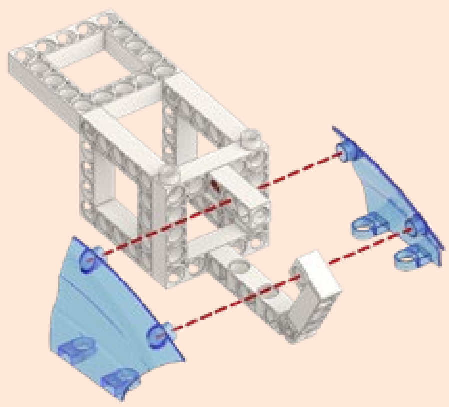
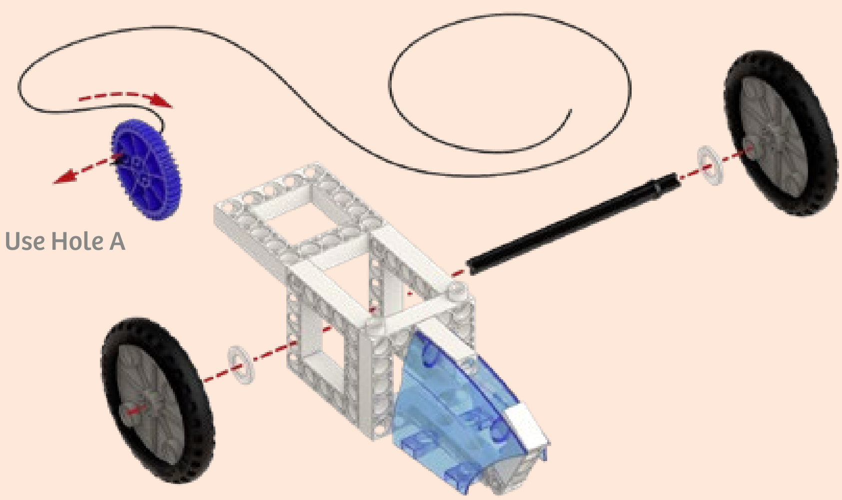
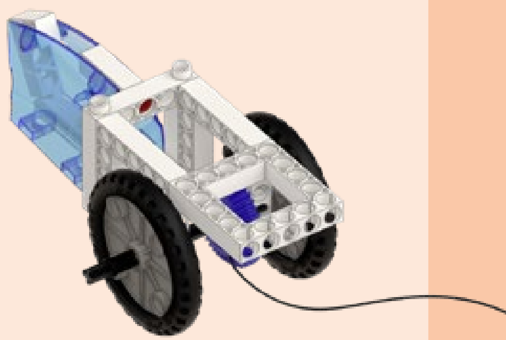


3 Insert one end of the elastic cord through the gear wheel hole and tie a thick double knot.



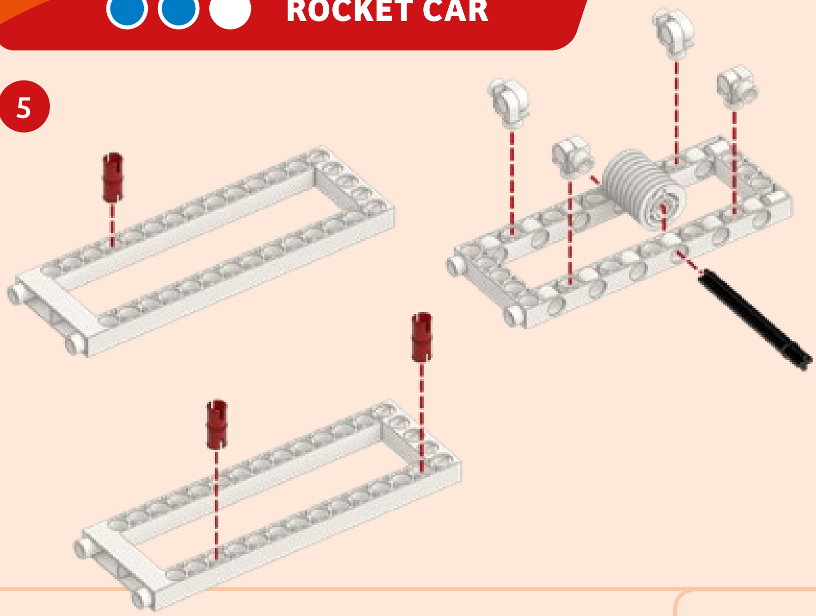
4

Turn 180°



ROCKET CAR

5



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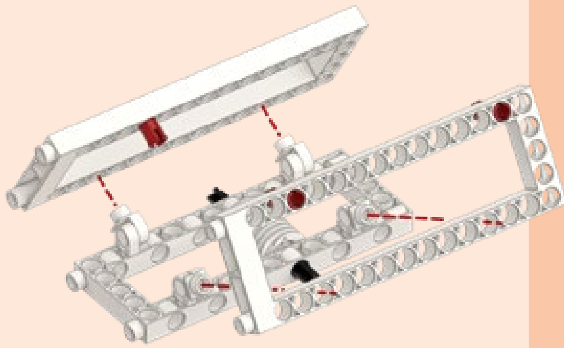

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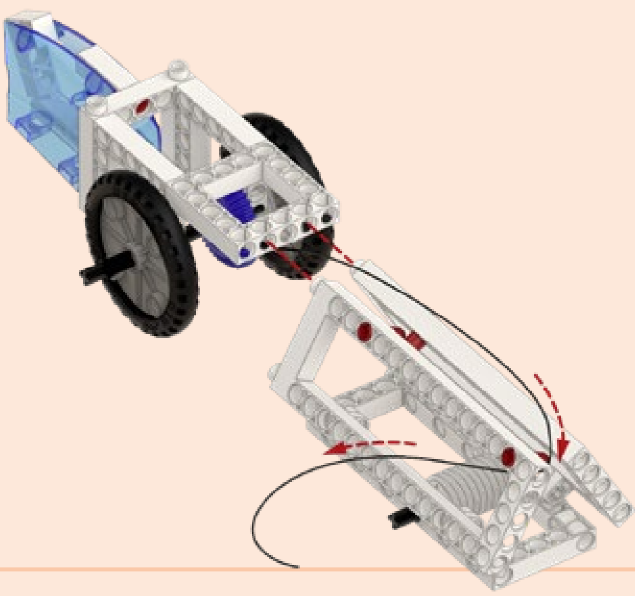

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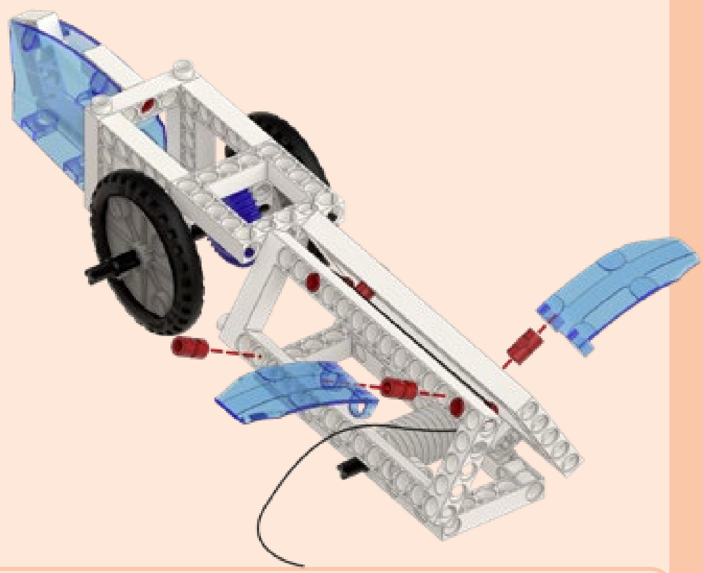

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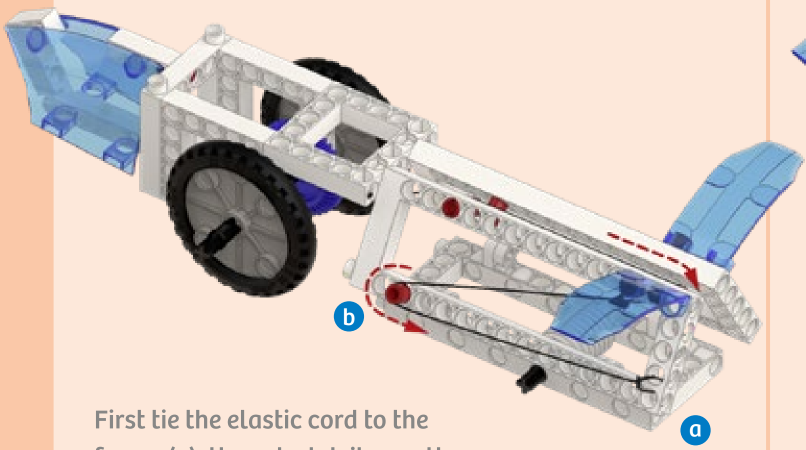


First tie the elastic cord to the frame (a), then stretch it over the anchor pin (b).

10

Done!

EXPERIMENT 8

Speed record

YOU WILL NEED

- **Assembled framework**
- *An area with lots of room and a flat surface*

HERE'S HOW

- Pull the rocket car back, move it forward, and pull it back again.
- Let the rocket car go.

WHAT'S HAPPENING?

When it's stretched, the elastic cord gains potential energy:

potential energy [J] =
½ • spring constant [N/m] • distance stretched [m] • distance stretched [m]

The spring constant is different for any two springs. In the case of your elastic cord, it's about 17 [N/m].

Your rocket car accelerates with the help of its potential energy, gathers speed, and covers a certain distance in a certain amount of time. The longer your rocket car accelerates, the faster it goes.

speed [m/s] = acceleration [m/(s•s)] • period of time [s]

DID YOU KNOW ...

An easy way to store mechanical energy is by stretching a spring or rubber band. But first you have to apply force and stretch the spring or band a certain distance. Does that sound familiar? Mechanical energy is none other than stored work! That's why they use the same unit, the joule.

This work can later be released, as in this experiment, and used for a force of acceleration.

HOW LONG TIL WE GET THERE...?

You've probably asked that question a lot when taking a car trip. From now on, you'll be able to answer the question yourself! This is how:

$$\text{period of time [h]} = \frac{\text{distance [km]}}{\text{speed [km/h]}}$$

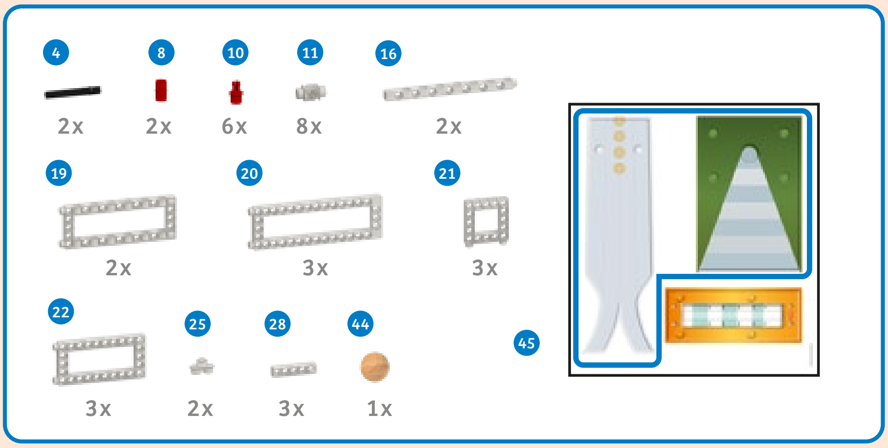
In physics, speed is often indicated in meters per second (m/s). Roads and highways are usually measured in miles (mi) in the U.S. or kilometers (km) in Europe. Car speedometers measure speed in miles per hour (mph) or kilometers per hour (km/h).

One m/s = 2.2 mph, or one mph = 0.45 m/s.

One m/s = 3.6 km/h, or one km/h = 0.28 m/s.

One mph = 1.6 km/h, or one km/h = 0.62 mph.

SKEE BALL GOLF



Constantly-changing energy — potential energy and kinetic energy switching back and forth.

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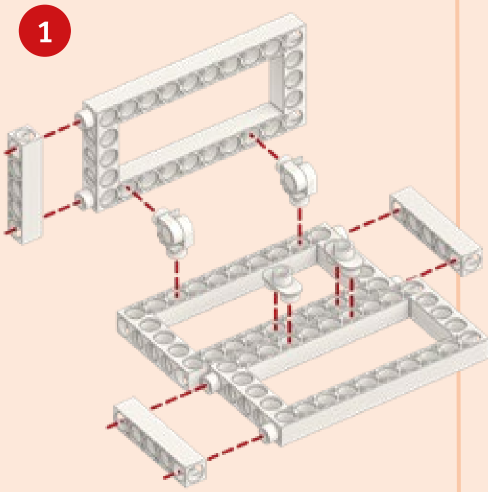

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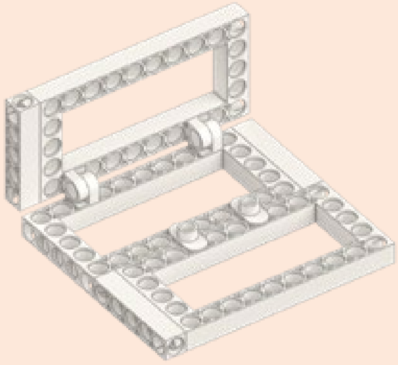

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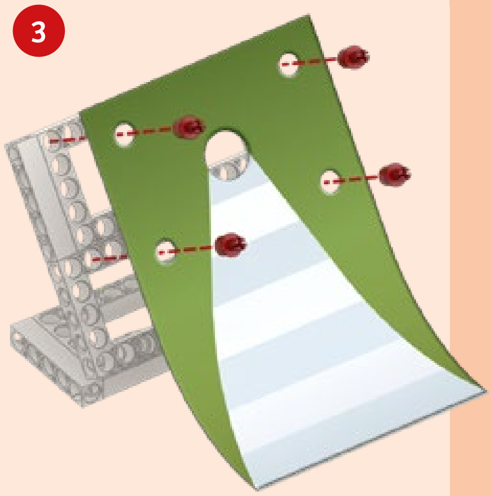

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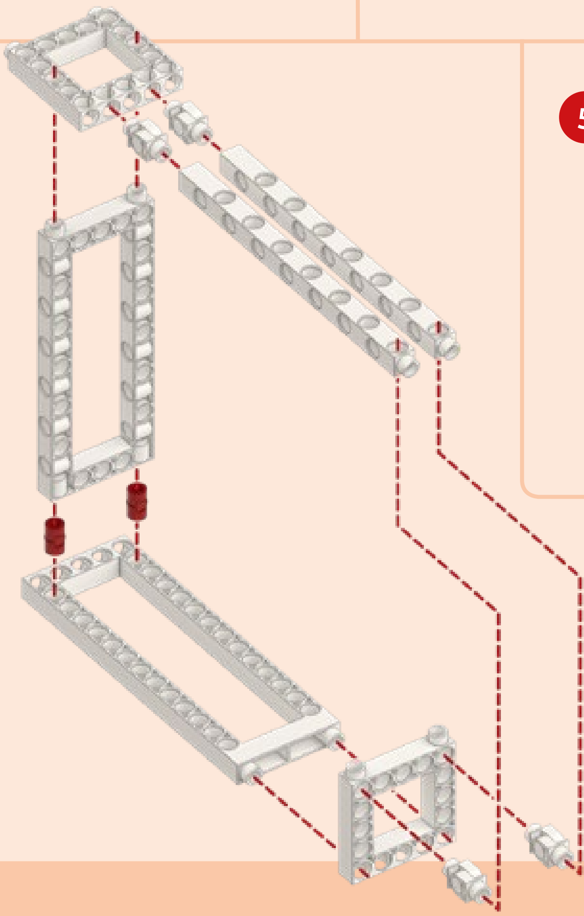

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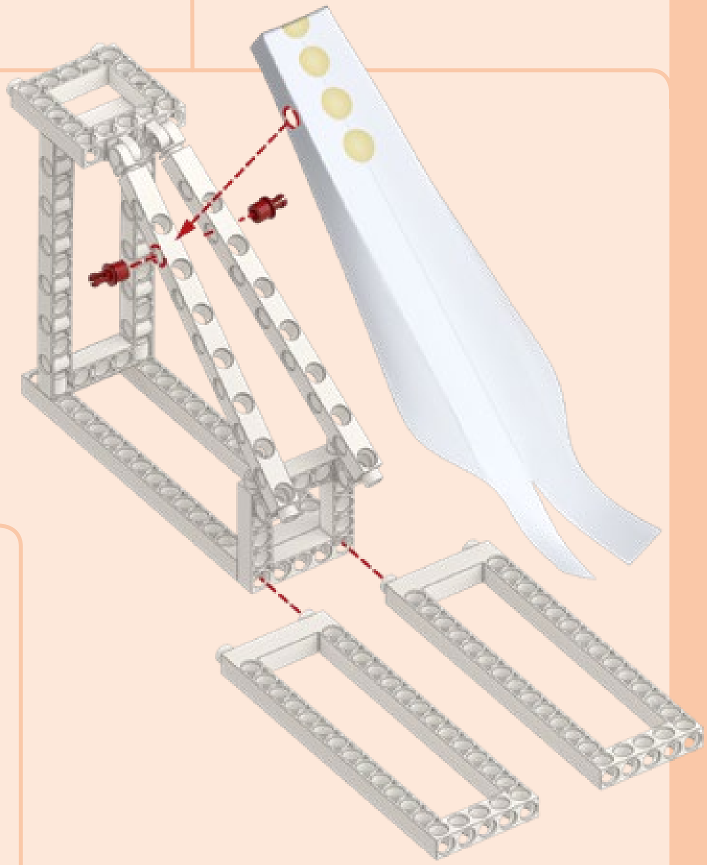

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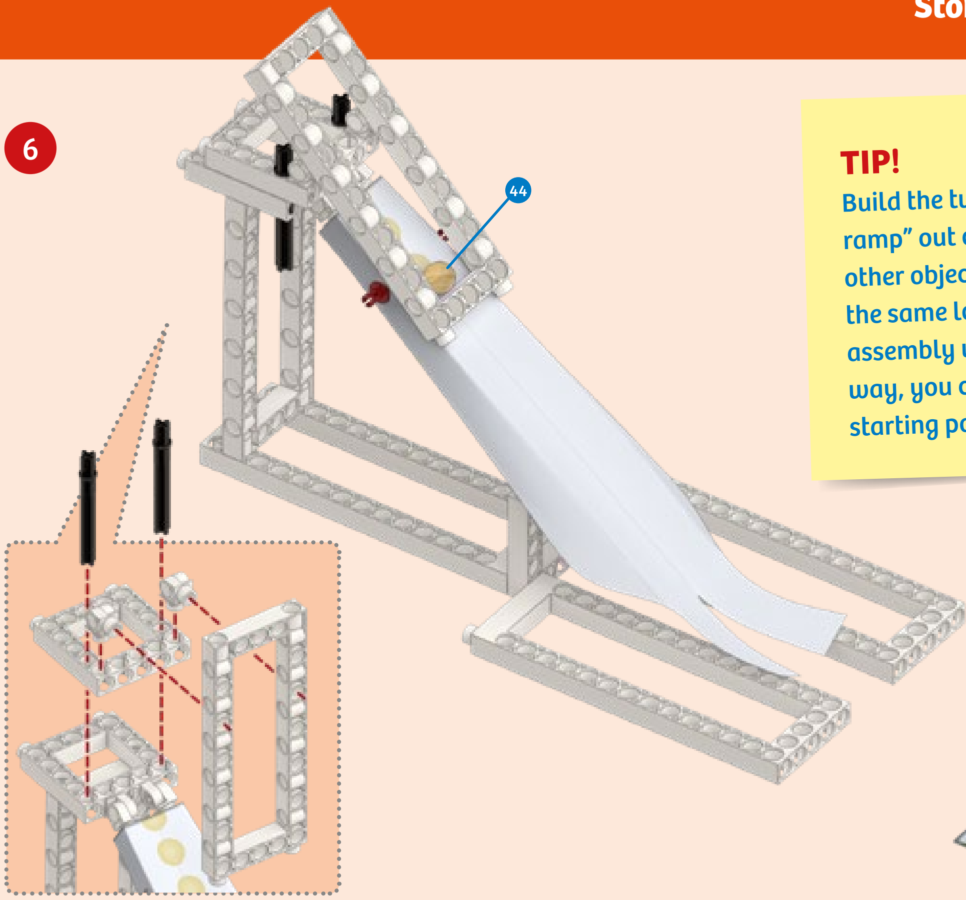
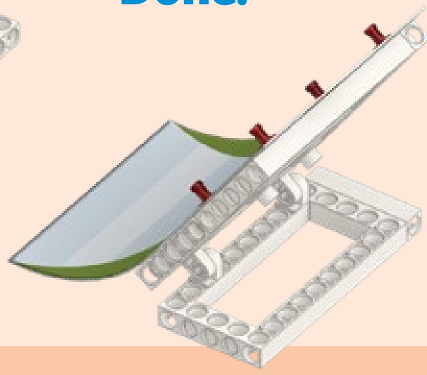


TIP!
Build the two "banks" of a "skee ball ramp" out of paper, tape, and various other objects. Always start the ball at the same location and try adjusting the assembly until you hit your target. That way, you can measure where the best starting position is.

Done!



EXPERIMENT 9

Energy never disappears

YOU WILL NEED

- **Two assembled ramps**
- **Ball**
- *Measuring tape or ruler*
- *Smooth surface (e.g., wood or linoleum floor)*

HERE'S HOW

- On the start ramp, adjust the starting position of the ball by using the frame holder set on top. Begin by starting the ball at the lowest position.
- Place the second ramp directly across from the start ramp, at a distance of at least 100 cm.
- Let the ball roll off, and watch how far up the second ramp it goes! Do you hit the hole?
- Change the starting position of the ball (higher up). What happens?

WHAT'S HAPPENING ?

When the ball rolls down the ramp, its potential energy is converted into kinetic energy. As it arrives at the bottom, it has acquired the same amount of kinetic energy as the potential energy that it had at the start.

If the ball now rolls straight up the second ramp, it loses its kinetic energy again but accumulates potential energy. So what is the greatest height that it can (theoretically) attain?

In addition to height, the potential energy depends on the mass of the ball and the local gravity.

potential energy [J] =
height [m] • mass of ball [kg] • local gravity [N/kg]

DID YOU KNOW ...

The exact "measurement" of variables (in this case, of direction, height, and starting position) has an important role to play in science. It is only with exact measurements that a lot of systems (such as the ball on the ramp) can really have their behavior investigated. For that kind of measurement, though, you need precisely adjustable measuring devices (in this case, the starting ramp). If you were merely to flick the ball from an approximate starting position with your finger, you would hardly ever manage to achieve a specific given direction and speed.

CHECK IT OUT

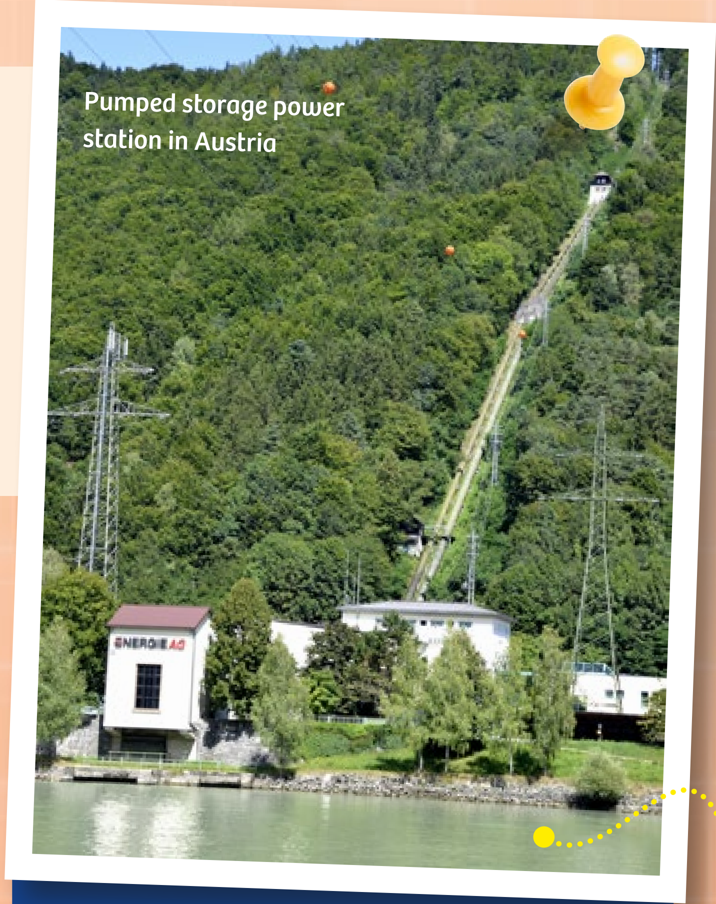
Forms of energy storage

Energy can be stored in many ways, but only a few of them are effective or efficient.

BATTERIES

Electrical energy can be easily converted into other forms (which is why it is often used for transporting energy), but it's hard to store. A battery produces electrical energy, but it is stored in the form of chemical energy (meaning that the acid inside the battery undergoes a change in order to release electrical energy).

If a battery is capable of being recharged, it may be called a rechargeable battery or an accumulator. Large rechargeable batteries are an important component in electric cars.



Pumped storage power station in Austria

Pumped storage

One way to store mechanical energy on a large scale is in a pumped storage power plant. These pump water up to a reservoir so the water "stores" more potential energy. When needed, the water is released through penstocks or sluice pipes, thus converting the potential energy into kinetic energy. Turbines are then used to convert the kinetic energy into electrical energy.

The largest pumped storage power station in the world is in Bath County, Virginia. With a generation capacity of over 3,000 megawatts, it is sometimes called the "largest battery in the world." By comparison, the largest nuclear power plant in the U.S., Palo Verde in Arizona, uses three reactors for a total capacity of 3,937 megawatts. But that plant is only designed to produce energy, not to store it.

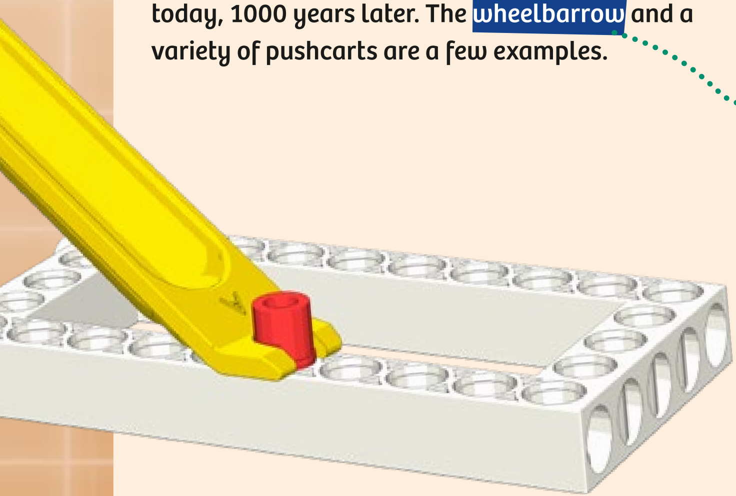
Machines from the Middle Ages

Even in the Middle Ages, people were making use of the laws of physics — even if they didn't know it. Inventions such as the wheelbarrow, the beam balance scale, and the catapult come from this time period.

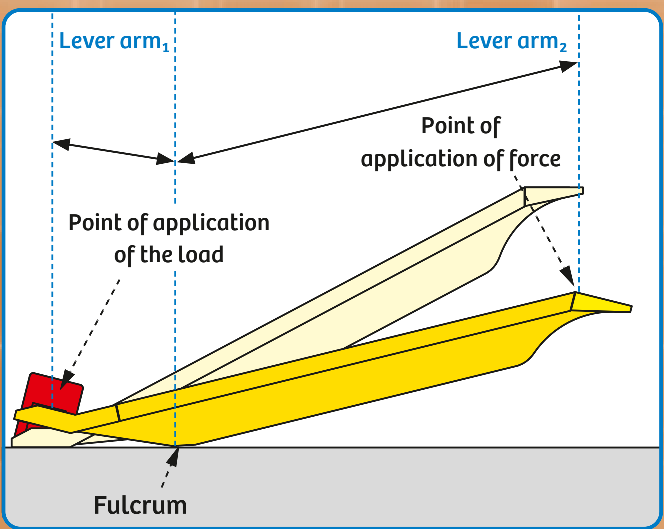
Do you know what a playground seesaw has in common with these medieval machines? This chapter will explain!

Energy and work

In the Middle Ages, there were no motors, steam-powered machines, or electrical power grids, so everything had to be moved by hand. People had to be particularly ingenious in finding ways to use their own manual power to accomplish more. Some of the devices that they invented are still used today, 1000 years later. The wheelbarrow and a variety of pushcarts are a few examples.



In the last chapter, you learned a little about the forms of energy that were most often used at that time: various kinds of potential energy and kinetic energy. These are forms of what is known as mechanical energy. As you know, this is a kind of energy that can be used to perform work. Another clever and very simple device for saving force while performing work is the lever.



THE DOUBLE-SIDED LEVER

The simplest lever in your experiment kit is one you have already used many times, including in the "experiment to hit the ground running" on page 1: the anchor pin lever. That lever takes the force that you apply and transmits it with the help of two lever arms and a fixed fulcrum (pivot point). In this way, you can create a large force under the anchor pin by applying a small force on the lever arm. The exact law for various lengths of lever arm is as follows:

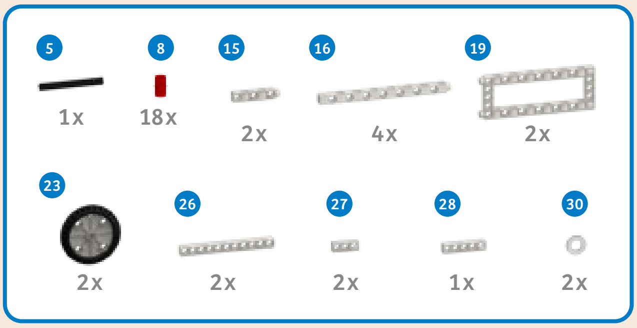
force on the handle [N] • handle length [m] =
force on the anchor pin [N] • length of the lever arm up to the fulcrum [m]

or more generally

force_1 [N] • lever arm_1 [m] = force_2 [N] • lever arm_2 [m]

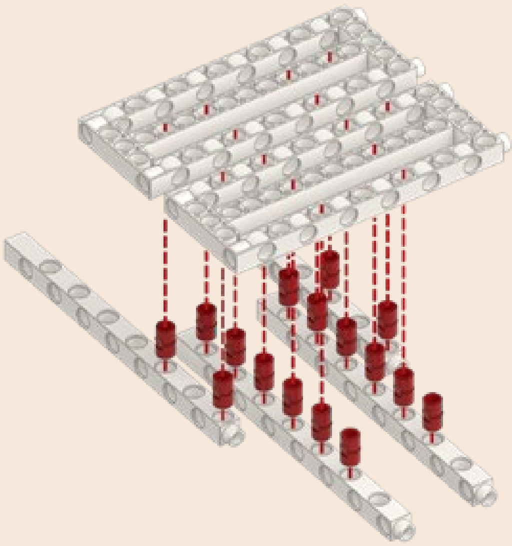
Since the fulcrum is located between the two lever arms, you can refer to this as a "double-sided lever." It is also known as a "class 1 lever" or "type 1 lever."

WHEELBARROW



A wheelbarrow carries heavy loads with a lower expenditure of force.

1



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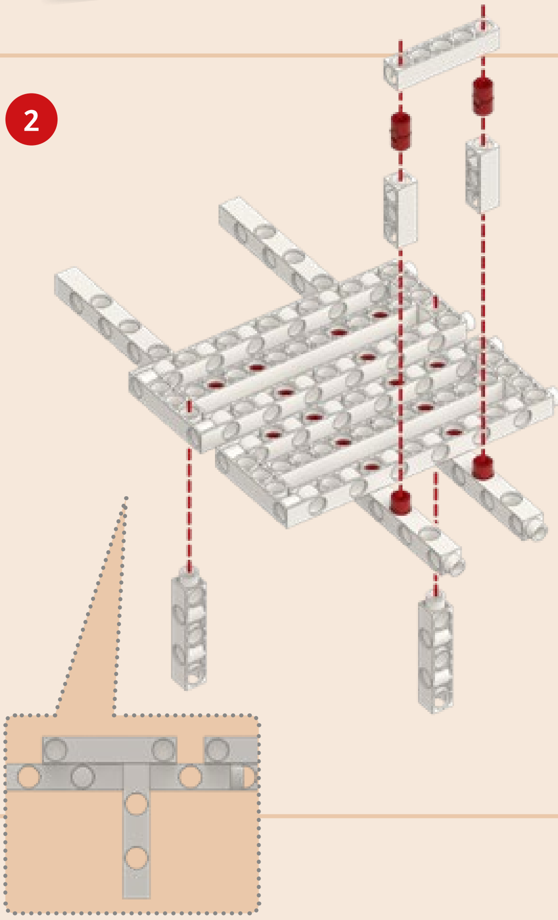

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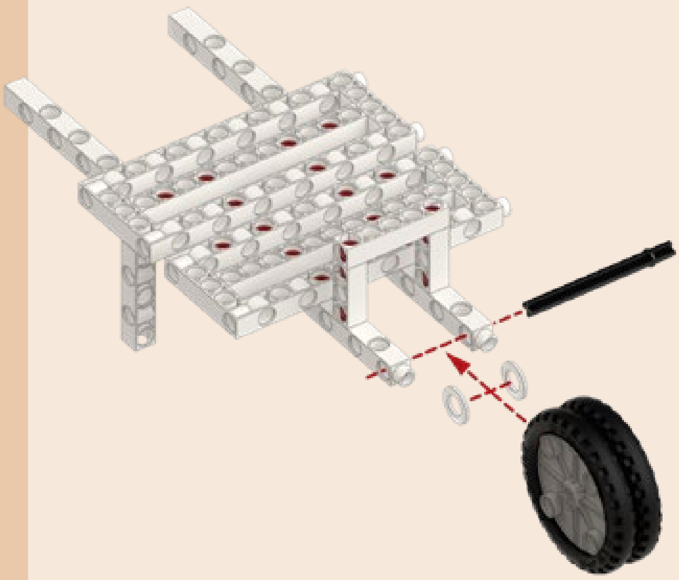

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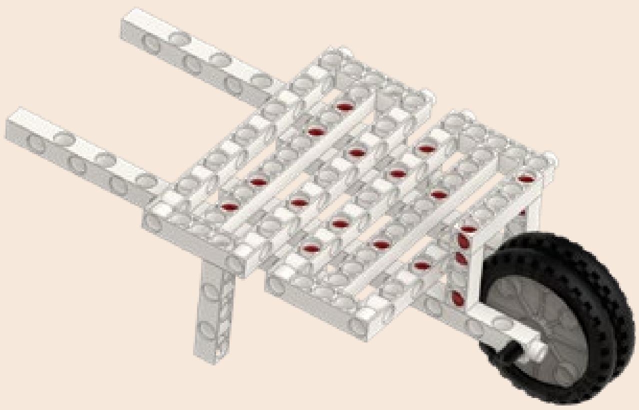


Done!

EXPERIMENT 10

Heavy reading, easily handled

YOU WILL NEED

- **Assembled Wheelbarrow**
- *A few books*

HERE'S HOW

- Place a few books on the cargo bed and check to see if they are easier to transport with the wheelbarrow than without it.

WHAT'S HAPPENING?

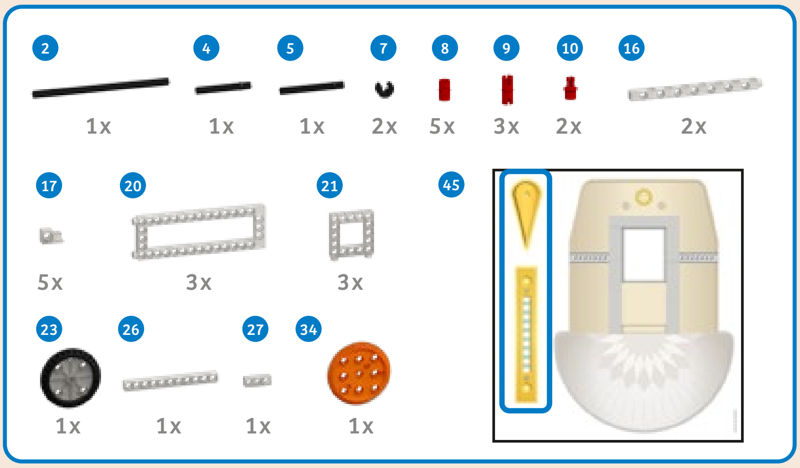
The wheelbarrow makes use of a different kind of lever to reduce the force that you need to lift the books.

In this case, the wheelbarrow's wheel acts as the lever's fulcrum. The two lever arms are the distance to the center of mass of the load, on the one hand, and the distance to the wheelbarrow's handles, on the other. Since both lever arms are on the same side, this is known as a "one-sided lever," or a "class 2" or "type 2" lever. But the principle is the same as with the anchor pin lever!

DID YOU KNOW ...

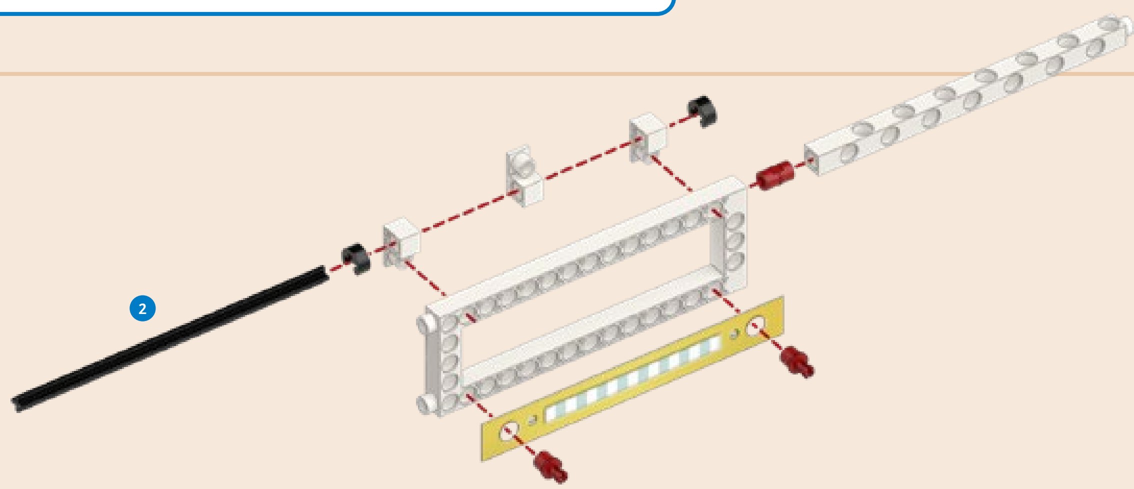
An important part of physics involves checking formulas that were developed on a purely theoretical basis. So check as often as you can whether the formulas really do apply in all situations.

SCALE



Tare the scale (zero the scale) with the sliding counterweight and then use it to determine the mass of various objects.

1



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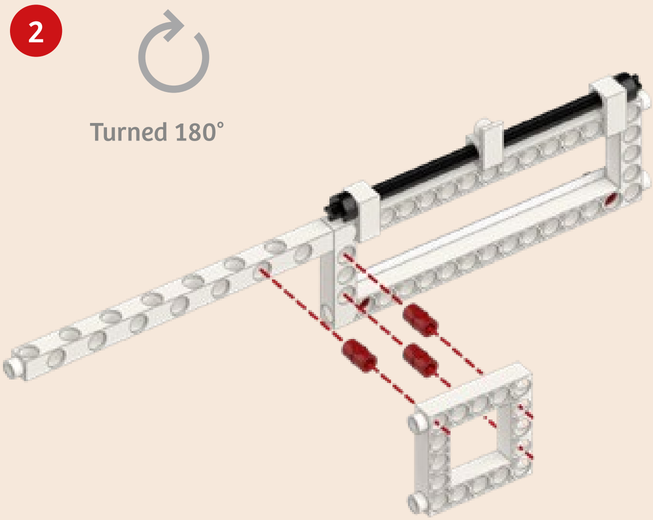
Turned 180°



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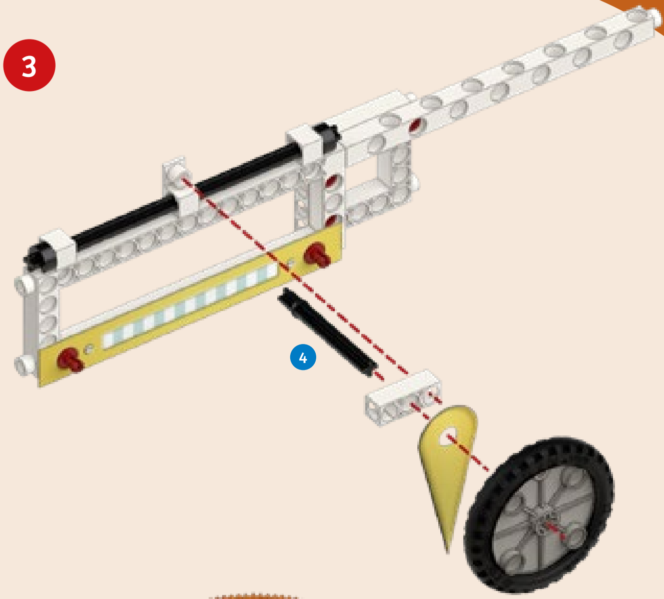

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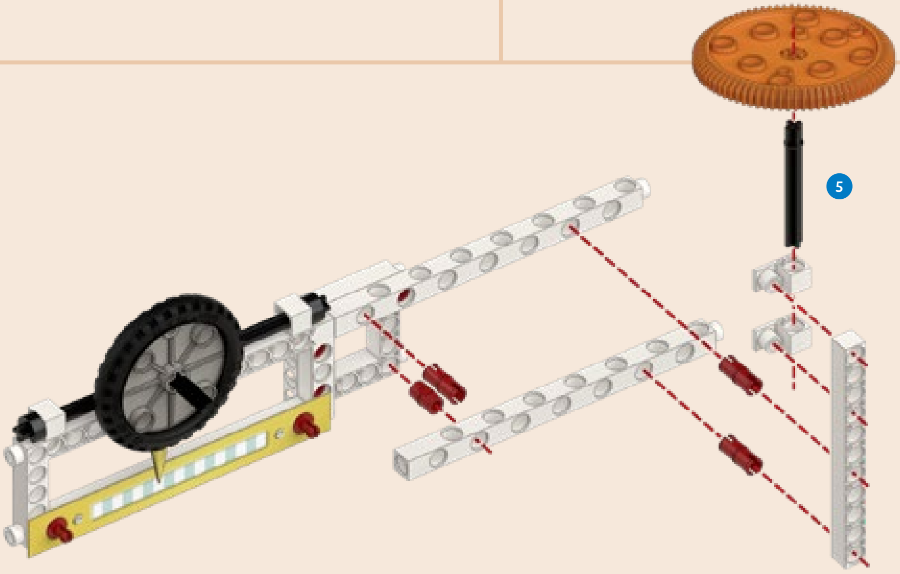

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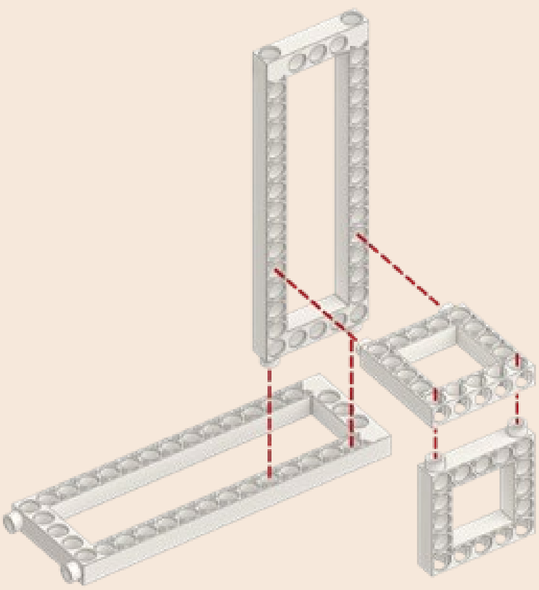

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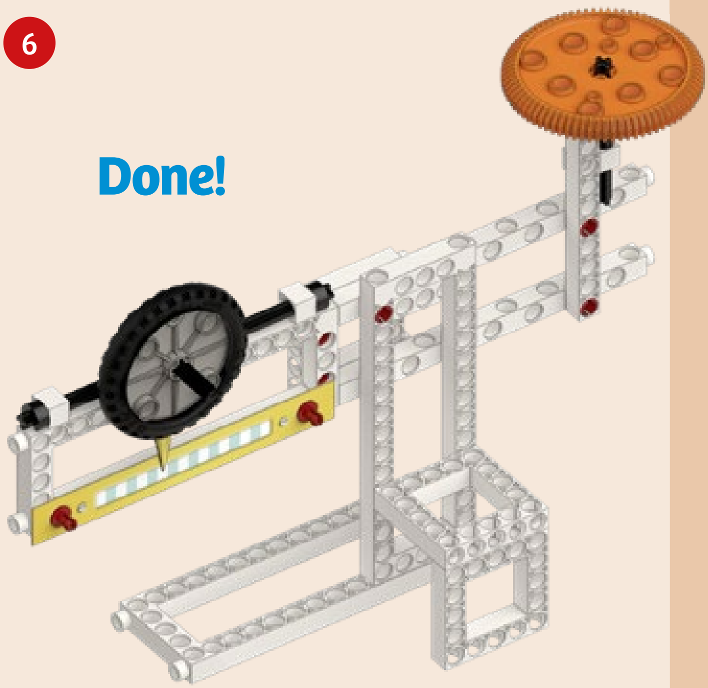
Done!



EXPERIMENT 11

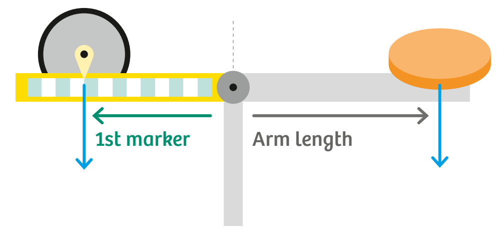
Weighing objects

YOU WILL NEED

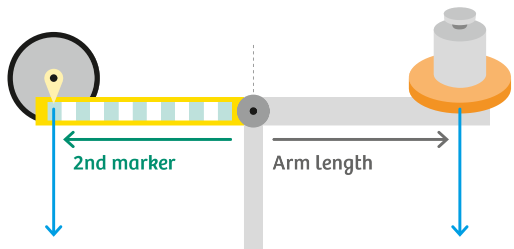
- **Assembled scale**
- *A few lighter objects (such as pens, erasers)*

HERE'S HOW

- Slide the counterweight until the scale doesn't fall or rise when you press on the weighing pan and then let go. It is now balanced. Mark the position of the counterweight on the scale.
- Place the object that you want to weigh on the pan. Readjust the position of the counterweight so the scale is balanced again.



Scale (empty) in balance



Scale (with object) in balance

TIP!
You can also weigh heavier objects as long as you use a heavier counterweight. But you will have to compensate for the extra weight by adding it to the scale pan side.

WHAT'S HAPPENING?

This scale also has two lever arms, but it also relies on a counterweight with its own additional "lever arm." This can be lengthened or shortened by sliding the weight. If both sides of the scale are in balance, it means that the forces (transmitted by the lever) cancel each other out. Since we know the mass of the counterweight, we can also determine the mass of the object on the scale pan.

DID YOU KNOW ...

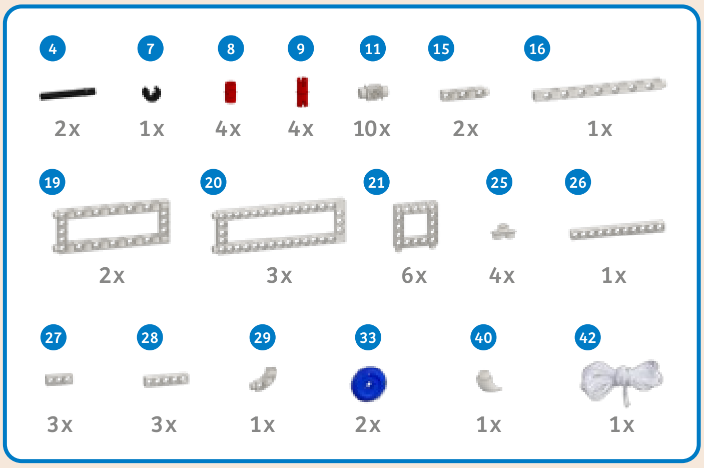
The length between the two markers on the scale shows you how much the object weighs, because:

$$\text{mass [kg]} = \frac{\text{distance between markers} \cdot \text{mass of counterweight [kg]}}{\text{length of arm with scale pan}}$$

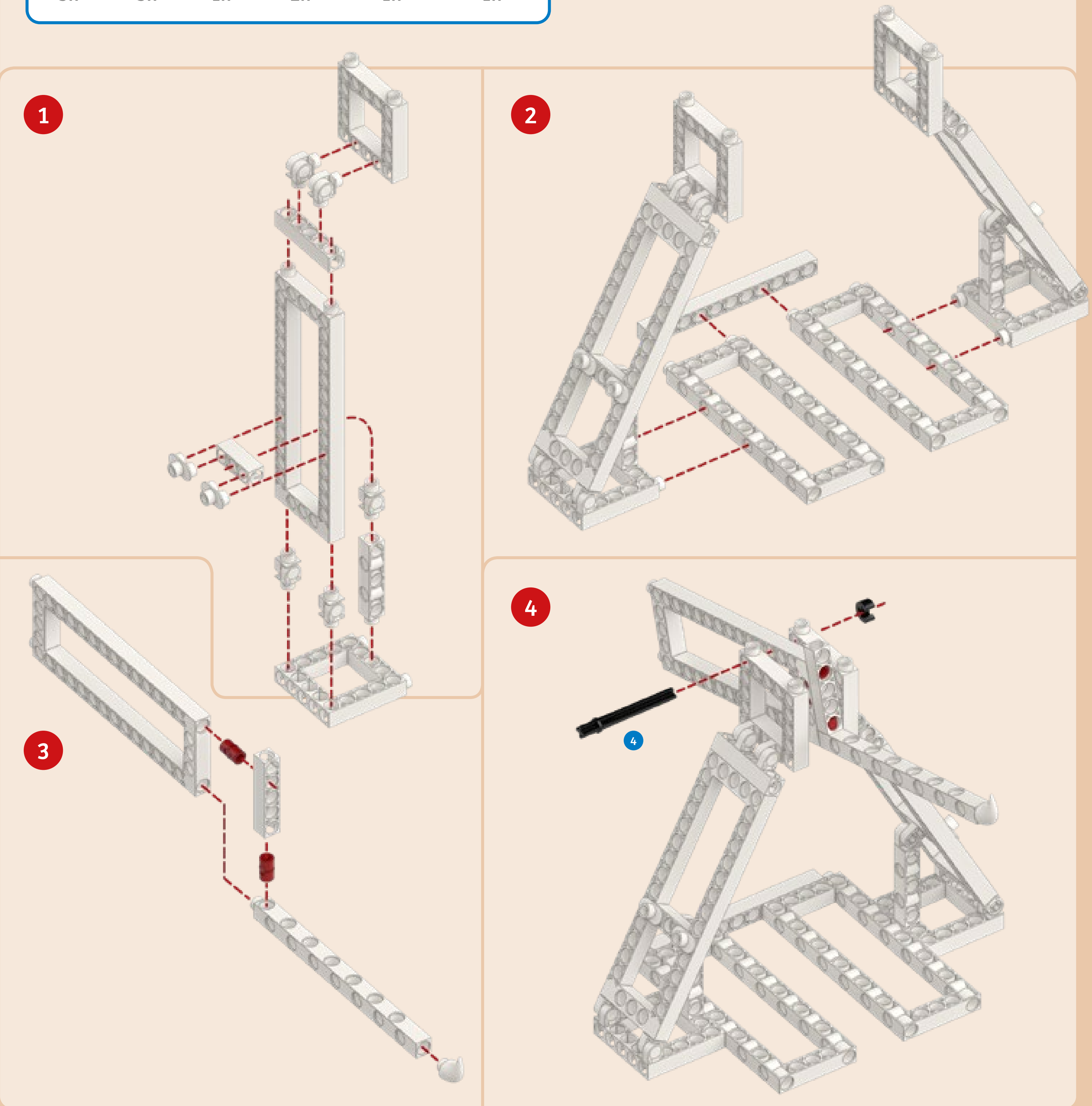
(The counterweight weighs about 30 grams (0.030 kg).)

You may have a kitchen scale at home. Modern scales like that are more precise than this one. Compare the readings that you got here with those of your kitchen scale. Do they match?

TREBUCHET



The trebuchet is a kind of catapult that was used as a siege weapon in medieval times.



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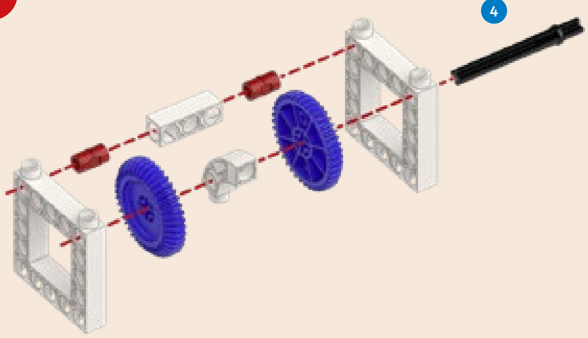

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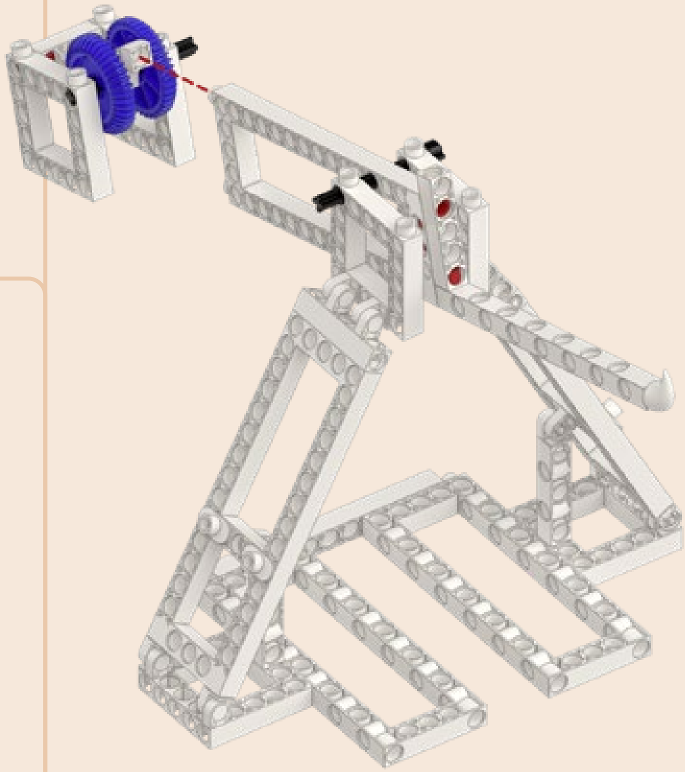

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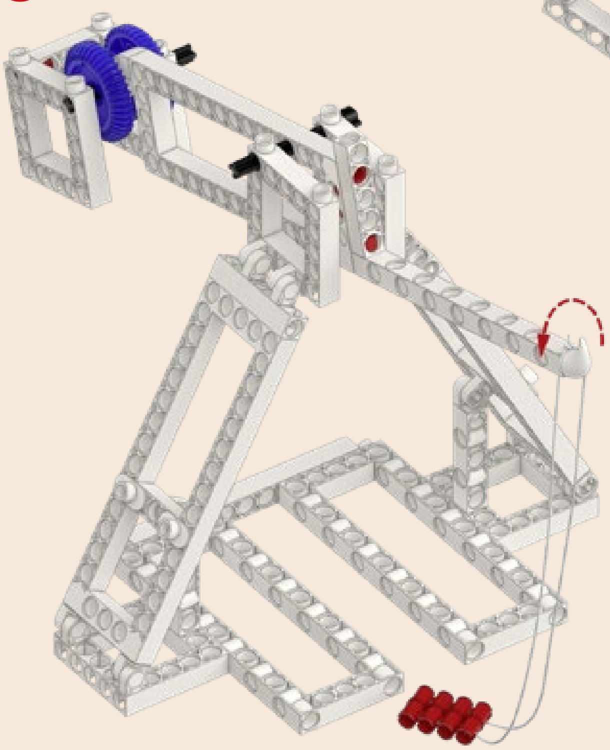
Sling and payload

8



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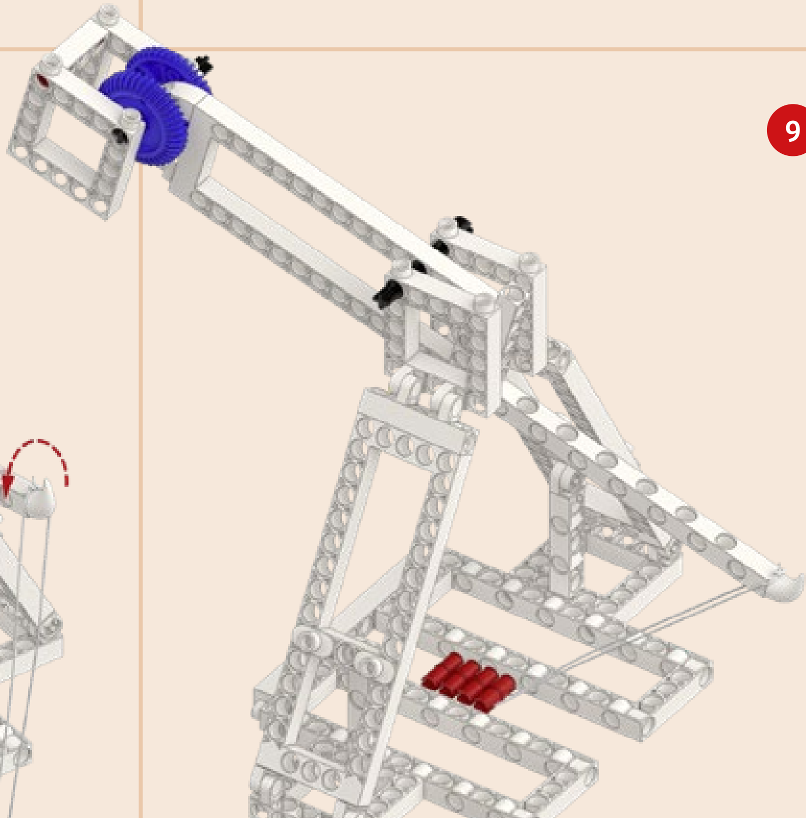


Done!

EXPERIMENT 12

Catapult competition with the trebuchet

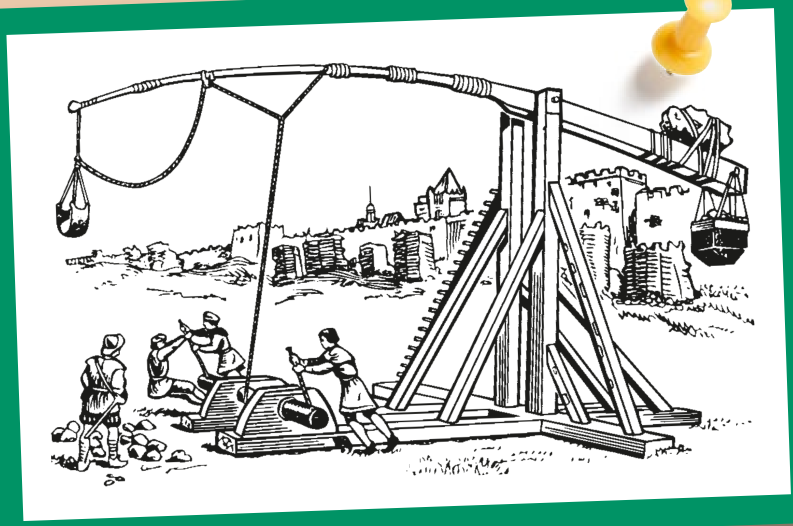
TIP!
You can change the throwing angle of the stone by twisting the horn. There is a best angle! Learn more in the "Check It Out" section.

YOU WILL NEED

- **Assembled trebuchet**
- *Someone to compete against*

HERE'S HOW

- First wrap the sling around the horn, then pull the payload down between the two feet, and quickly remove your hand.
- Remembering what you learned in chapters 1 and 4, think about how you might increase the throwing distance. (Tip: Try adjusting the lever arm mount, the weight, or the sling.)
- Have a competition against your friends to determine the catapult champion!



WHAT'S HAPPENING?

The trebuchet is a counterweight catapult. That means that the energy that accelerates the stone comes from the potential energy of the counterweight on the lever arm. Additional acceleration is provided by centrifugal force in the sling. So with the trebuchet, several things come together that we have already learned a little about: lever arm, gravity, and centrifugal force.

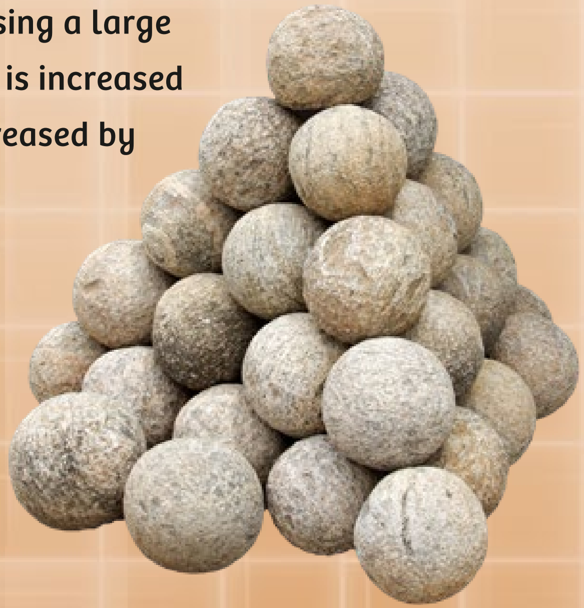
DID YOU KNOW ...

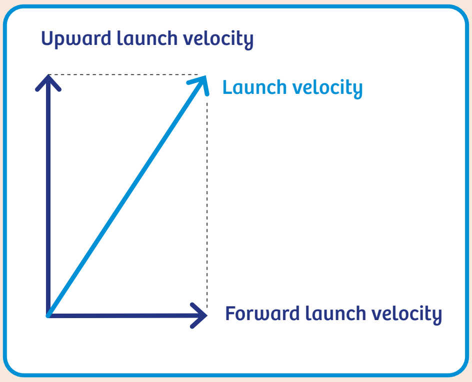
...that in the Middle Ages, the influence of a knight on his fief had a lot to with his castle? If a knight wanted to enlarge his dominion, he had to initiate a feud with another knight and take his castle. Easy to say, not so easy to do. It was common to have to lay siege to a castle for months or even years. But siege machines like the trebuchet made it possible to take a castle much more quickly. Before the invention of the cannon, the trebuchet was the most effective siege device of the Middle Ages.

CHECK IT OUT

Flight paths of the catapult stones

The flight path of a stone depends on its throwing speed, or launch velocity, and angle. The launch velocity can be increased by using a large counterweight or a large catapult (since the leverage is increased by a longer lever arm and the centrifugal force is increased by a longer sling).





PARTIAL VELOCITIES

You can divide an angled launch velocity into two parts: the forward launch velocity and the upward launch velocity.

THROWING RANGE

The distance covered by the stone during its flight simply depends on the launch velocity (LV) in the forward direction and its time of flight! From Chapter 3, we know:

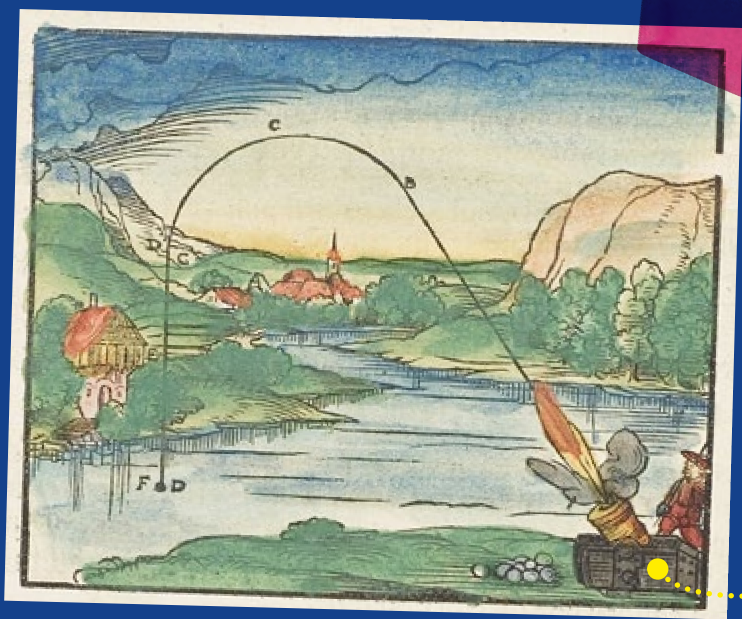
$$\text{distance [m]} = \text{time of flight [s]} \cdot \text{forward LV [m/s]}$$

TIME OF FLIGHT

If you throw the stone straight up, it will be slowed down by gravity and then reverse itself and fall right on top of you. The time to the reversal point can be found with the formula for speed that you learned in Chapter 3 (with local gravity being equal to acceleration in this case):

$$\text{time period until reversal [s]} = \frac{\text{upward LV [m/s]}}{\text{local gravity [m/(s} \cdot \text{s)]}}$$

Then, the stone will take the same amount of time to come back down. The stone's total time of flight is therefore twice the amount of time that passes before it reverses course and starts to fall.



Even in the 16th century, people tried to calculate the flight path of cannonballs.

AIR RESISTANCE

In reality (with large catapults), though, it's better to choose a somewhat flatter angle because air resistance will slow down the stone. The faster the launch velocity, the flatter the optimal angle.

LAUNCH ANGLE

If we insert the time of flight, this is what we get for the distance:

$$\text{distance [m]} = \frac{2 \cdot \text{forward LV [m/s]} \cdot \text{upward LV [m/s]}}{\text{local gravity [m/(s} \cdot \text{s)]}}$$

The distance is greatest if both parts of the launch velocity are equal. That is the case when the launch angle is exactly 45°!

TIP!

If you take a sheet of paper and fold it at one corner such that two edges meet, you will get a 45° angle.

The Flow of Air

You can't see air with your eyes, but you can feel it when it moves, like when you're hit with a gust of wind. The air flowing under, over, and around us makes a lot of astounding things possible. It allows airplanes to fly and wind turbines to produce electricity, for example.

Here's where we will explain the importance of the shape of an airplane's wings or a wind turbine's blades, and why it is that a parachute doesn't just fall straight down to the ground.

The flow of air

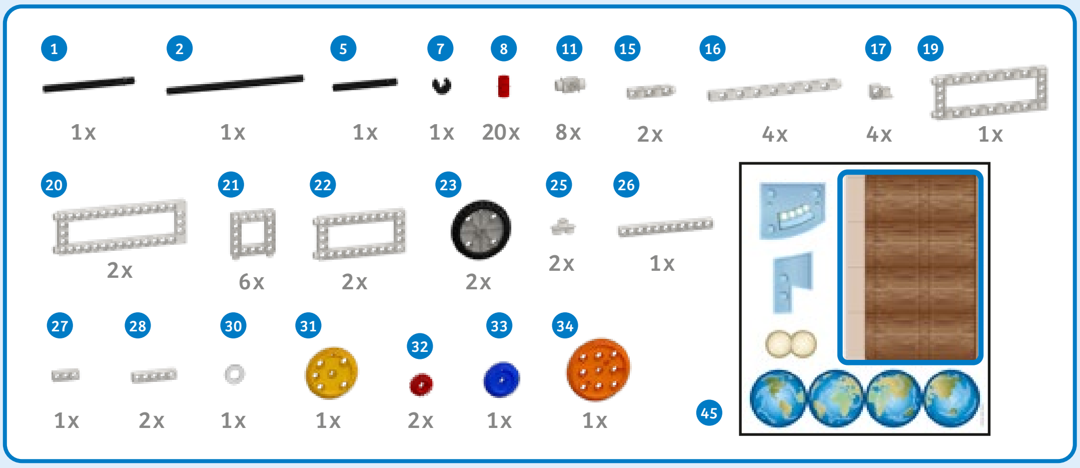
When you move your hand through air or water, the medium offers a certain degree of resistance. The faster the movement, the more obvious the resistance becomes.

Before a skydiver opens his parachute, he goes into "free fall," just like an apple from a tree.

It may be most helpful to think of air as being like water. After all, our atmosphere is nothing other than a big ocean of air covering the entire planet. In water, you can move yourself along by swimming or paddling, and the air can also be used for propulsion with the help of a propeller or helicopter blades.

The way that air flows around a surface determines its effects on that surface. Based on this knowledge, we can construct airplanes and helicopters or build large windmills or wind turbines that provide us with power, and we can fly through the air using parachutes or paragliders.

WINDMILL



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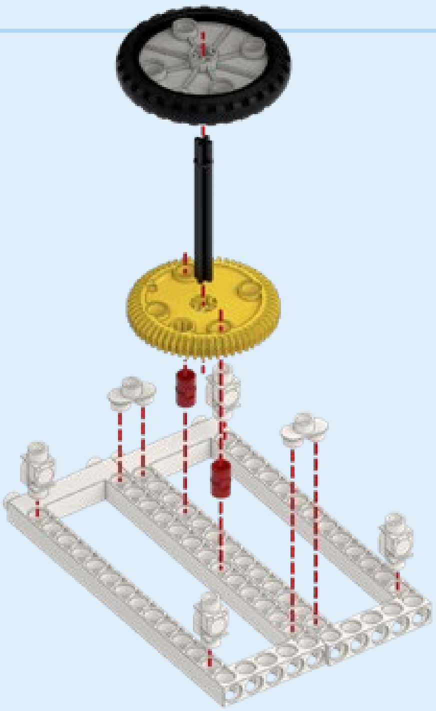

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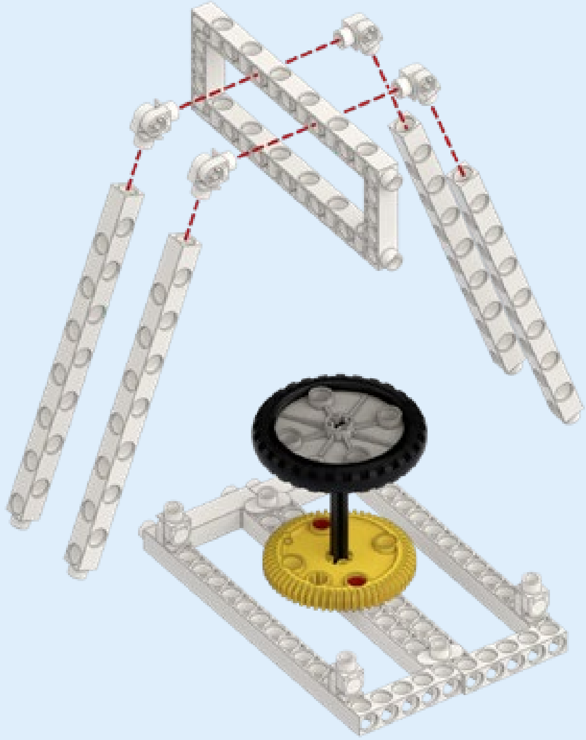

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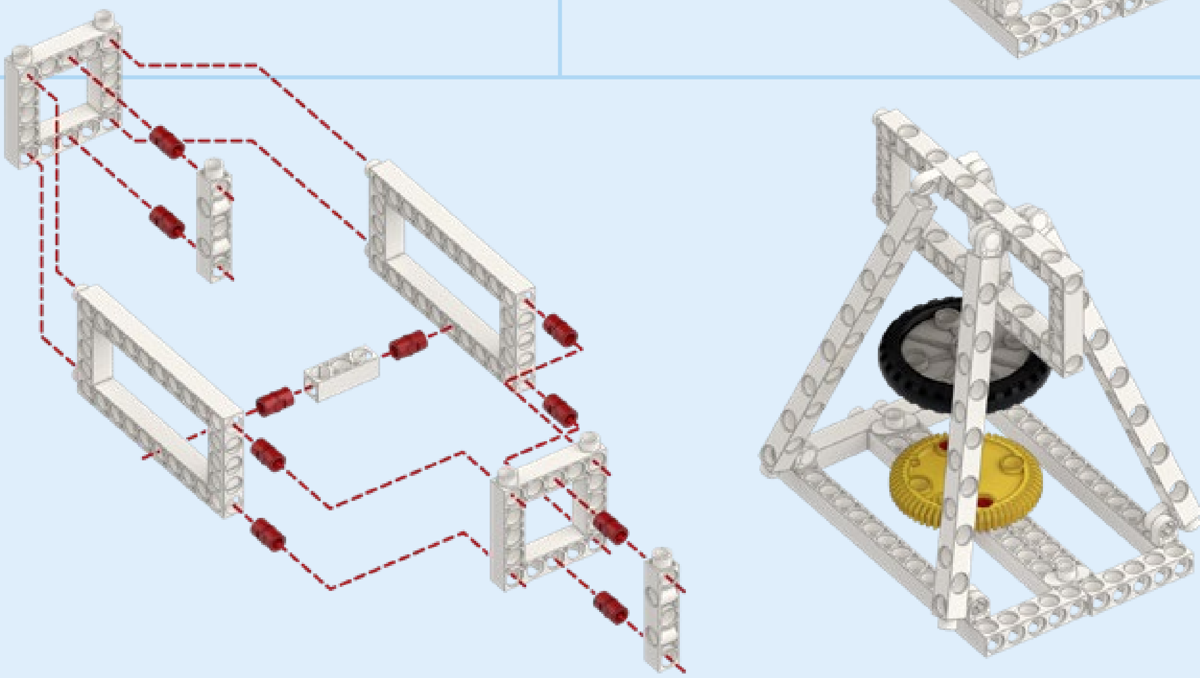

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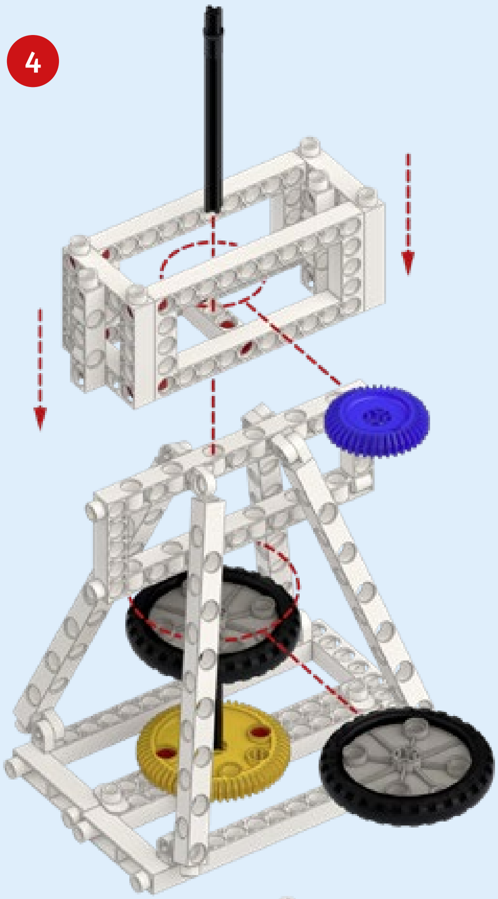

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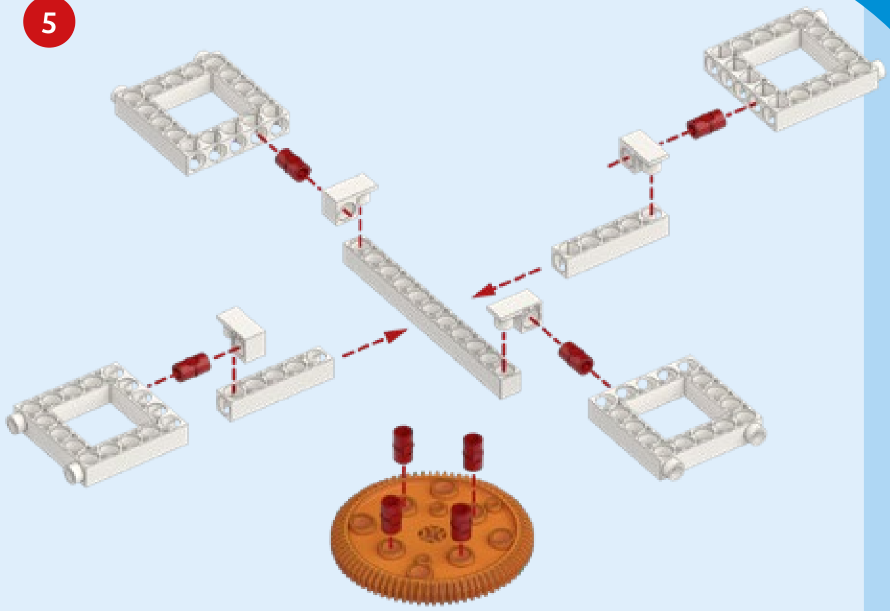

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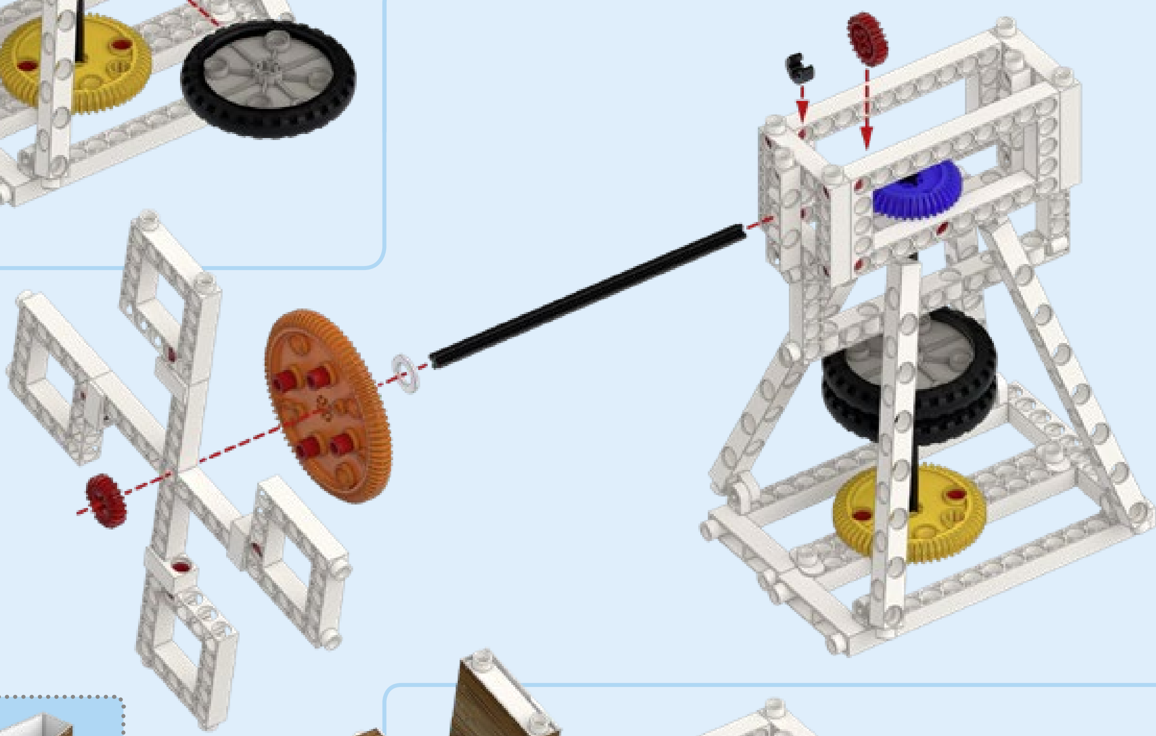

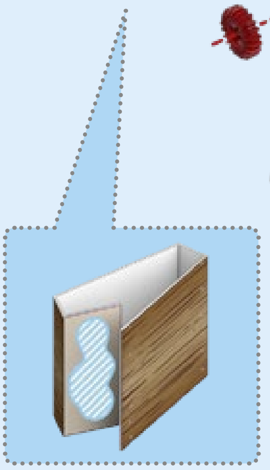

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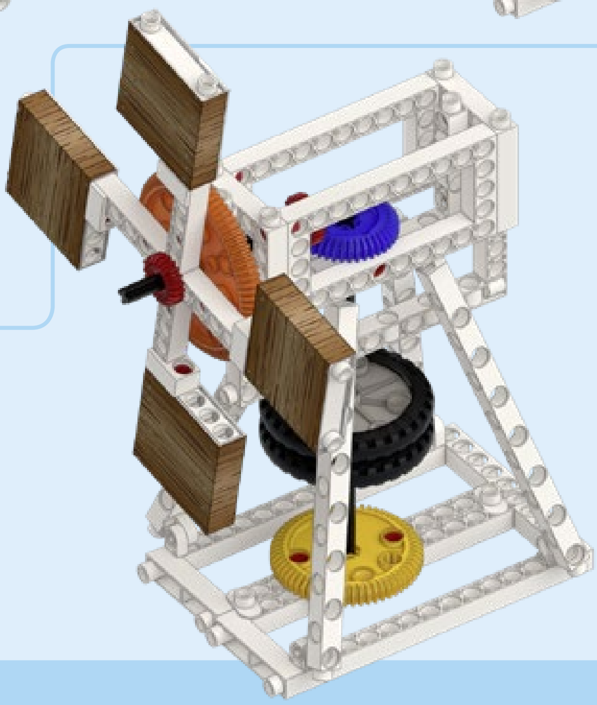


Done!

EXPERIMENT 13

The force of the wind

YOU WILL NEED

- **Assembled windmill**
- *A hair dryer (cold air setting) — or a lot of breath*

HERE'S HOW

- Adjust the angles of the windmill blades so they look flat when you see them from the front. What happens when you blow against them?
- Shift the surfaces a little to the rear and try it again. What settings make the windmill turn the fastest? When won't it turn at all?

WHAT'S HAPPENING?

The rotor blades turn because the air has to change its direction as it flows across them. (Hold the windmill tight and feel with your hands where and in what direction the air passes by the blades.) As that happens, the force is transmitted against the direction of the change in air flow, and the windmill turns. When you adjust the surfaces so they are completely flat, there is an equal amount of air diverted around the right and left sides of the rotor blade, so the forces cancel each other out and the windmill won't move.

WHERE DOES THE WIND BLOW?

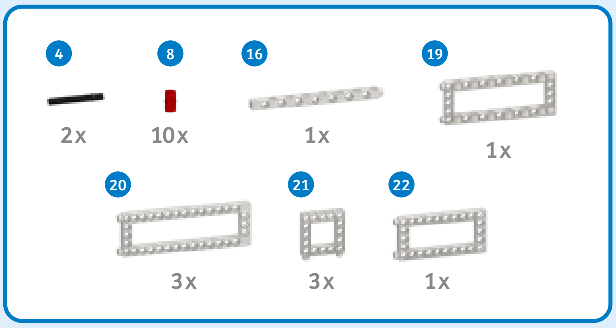
The location of a windmill can make all the difference, because the wind doesn't blow equally hard everywhere. Good locations are in open fields, on hills or mountain ridges, and on the coast or on the water near the coast.

DID YOU KNOW ...

...that millstones and power generators share something in common? Windmills used to be used mainly for grinding the grain used in people's daily bread. The process involved two millstones steadily turning against each other in order to grind the grain.

In much the same way, today's windmills or wind turbines contain electromagnets and coils that turn against each other to produce electrical power. You will learn more about this in the Thames & Kosmos "Physics Solar Workshop" and "Wind Power" kits.

DROP DEVICE



The structures suspended from the axles start to fall as soon as you pull out the handle.

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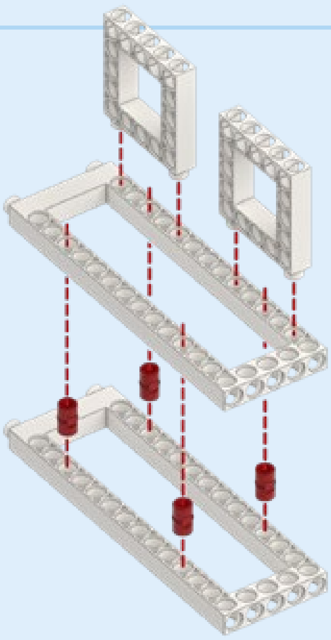

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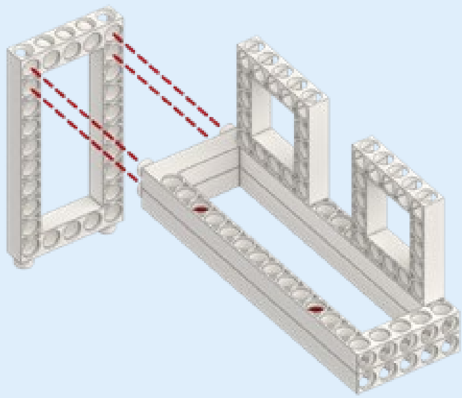

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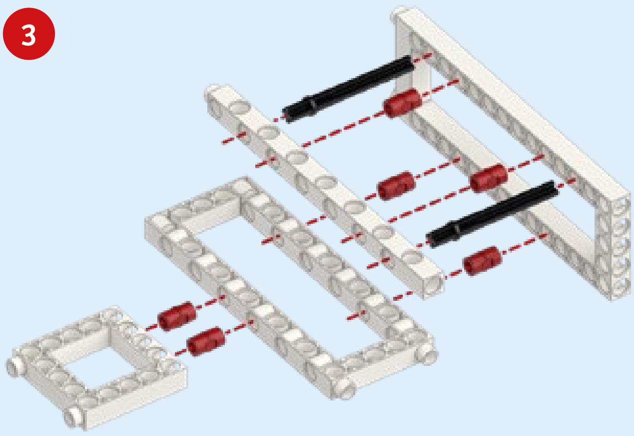

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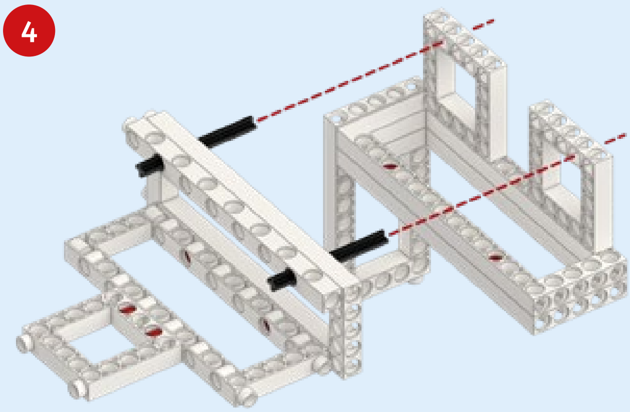

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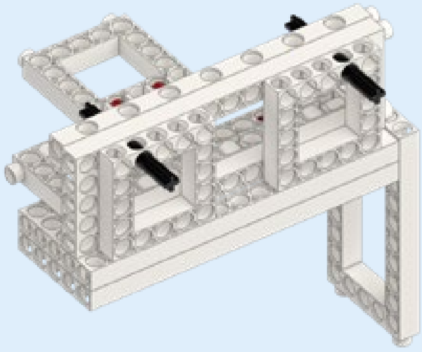


Done!

EXPERIMENT 14

DROP TEST

YOU WILL NEED

- **Assembled drop device**
- **Two components with different weights, such as a large yellow gear wheel (31) and a square frame (21), to serve as "test objects"**

HERE'S HOW

- Suspend the test objects from the two projecting axles, set yourself on a soft surface, and lift up the drop device in front of you.
- Pull out the handle. Which test object drops faster to the ground? The heavier one or the lighter one? For a clearer result, lift the drop device a little higher.

View into a well shaft

WHAT'S HAPPENING?

As you can see, both fall equally quickly! It makes no difference how heavy an object is — it will always drop at the same speed. That's because gravity per kilogram is the same for all objects:

$$\frac{\text{gravity [N]}}{\text{mass [kg]}} = \frac{\text{mass [kg]} \cdot \text{local gravity [N/kg]}}{\text{mass [kg]}}$$

local gravity [N/kg] = 9.81 [N/kg]

Why, then, will a feather fall more slowly than an equally heavy pebble? You will learn the answer to that in the next experiment...

DID YOU KNOW ...

...that you can use a falling rock as an easy way to estimate the depth of a well? Just drop the rock and count the seconds until you hear it hit the water. Then use this formula to determine the depth resulting if you assume a fixed acceleration ("one g") due to gravity:

depth [m] = 5 [m/s²] • falling time [s] • falling time [s]

EXPERIMENT 15

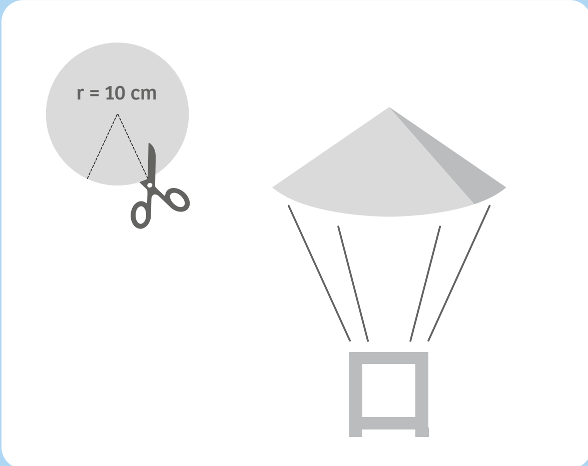
Various parachutes

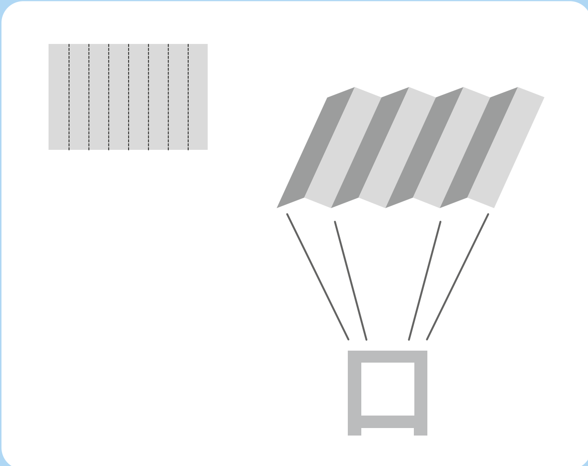
YOU WILL NEED

- **Assembled drop device**
- **Two identical "test objects," such as two square frames (31)**
- **String**
- *Two sheets of paper*
- *Compass, ruler, scissors, tape*

HERE'S HOW

- First make a round parachute. Use the compass to draw a circle with a 10-cm radius on a piece of paper. From the edge of the circle to the center, draw two lines to make a narrow "pie slice." Cut out the circle and the "pie slice."
- Tape the parachute together and tape on 4 sections of string (each about 15 cm in length). Then tie a test object to the end of the string sections.
- Now make a second parachute with a rectangular shape. Use half a sheet of paper and fold it into pleats (eight times, say) like an accordion.
- Again, tape on 4 pieces of string (each about 15 cm in length) and tie your second test object to their ends
- Use your drop device to drop both at the same time, and observe their flight.





You will learn "What's happening?" on the next page.

WHAT'S HAPPENING?

The two test objects fall considerably more slowly to the ground than in the previous experiment. That has to do with the air resistance provided by the parachute, which the object in the prior experiment (in "free fall") didn't have. The object with the larger parachute should take a little longer to reach the ground.

FLYING WITH FEATHERS AND PARACHUTES

In nature, the seeds of some plants, like the dandelion, or the feathers of birds will fall very slowly to the ground due to a great degree of air resistance. Just think — without air resistance, a feather would fall as fast as a rock!

We humans prefer to depend on variously-shaped parachutes to help us take advantage of air resistance to slow our fall. There are round parachutes and so-called gliding parachutes, which can be steered to allow the jumper to move in a desired direction. You will sometimes see ones that are designed to let you take off from the ground (from the edge of a cliff, say). These are known as paragliders.

TIP!

Air resistance depends to a great extent on the shape and surface of the object or parachute. The more surface area there is, the greater the resistance. The shape of the parachute also contributes to air resistance as well as contributing to the parachute's stability. What we're looking for is the most evenly-distributed flow of air possible over the entire surface. To help the air escape, and to prevent the parachute from rocking back and forth, round parachutes often have a hole in the center.

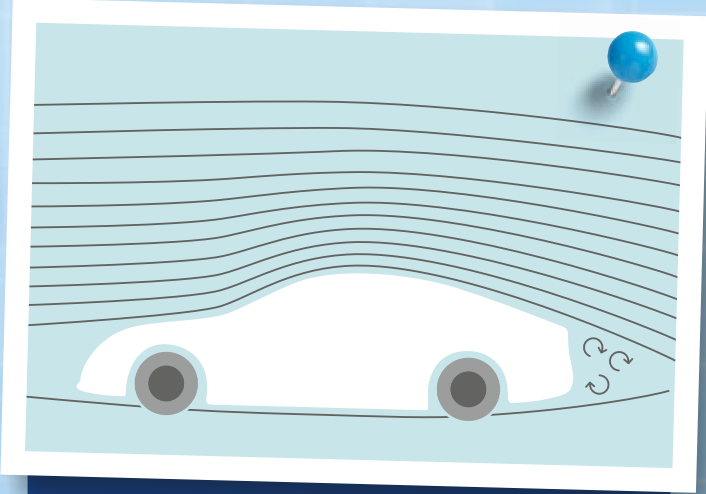
DID YOU KNOW ...

...that the human body also has its own air resistance? This means that when a skydiver is in free fall before opening the parachute, he or she will only be able to fall 200 to 300 km/h at most. At that speed, the force of the air resistance and the weight of the parachutist will cancel each other out. The skydiver can stretch out his or her arms and legs like a spider in order to slow down or to prepare for the dive.

CHECK IT OUT

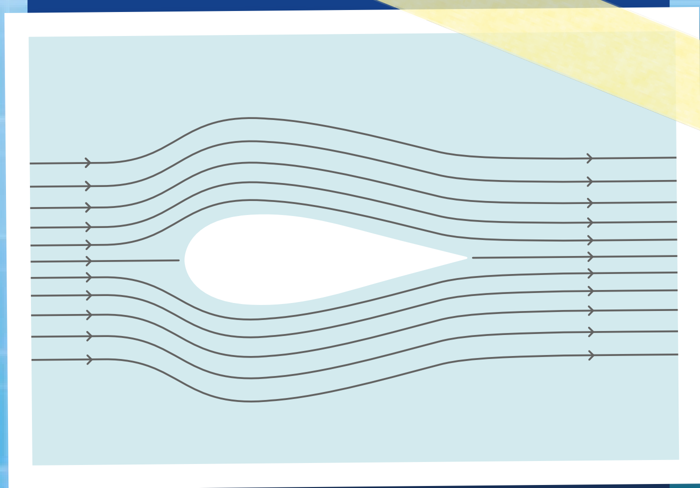
Streamlines of air

Streamlines indicate the flow of air around an object. An object with little air resistance will hardly alter the streamlines of the passing air and will produce no turbulence. The closer a vehicle is to matching these criteria, the more "streamlined" it is.



A car's fuel consumption at high speeds is strongly influenced by how streamlined it is. That's why a car prototype is often tested in a wind tunnel as a new model is being developed, to make sure that it has a streamlined shape and so that adjustments can be made if it doesn't.

The turbulence created by a rotor blade or an airplane's wing can be disruptive or even dangerous. Windmills or turbines have to have a certain distance between them (depending on their size), so the turbulence can calm down again and a steady airstream can reach the next one. Airplanes also create a lot of turbulent air behind them, called "wake turbulence." An airplane following close behind another one can be hard to control in this kind of turbulent air, so an airport control tower will usually allow long enough pauses between takeoffs or landings for the turbulence to settle.



The path of streamlines is especially important for airplane wings, helicopter rotor blades, and wind turbines, since they determine how stable the plane will be in the air or how efficient the wind turbine will be.

Our Solar System

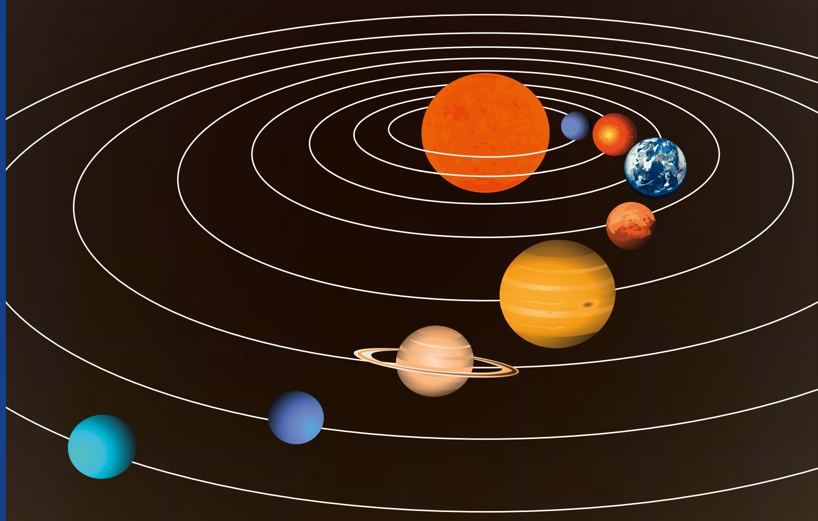
Ever since Copernicus, we have known that the Earth circles around the Sun. But have you ever wondered why it gets dark at night or why the Moon changes its appearance?

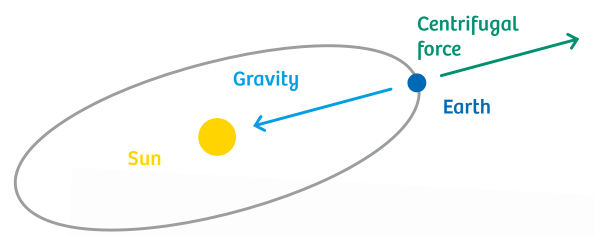
In this chapter, you will use a model of the Earth and Moon to investigate these questions and you will learn how to use the Sun to tell precise time.

Sundials like this can sometimes be found in parks or gardens.

INTRODUCTION

As you probably already know, our Solar System has eight planets — Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. There used to be nine, but Pluto was deprived of its planet status in 2006. In addition to these large planets, there are lots of smaller objects orbiting the Sun. They are all moving in accordance with a single law of physics. That law is gravity, which you already learned about in the first chapter of this manual.





THE SUN ATTRACTS

But why don't the planets simply go crashing into the Sun's surface? The answer to that lies in the fact that the Sun's gravity and the centrifugal force of the planets in their orbits, which pull in opposite directions, are equally strong.

PLANETARY ORBITS

The planets remain in their more or less circular paths around the Sun because there in nothing in space that can slow them down. The Earth needs exactly one year to make a single orbit around the Sun. Other planets need more or less time than that depending on whether they are farther away from the Sun or closer to it.

SUNDIAL

The string's shadow shows the time.

You will also need a sheet of white paper (letter size). Cut it in half lengthwise and then fold the edges back at the narrow ends. Glue it to the main structure to form a semitransparent "screen" (see step 4, below).

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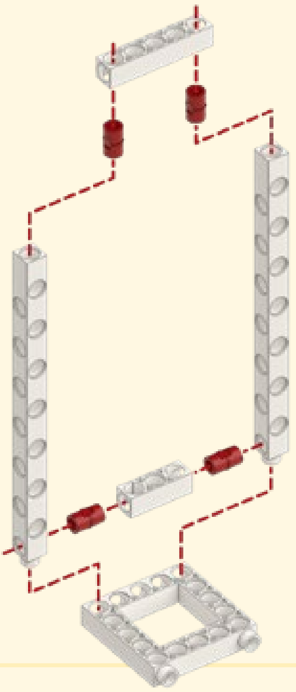

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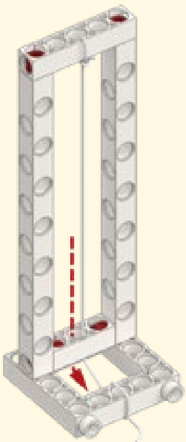
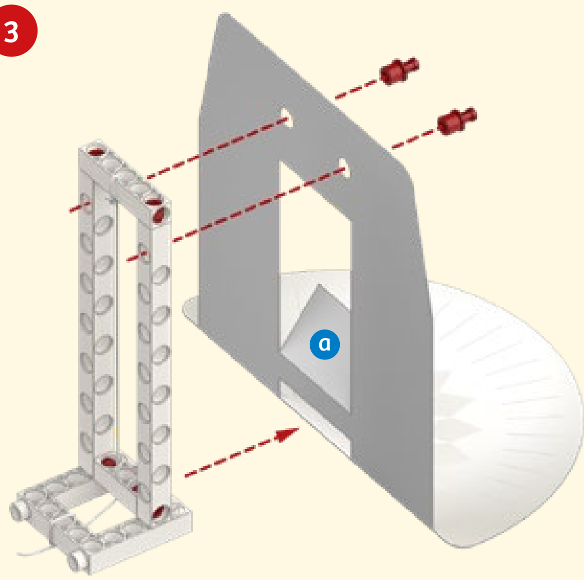


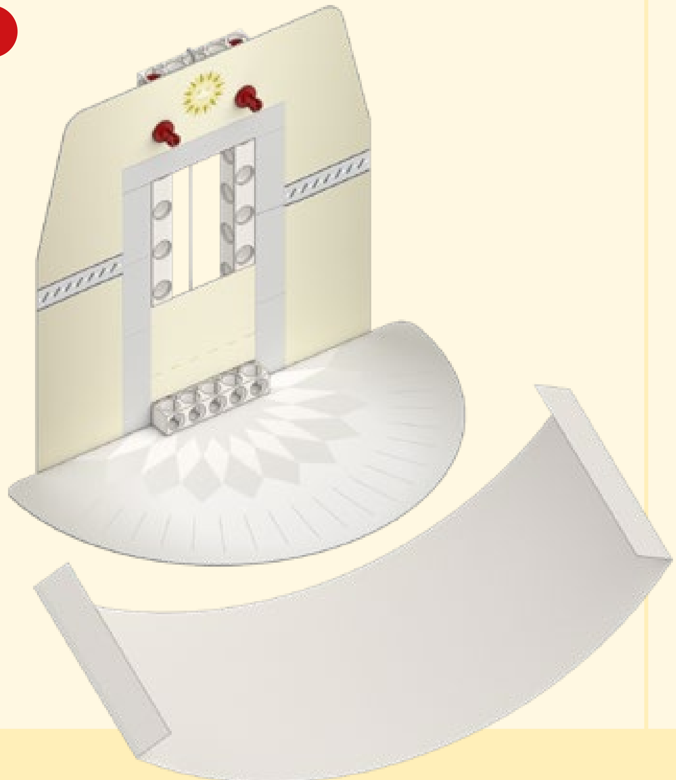
Take a piece of string about 30 cm in length and start by tying it through the center hole at the top of the frame. Then pass it through the bottom and finally tie it to the front of the square frame.

3



Part (a) will have to be folded down, with the exact angle depending on the location of the sundial, to increase the amount of light.

4



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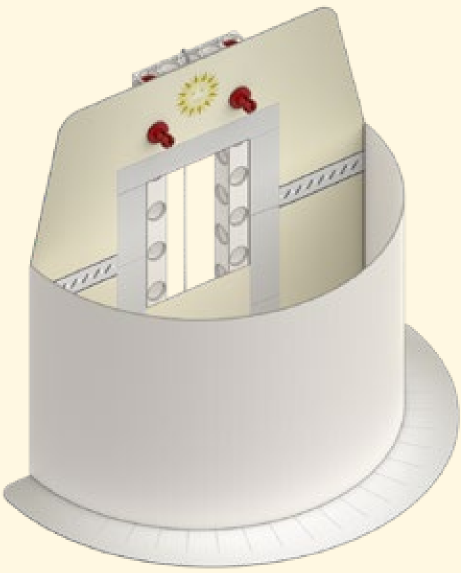


Done!

EXPERIMENT 16

The sun shows the time

YOU WILL NEED

› **Assembled sundial**

HERE'S HOW

› Place the sundial by a window when the sun is shining through it.

› While the sun is shining, note the current time on the scale on the floor of your model a few times during the day. Make sure the sundial stays in exactly the same place.

› Then, use the string's shadow to tell the time. That's how you make your very own sundial!

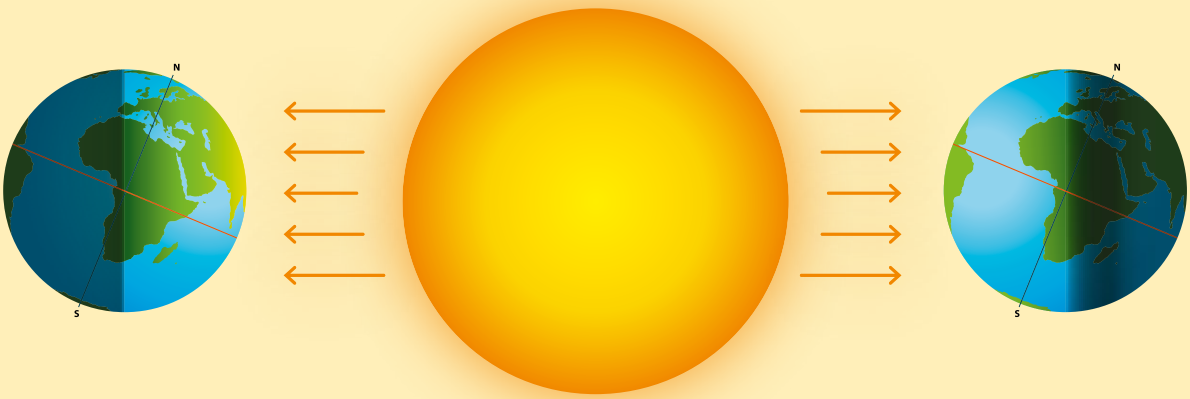
WHAT'S HAPPENING?

Every day, the sun rises and sets because the Earth rotates once around its own axis every 24 hours.

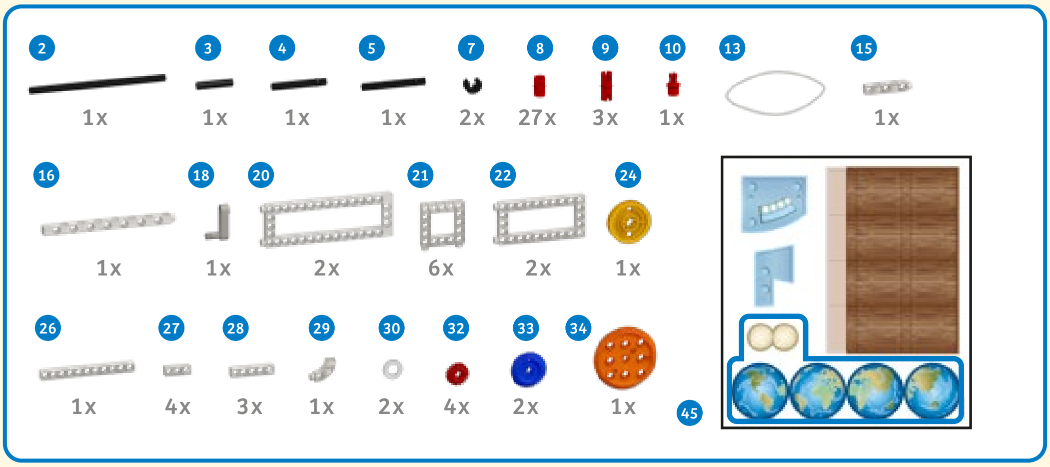
For the seasons, we have a slight tilt of the axis to thank. That makes less light and warmth fall on the northern half of the planet's sphere in winter, while summer prevails in the southern half at the same time!

TIP!

You can color the back side of the curved paper sheet with colored pencils or watercolors. That way, only the part of the drawing being illuminated by the sun will shine through. Be careful to apply the pencil strokes lightly, or they will poke through to the front side.



EARTH AND MOON MODEL



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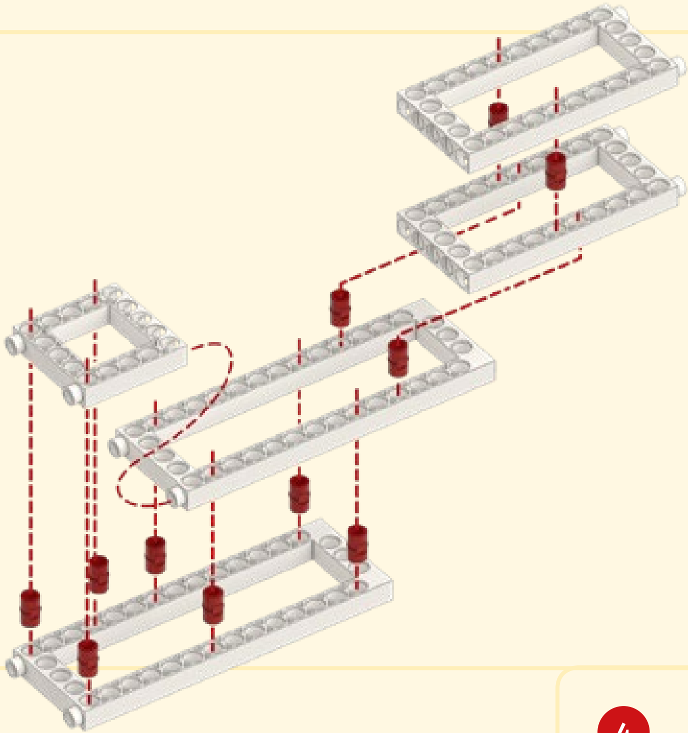

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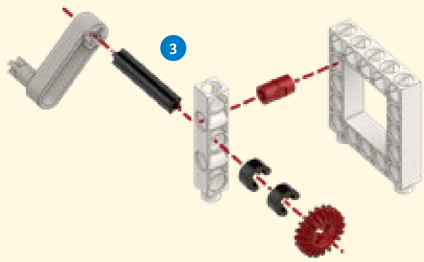

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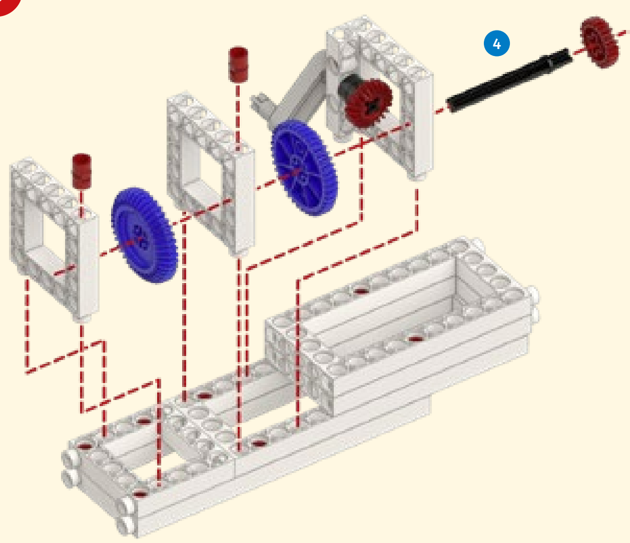

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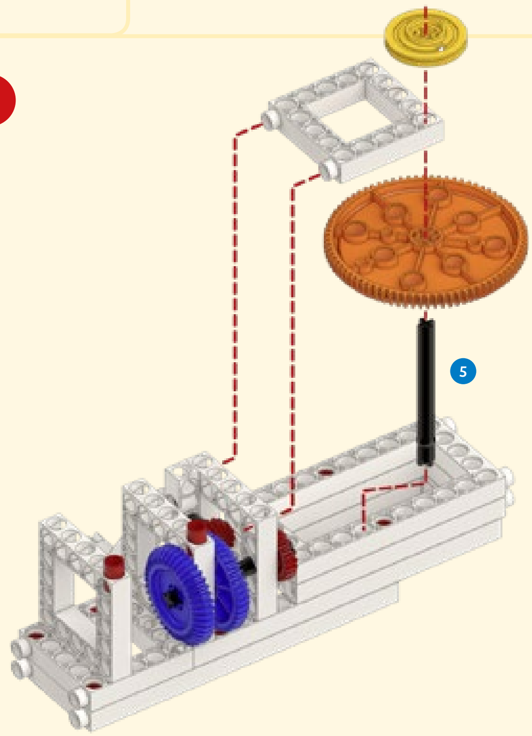

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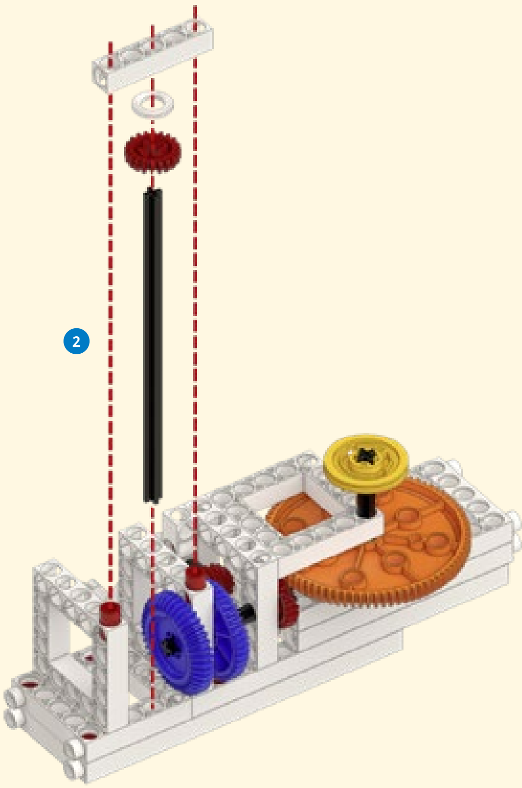

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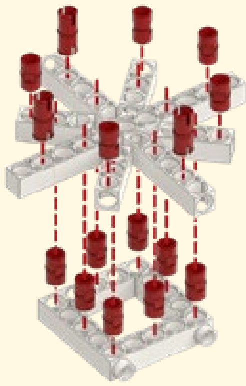

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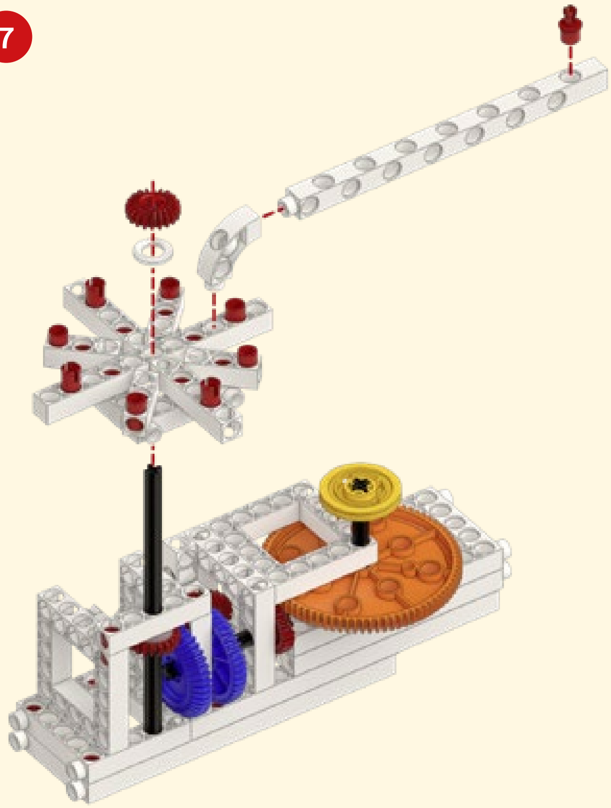
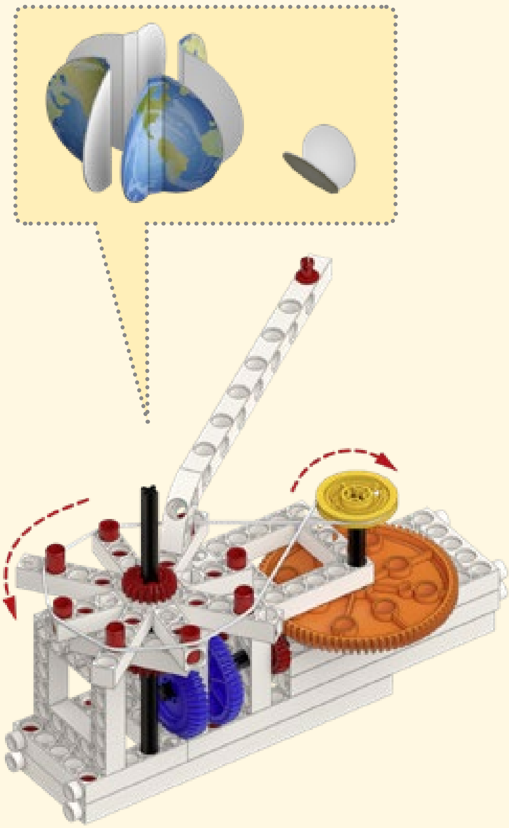


8

Fold the die-cut sections and glue them together.



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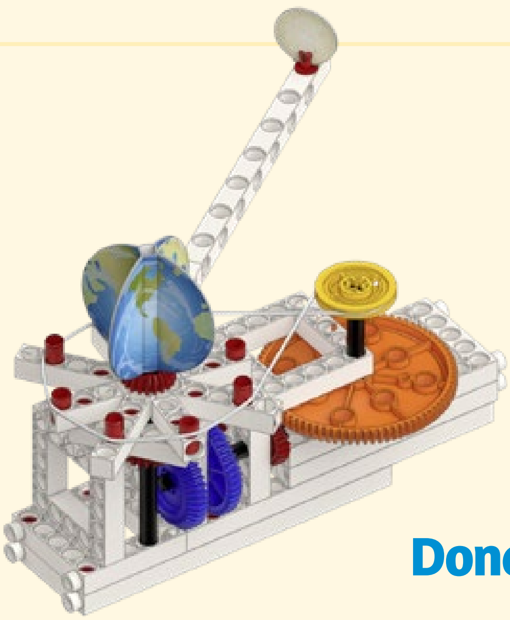


Done!

EXPERIMENT 17

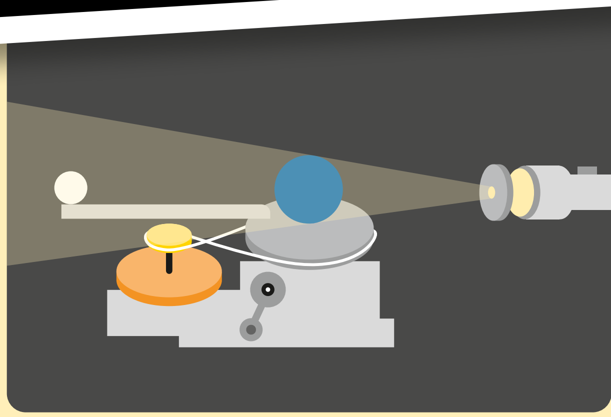
Phases of the Moon and solar eclipse

YOU WILL NEED

- **Assembled model**
- *A flashlight (LED if possible)*
- *A paper disk (if you don't have an LED flashlight)*

HERE'S HOW

- It's best to use a flashlight that shines a bright, tightly focused beam of light. If the beam of light is too diffuse, fashion an aperture (a disk of paper with a small hole in the center) and affix it to the front of the flashlight. You might want to have an adult help you. Direct the beam of light at the Earth and Moon. In this model, the flashlight is the Sun.
- Turn the crank to move the Moon to different positions in the beam of light.



WHAT'S HAPPENING?

To understand why we see the phases of the Moon, you have to imagine viewing your model Moon while standing on your model Earth. When the Moon is on the opposite side of the Earth from the Sun, the side of the Moon that faces the Earth will appear entirely illuminated to a viewer on the Earth. This is called a full moon. When the Moon is on the same side of the Earth as the Sun, the side of the Moon facing the Earth will be entirely dark to a viewer on the Earth. This is called a new moon. Between these two phases, the amount of the Moon that appears lit up to a viewer on the Earth will gradually increase (wax) or decrease (wane), moving through crescent, half, and gibbous (football) shapes.

If you move the Moon to the opposite side of the Earth from the Sun and position the model just right so that the Earth's shadow darkens the Moon, this mimics a lunar eclipse. When the opposite happens and the Moon comes between the Sun and the Earth, the Moon casts a shadow on a portion of the Earth, causing a solar eclipse.

DID YOU KNOW ...

Unlike in your model, the real Moon orbits the Earth in an inclined orbit. That means that a total eclipse of the Sun is actually a rare occurrence. The next total solar eclipse visible from some parts of the United States will be in 2017!

CHECK IT OUT

Calendars of the world

Even before people knew that the seasons were caused by the orbit of the Earth around the Sun, they developed calendars to keep track of the progress of the year.

The earliest calendars were oriented toward the Moon, which passes through its phases about 12 times a year. The legacy of this early calendar can still be found in the 12 months of the calendar we use today.

OUR CALENDAR TODAY

The calendar that is used throughout most of the world today is called the Gregorian calendar. It was introduced in 1582 by Pope Gregory XIII.

Before that time, there were many other calendar systems, and even today there are other systems in use around the world. One example is the Julian calendar, which goes back to Julius Caesar.

DID YOU KNOW ...

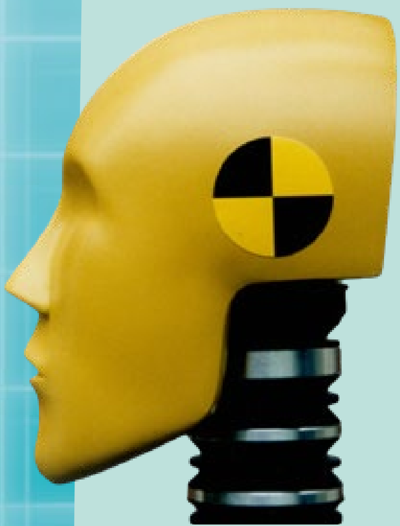
...that there is a leap year every 4 years? In a leap year, there is one extra (leap) day, the 29th of February. That's because the Gregorian calendar only has 365 days, while the Earth actually needs about a quarter of a day more than that to make one complete orbit around the Sun.

Not all calendars have the same year dates. The Islamic solar calendar (still used today in Iran and Afghanistan), which counts its years starting from the migration of the prophet Mohammed from Mecca, begins 621 years later than the Gregorian calendar. So the year 2021 AD corresponds to the year 1400 in the Islamic calendrical system.

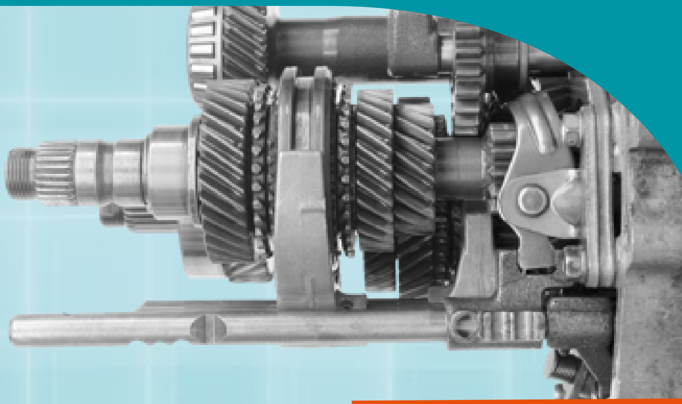
The ancient Egyptian calendar had 365 days, just like ours today, but no leap day, so it was imprecise. On top of that, each new Pharaoh would introduce a new era. The years were counted according to the current ruler: Year 1 of Tutankhamun, Year 5 of Ramses the Second, etc.

Automotive Engineering

Inside any car, there is a lot of technology that not only ensures that the car will drive but that also makes it less likely that a passenger will be injured in the event of a crash. This chapter will show you how a car is powered, what exactly happens in a crash, and how airbags can save lives.



INTRODUCTION



Car transmission

Engineers at work

In the world of automobiles, the laws of mechanics have a very important role to play. From a gear shift's transmission through all-wheel, rear-wheel, or front-wheel drive to accident safety, any automotive engineer has to pay attention to the laws of mechanics.

MOMENTUM

Momentum is an important concept in mechanics. Momentum is the product of the mass and the velocity of an object. The greater the mass of an object and the faster it moves, the more momentum it has.

momentum [m • kg/s] = mass [kg] • velocity [m/s]

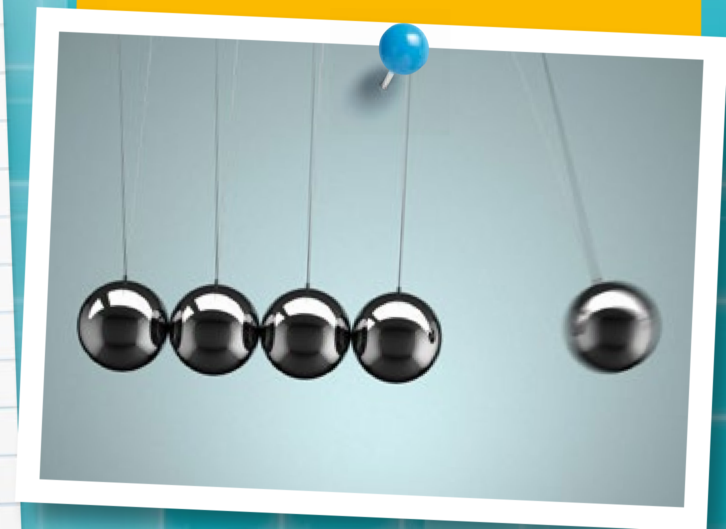
or

momentum [N • s] = force [N] • time [s]

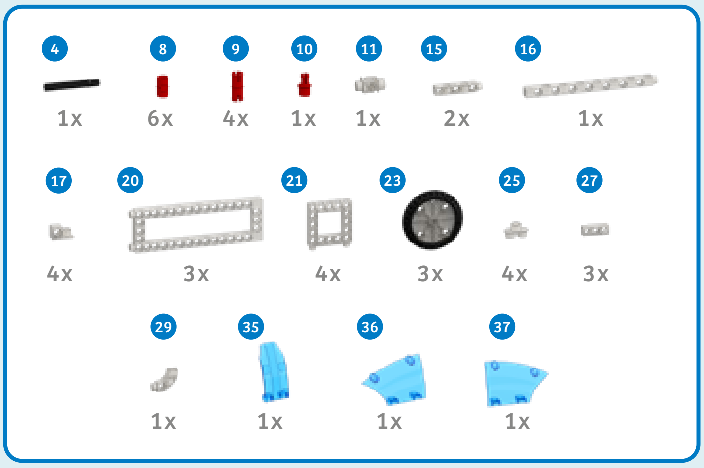
A heavy car rolling along the road has a larger momentum than a lighter car moving at the same speed, or than a slower moving car with the same mass. If the car hits another car, the momentum can be transferred from the first car to the second car, causing the second car to start moving.

It's also interesting that the momentum of colliding objects is always equally great before and after the collision. This fact is referred to as conservation of momentum, because all of the momentum is maintained when the collision occurs.

A collision can also be "elastic" or "inelastic." In an inelastic collision, the kinetic energy is "lost" by being converted into other forms of energy. In an elastic collision, no kinetic energy is lost. A typical elastic collision is what occurs between billiard balls, for example. If balls of clay collided, on the other hand, it would be an inelastic collision.



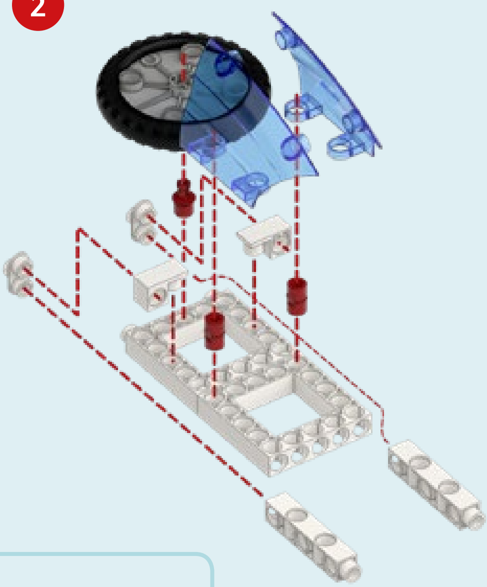
A Newton's cradle demonstrates the transfer of inelastic momentum.



Two vehicles on a track are made to collide with each other.

1

2



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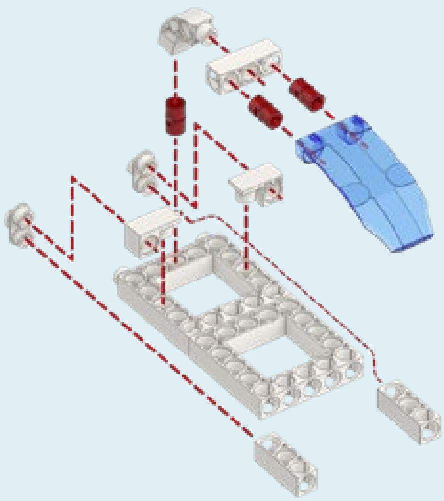

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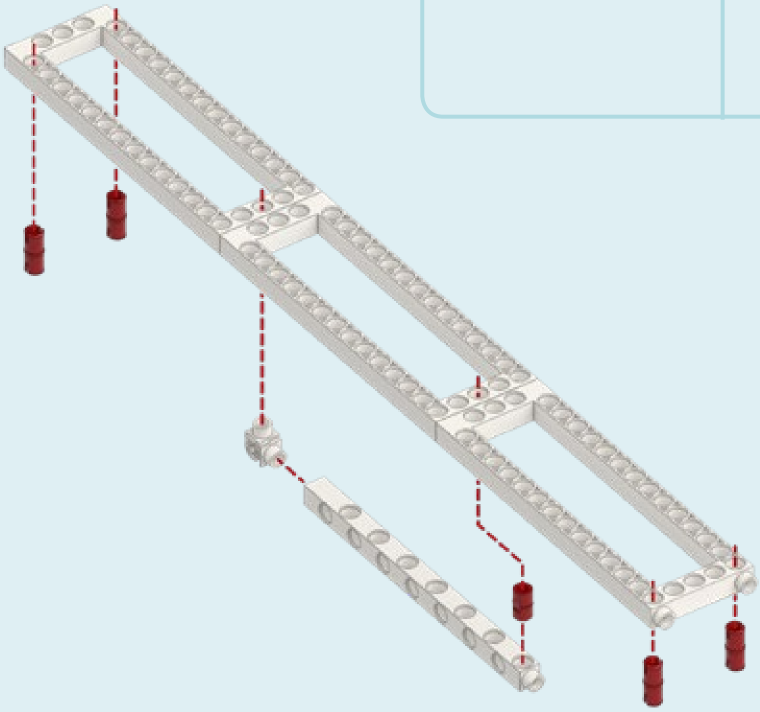

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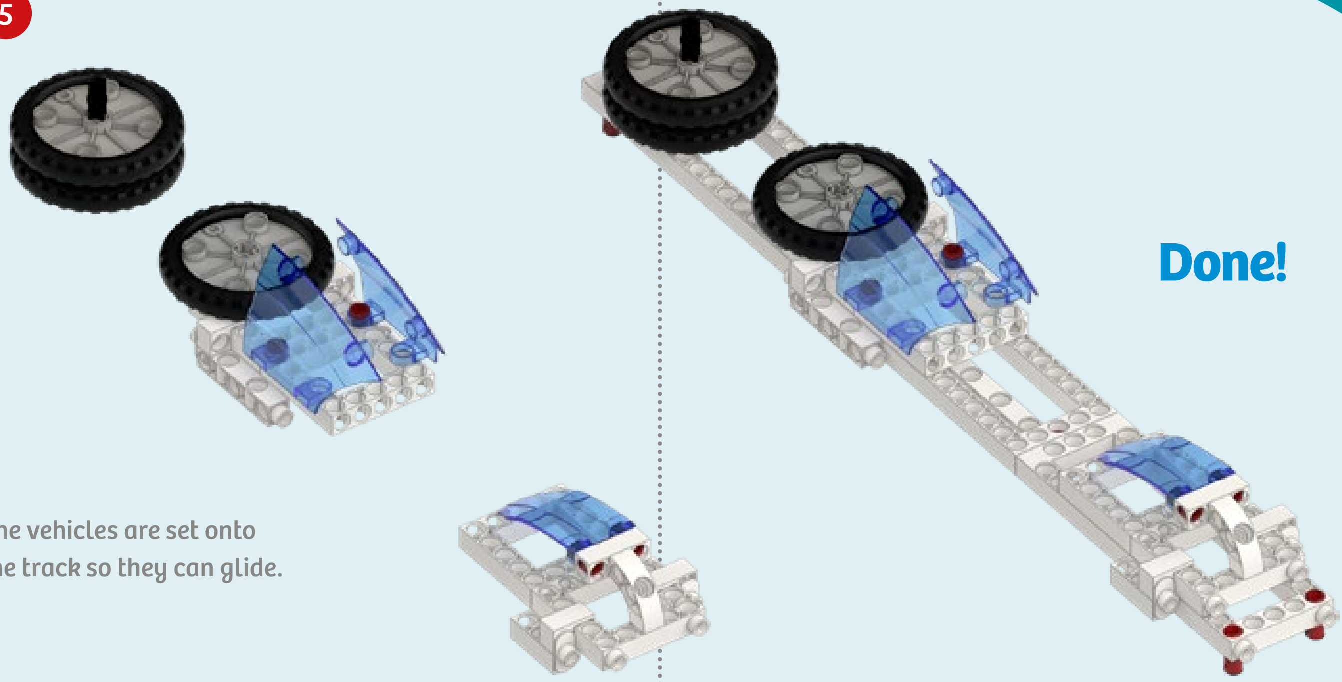


The vehicles are set onto the track so they can glide.

Done!

EXPERIMENT 18

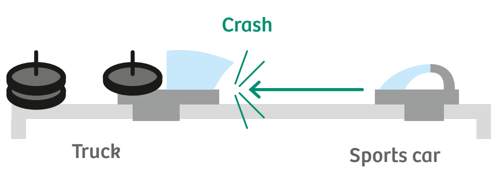
Crash test on tracks

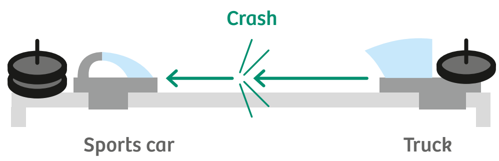
YOU WILL NEED

- **Assembled crash test track model**

HERE'S HOW

- The track is anchored down with tires to ensure stability.
- Set both "vehicles" on the track.
- Give the small "sports car" a strong push and let it crash into the "truck."
- Then, crash the "truck" into the "sports car."





You will learn "What's happening?" on the next page.

EXPERIMENT 18

WHAT'S HAPPENING?

In the first crash, the truck only moves a little, while in the second crash the smaller sports car really gets flung away. The heavy truck has so much mass that a portion of its momentum is transferred to the sports car on collision.

Exactly how much momentum is transferred during a crash has to do with the conservation of kinetic energy, as you already learned.

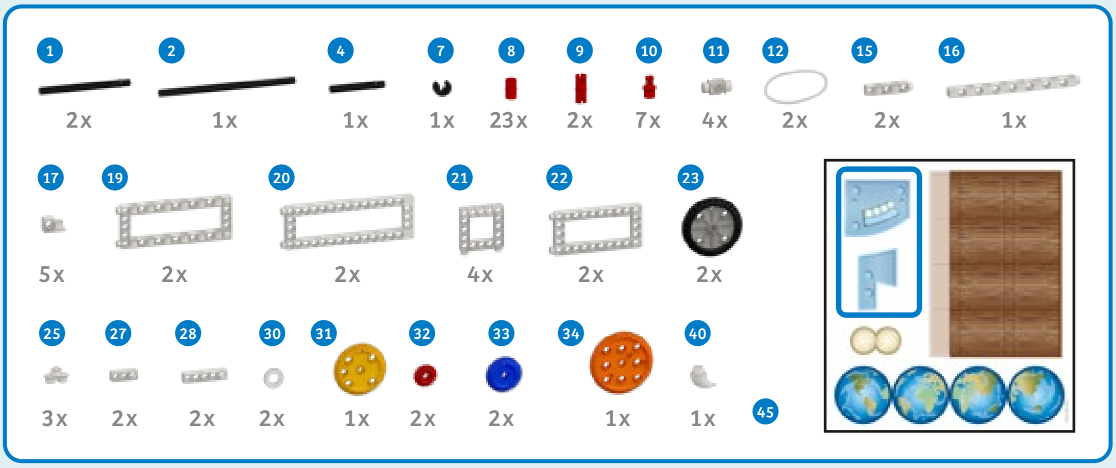
The heavier the moving vehicle, the less of its momentum is transferred to a lighter vehicle at rest. Or, in other words: The lighter the vehicle, the more of its momentum is transferred to a heavier vehicle at rest.

If the first vehicle is very light, so much of its momentum is transferred that it ultimately receives some momentum back in return, and it bounces backward.

DID YOU KNOW ...

Every newly-designed car has to pass a crash test to ensure that the risk of injury to the driver and passengers in as low as possible in any actual crash. Two vehicles are placed on tracks and made to crash into each other. High-speed cameras record exactly what happens so the engineers know just what to improve in the vehicle design.

AIR BAG TEST STATION



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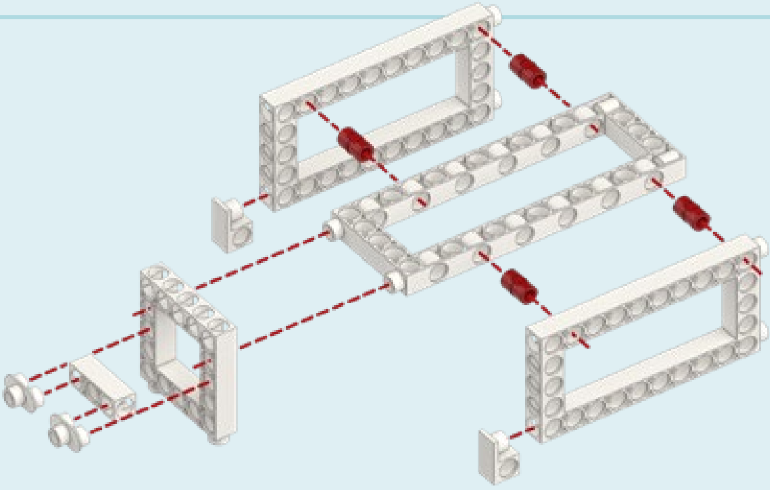

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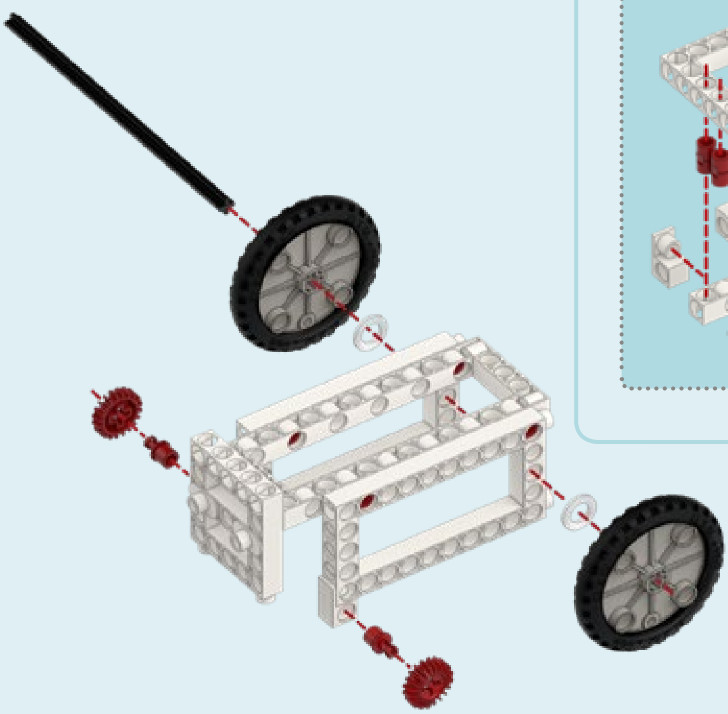
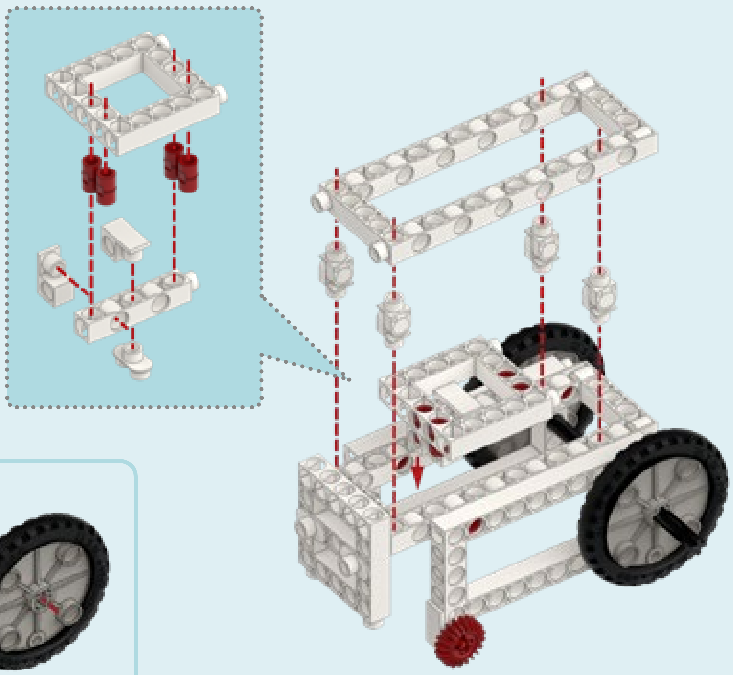


3 This "sled" slides freely between the "tracks."



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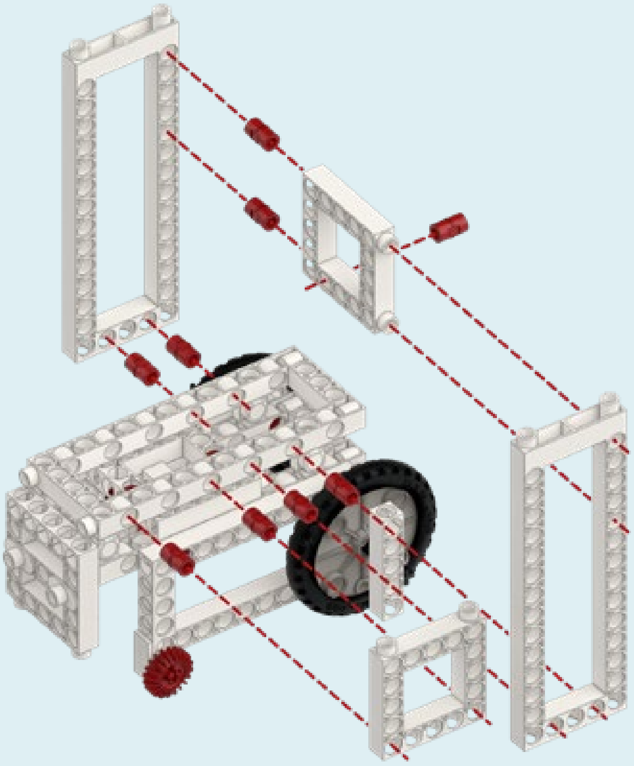

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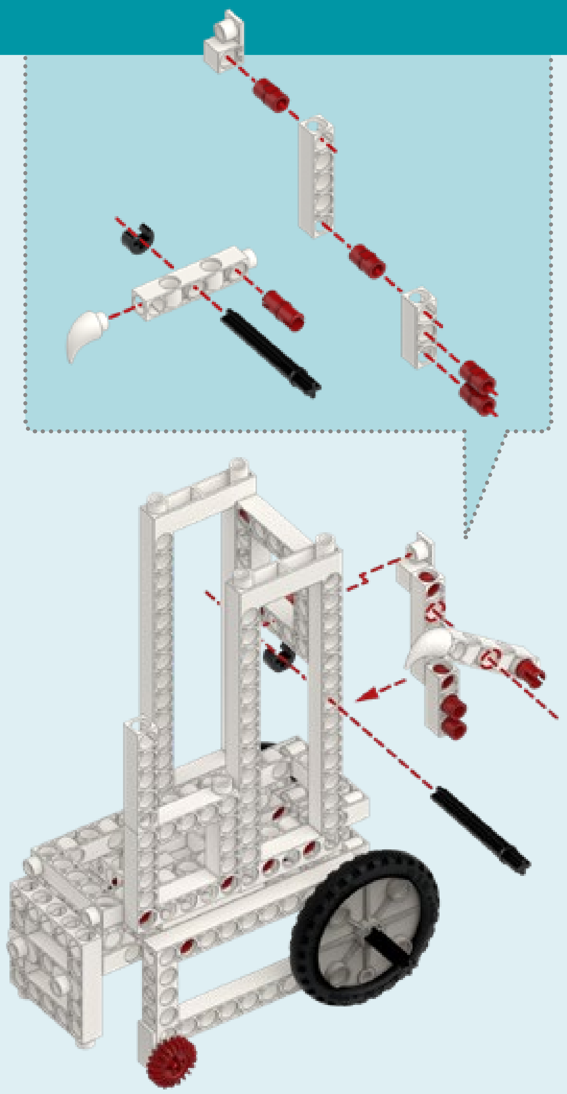

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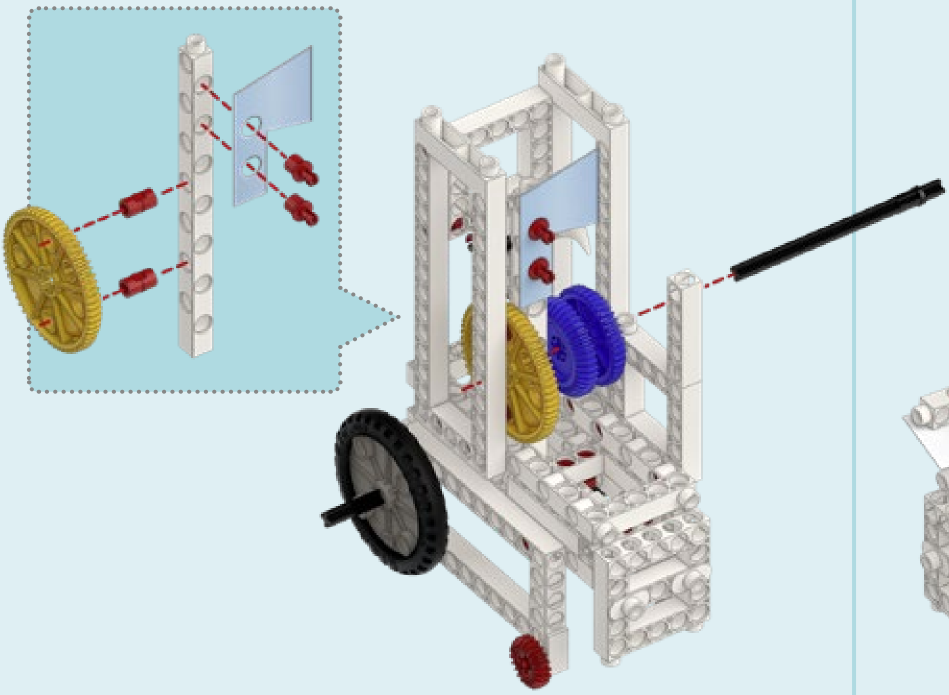

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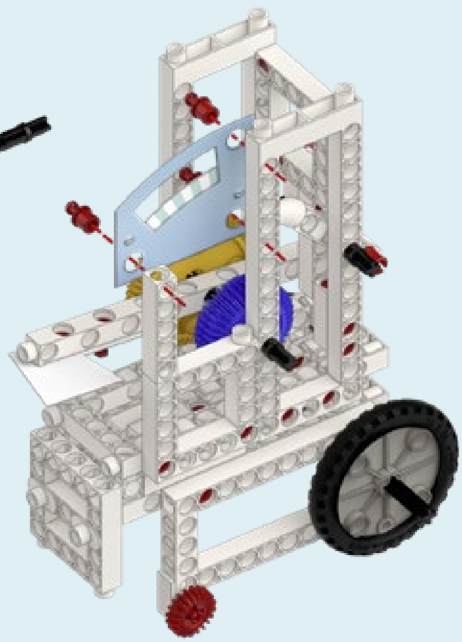
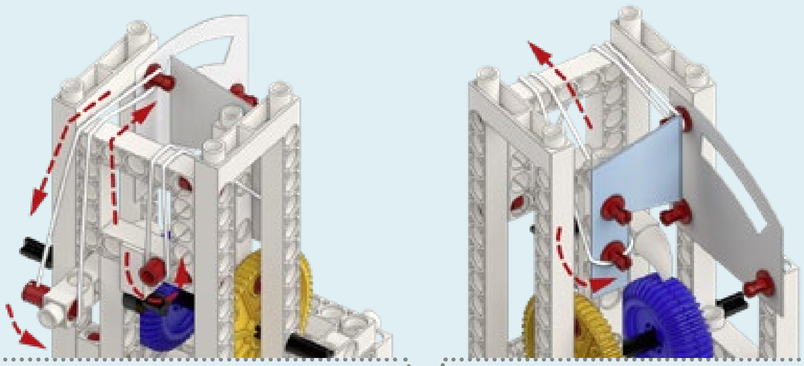


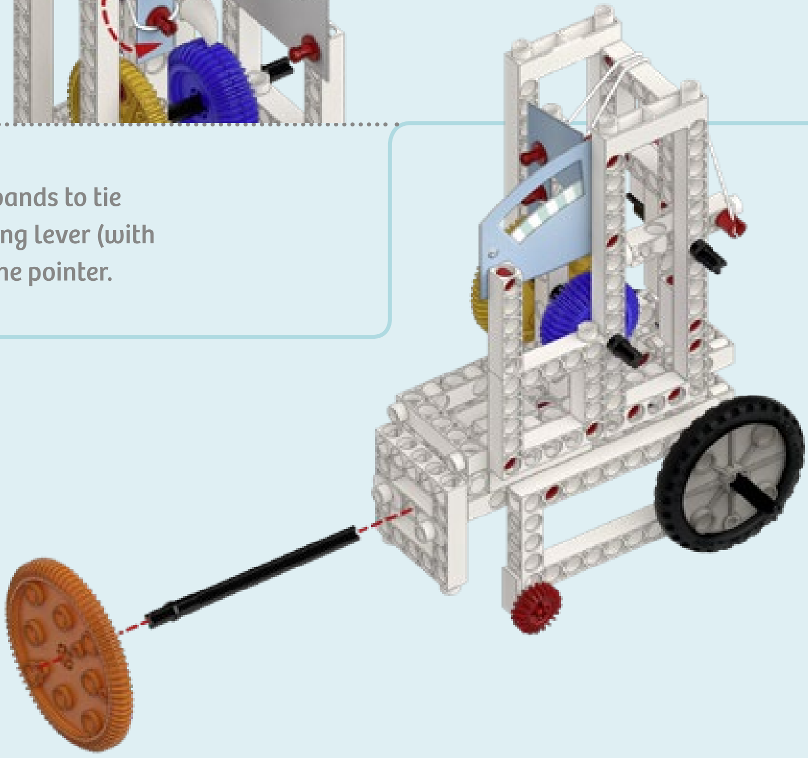
TIP!
Make sure that the horn is positioned in the center of the two gear wheels. Don't weigh it down unnecessarily and experiment with different settings. To reset it, press down on the horn's lever and return the bumper to its original position.

8



Use the rubber bands to tie together the blocking lever (with the horn) and the pointer.

9



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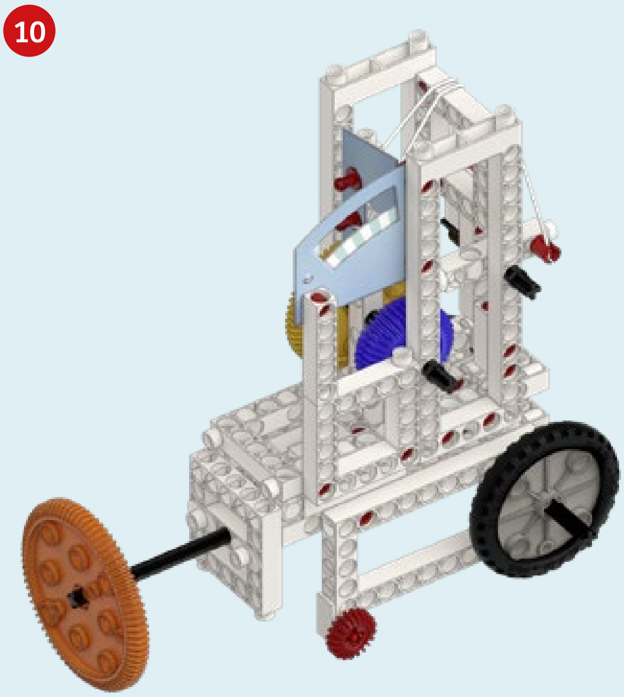
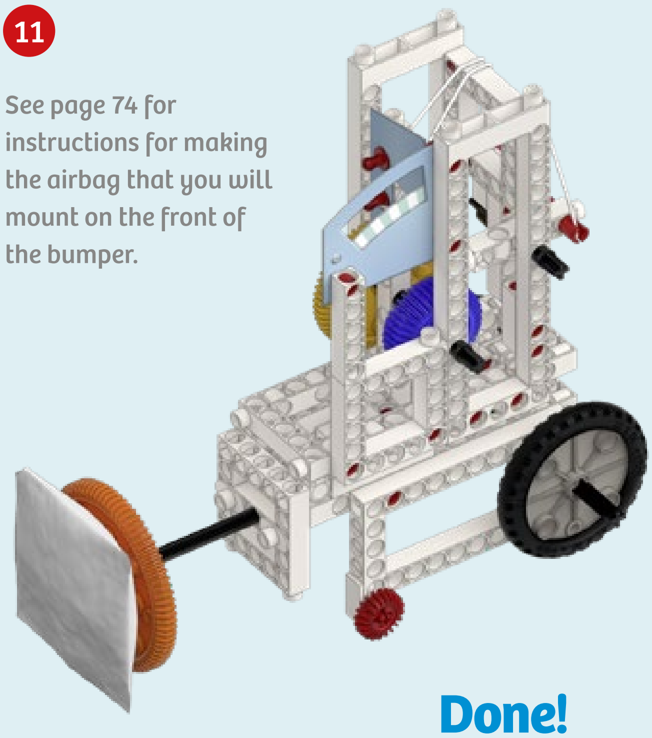


11

See page 74 for instructions for making the airbag that you will mount on the front of the bumper.



Done!

EXPERIMENT 19

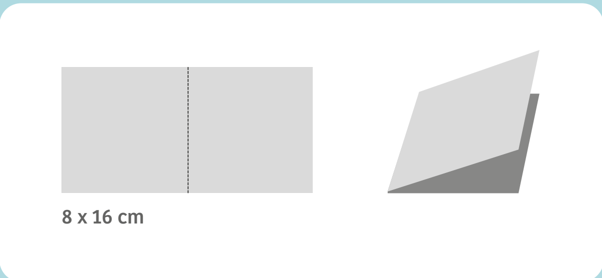
Crash test with airbag

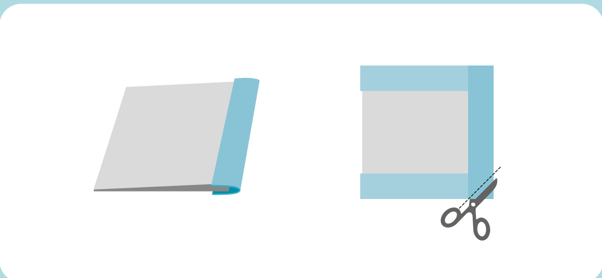
YOU WILL NEED

- **Assembled airbag test station**
- *A homemade airbag out of paper*

HERE'S HOW

- Draw an 8 cm x 16 cm rectangle (the airbag) on a piece of paper, and cut it out with a pair of scissors. Crumple up the sheet of paper and then unfold it again (4-5 times). This will make the paper softer. Now fold the sheet of paper along the center of the rectangle. Tape together the two halves of the sheet in as airtight a manner as possible. Then cut off a corner of the airbag and inflate it by blowing into the hole.
- Construct a ramp out of a (shelving) board and a few books. You will be rolling the model down the ramp, always starting from the same spot.
- Start by rolling it down the ramp with the bumper in place but without the airbag, letting the vehicle drive into a vertical obstacle (such as a wall). The pointer "records" the greatest force that occurs during the collision. Mark this on the scale.
- Reset the scale and tape the airbag to the bumper. Roll the model down the ramp again (from the same spot — and therefore at the same speed) and into the wall. Compare the reading on the scale with the previous mark.





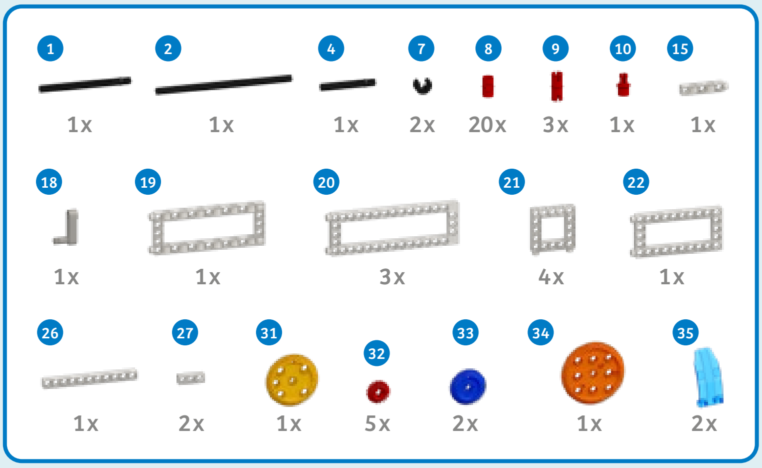
WHAT'S HAPPENING?

A car airbag is a fabric bag, usually hidden inside a vehicle's steering wheel, that inflates instantly in a crash. It then cushions the driver and slows his or her forward movement relatively gently.

In a car crash, what is dangerous is not so much the collision in itself as the length of time over which the momentum is transferred. The shorter it is, the stronger the force when the driver is slowed. The airbag reduces the force and thus its impact on the driver, since it makes more time available for transferring the momentum.

momentum [N • s] = force [N] • time [s]

GEAR TRAIN



Switching gears in the gearbox.

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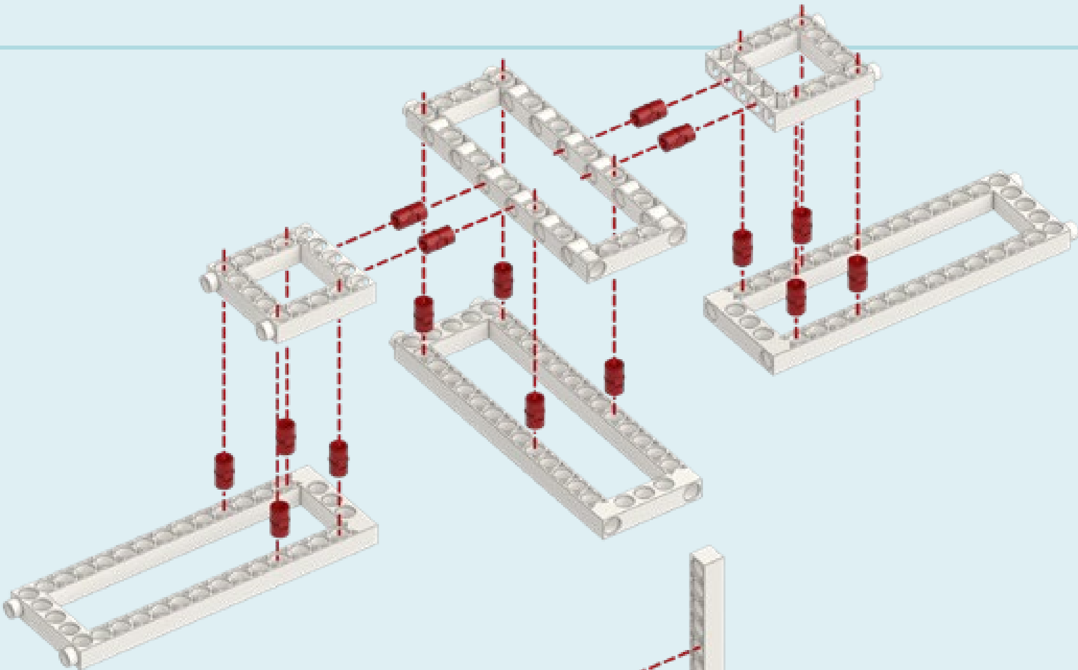

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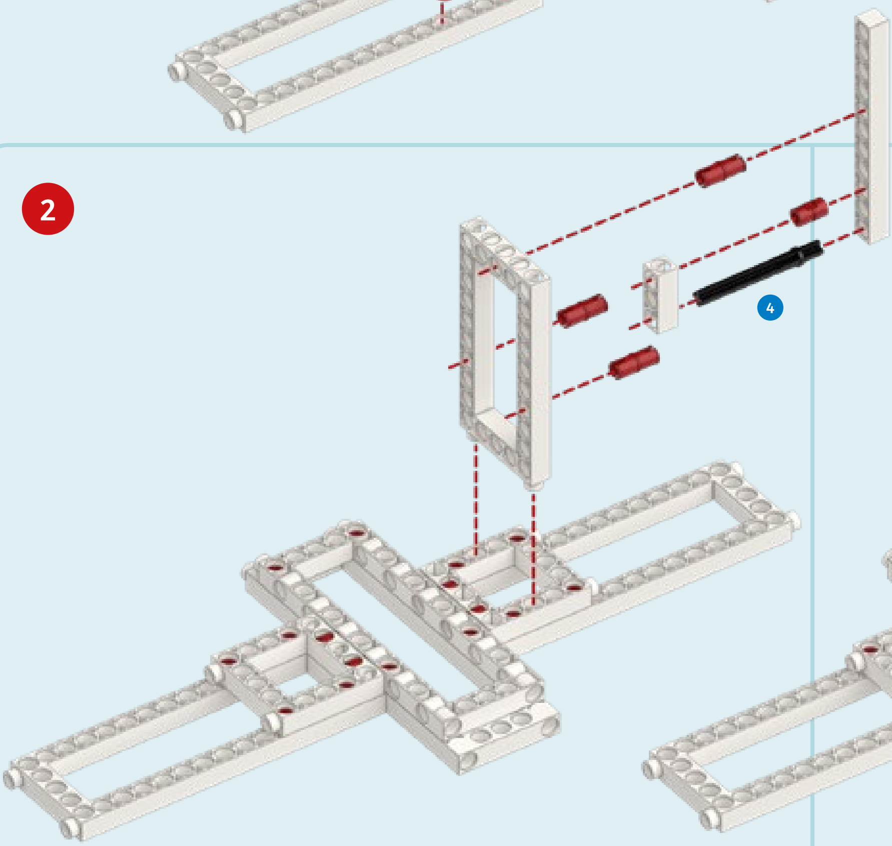

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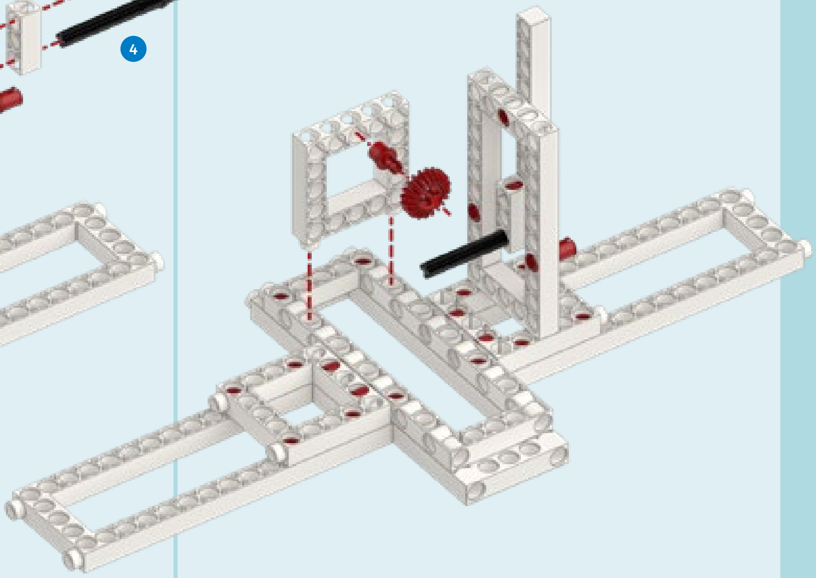

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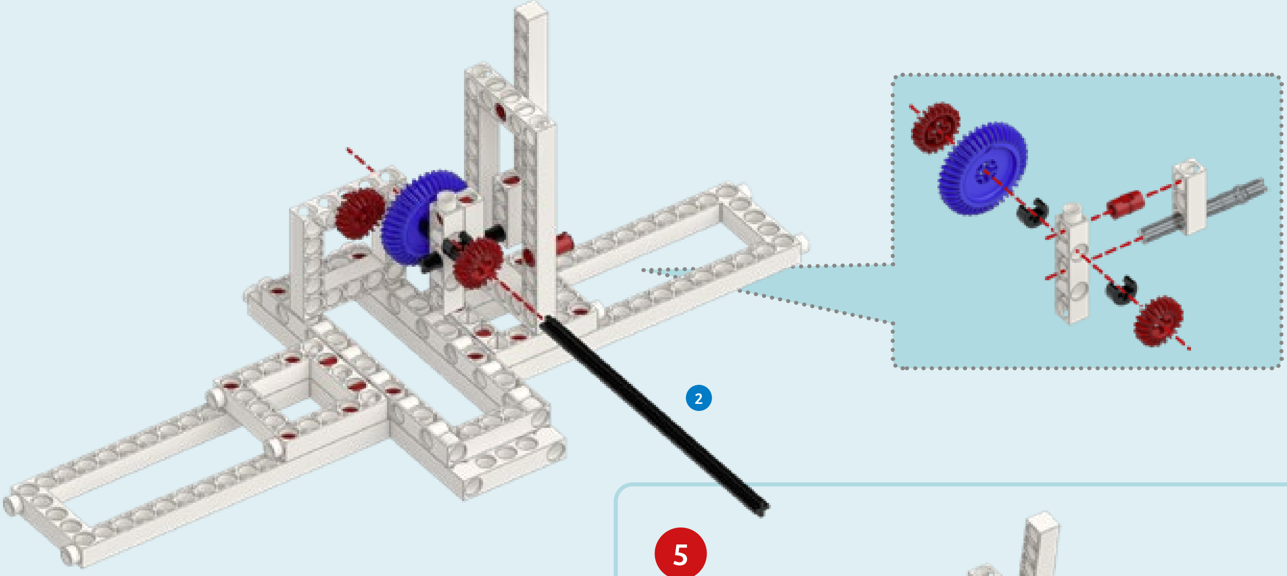

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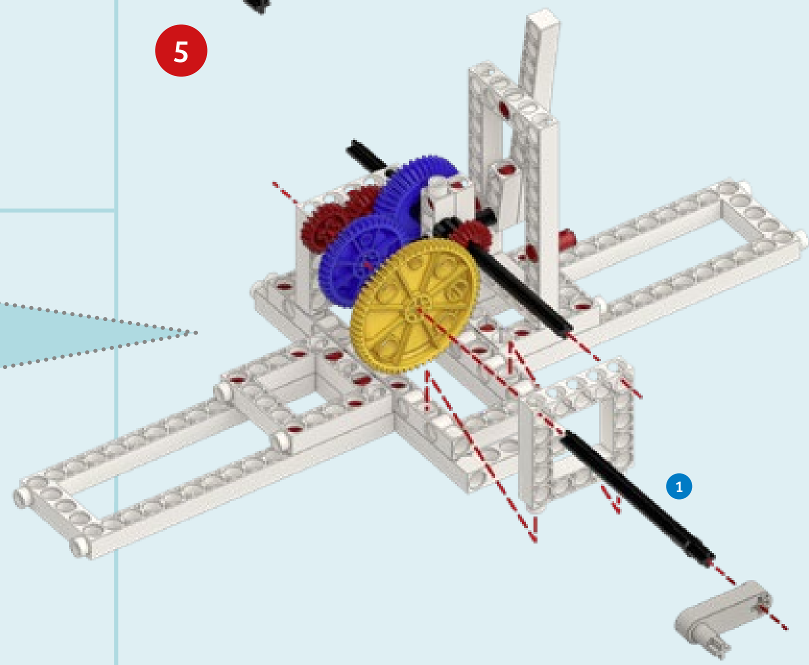

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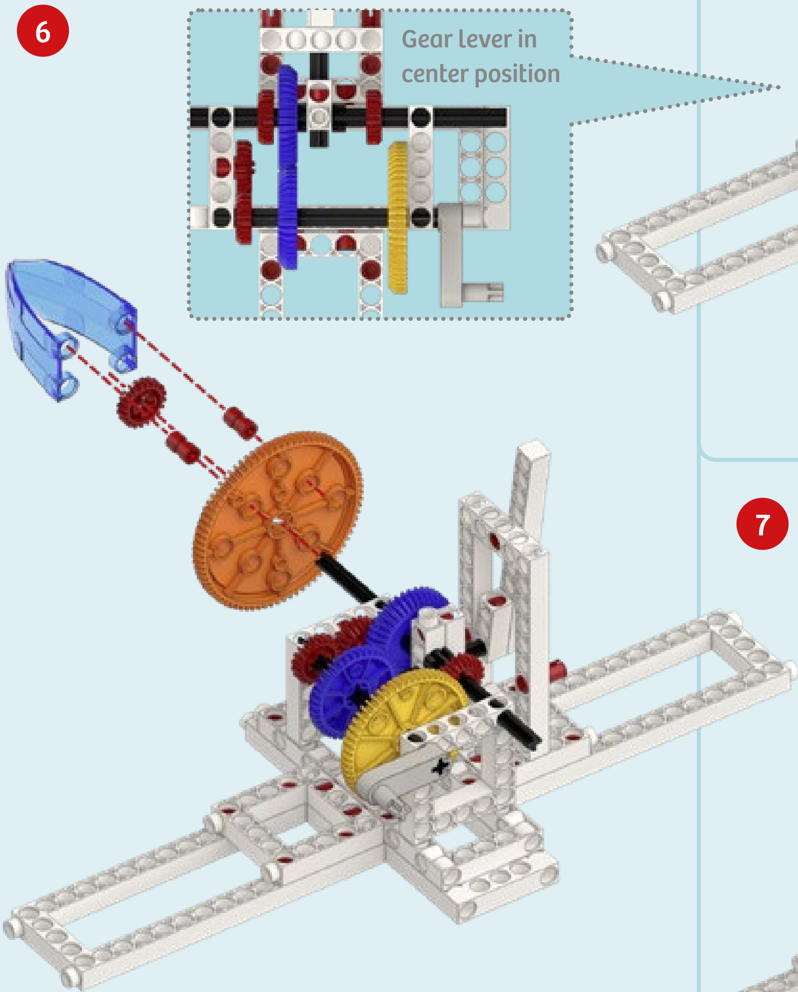

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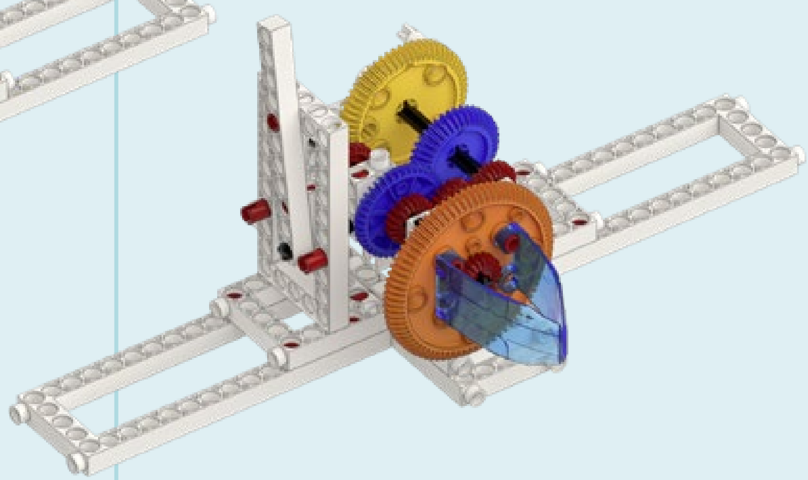
Done!



EXPERIMENT 20

Switching gears

YOU WILL NEED

› **Assembled gear train**

HERE'S HOW

› Turn the crank and watch how fast the large front gear wheel turns.

› Operate the gear lever to change gears.

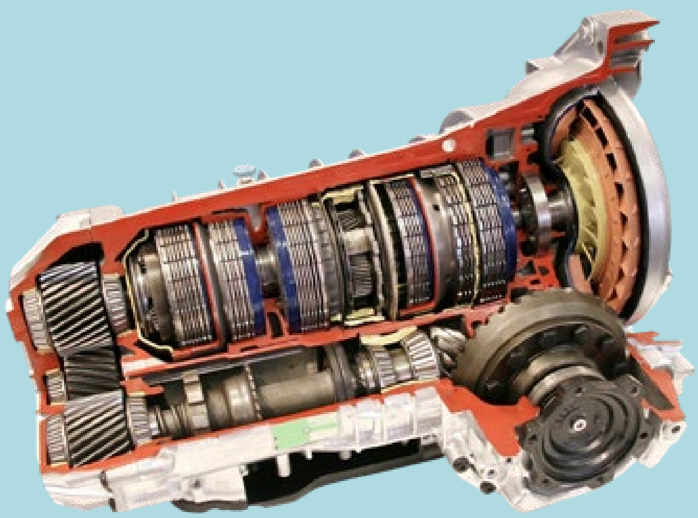
› Watch what happens to the large gear wheel when you do that. Does it change its speed? Or its direction of rotation?

TIP!
Mount the large yellow gear wheel and the small red one at the very ends of the fixed axle, so that there is enough space between them for the gears. Adjust the gear wheels so that just one pair of gears (red/yellow, blue/blue, or red/red) is meshing together at a time, or they will jam.

WHAT'S HAPPENING?

Almost all vehicles have a gear train to let you switch from one forward gear to another or into reverse. That kind of system is important for letting the engine run at its optimal level of performance at various speeds — so it turns neither too fast nor too slow. On top of that, when the car is in reverse it will drive in reverse even though its engine keeps turning in the same direction!

A gear train has to be able to do all that while being easy to operate (via the gearshift lever). In many modern cars, though, the switching is handled by an on-board computer — which is called an automatic transmission system. Your gear train is controlled by hand, so it's a manual transmission system.



DID YOU KNOW ...

Here's how you can calculate the transmission ratio between two gear wheels.

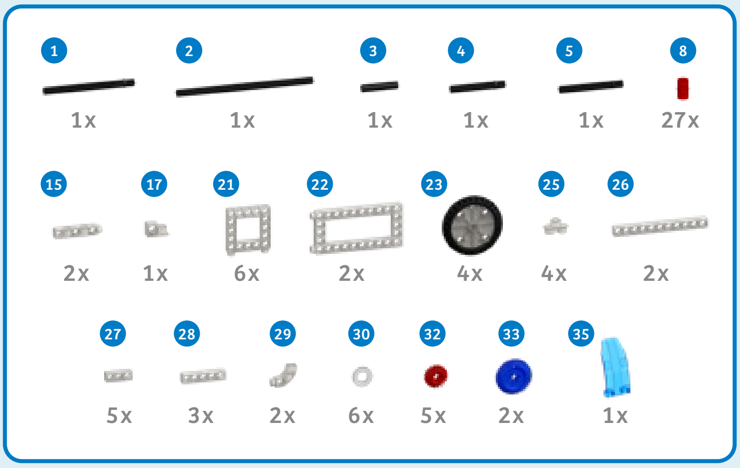
$$\frac{\text{diameter}_1}{\text{diameter}_2} = \text{transmission radio}$$

And the rotation speed of the shafts:

$$\text{rotation speed}_1 \cdot \text{transmission radio} = \text{rotation speed}_2$$

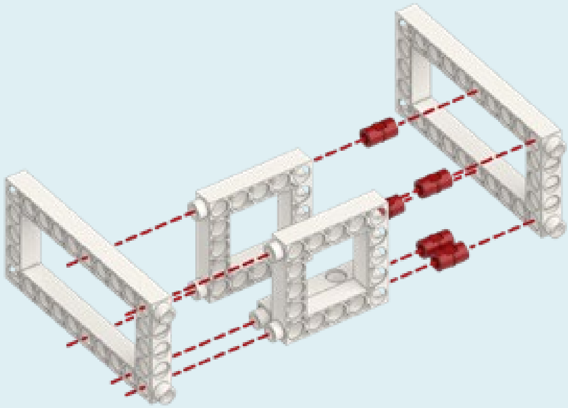
Note that the direction that the shaft turns is reversed with each transmission step!

ALL-WHEEL DRIVE TRUCK



Four-wheel drive and a flexible jointed design make for optimal performance on rough terrain.

1



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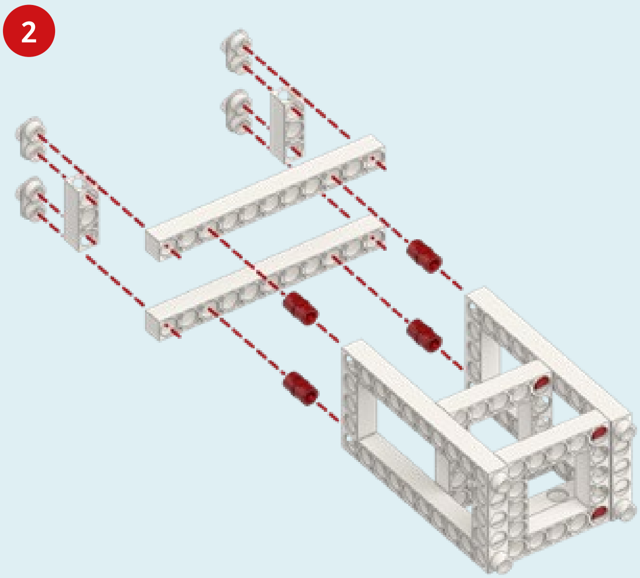

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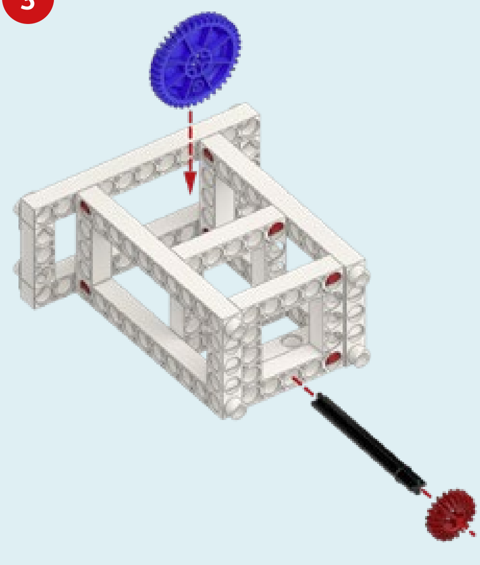

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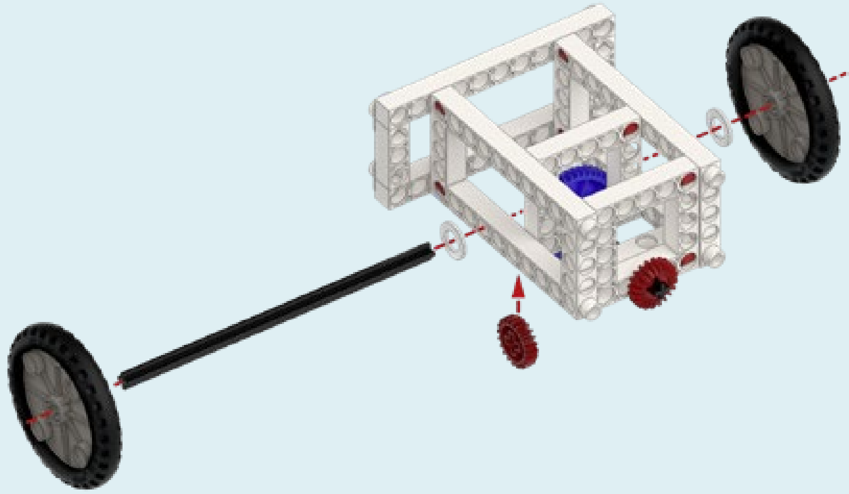

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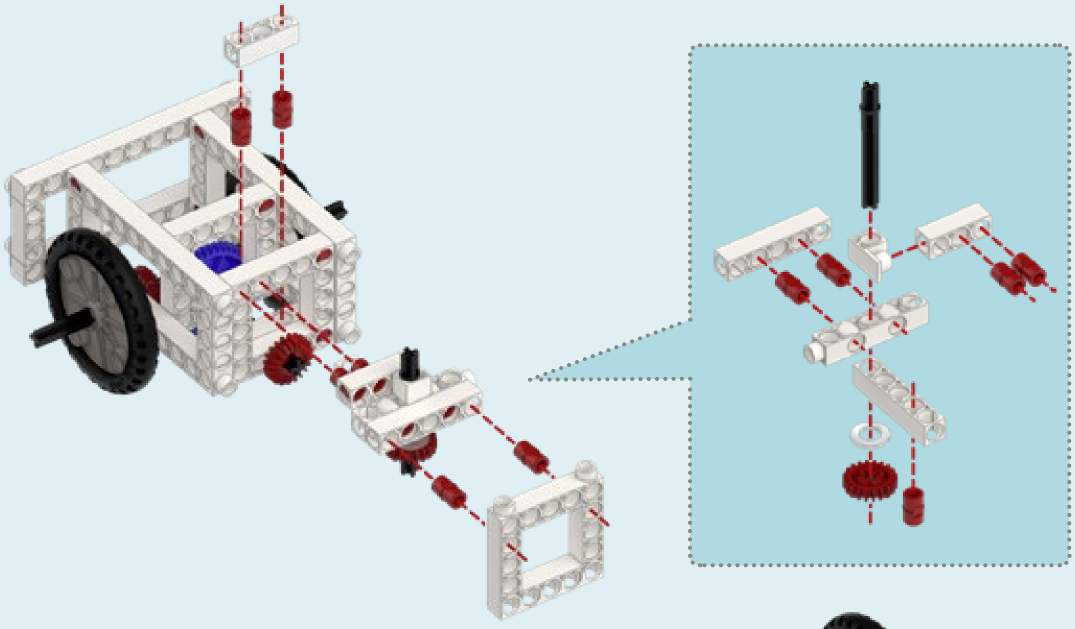

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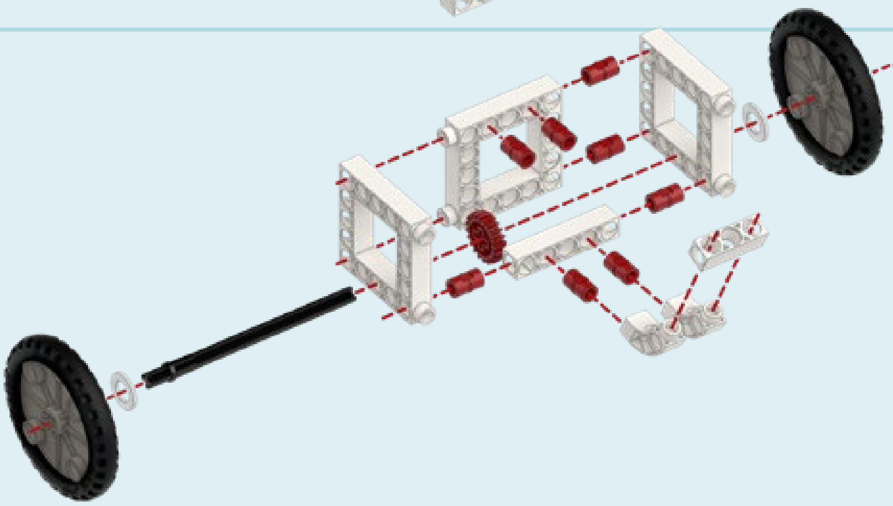

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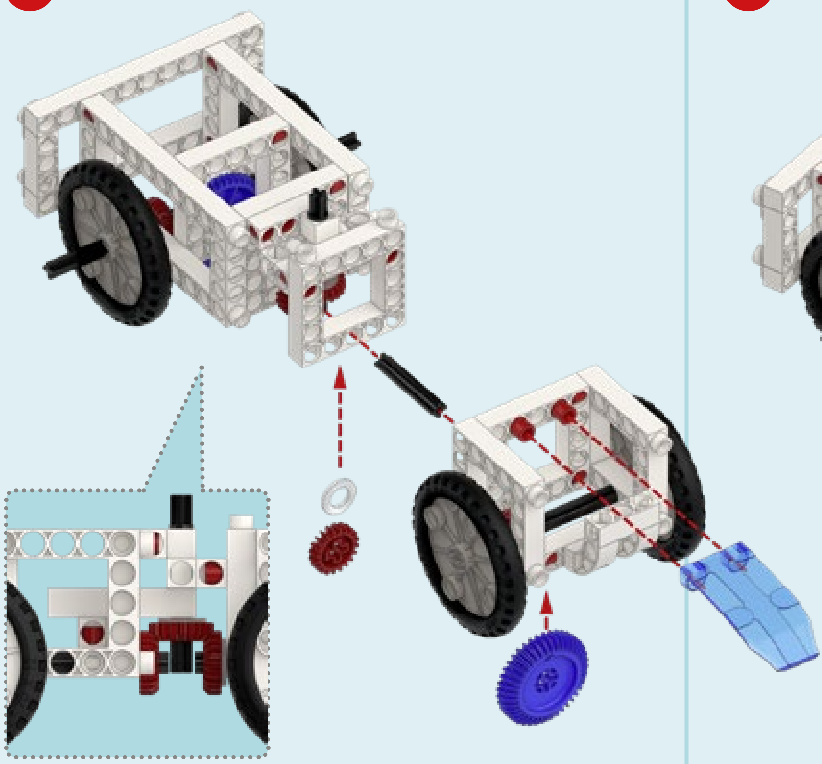

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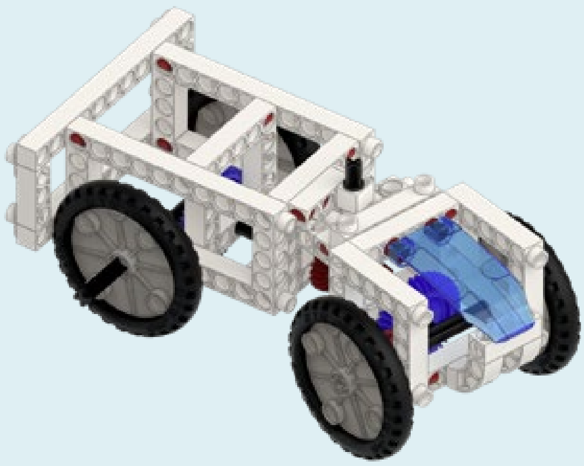


Done!

EXPERIMENT 21

Testing the all-wheel drive truck

YOU WILL NEED

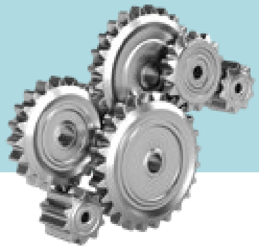
› **Assembled truck**
› *A few books or other "obstacles"*

HERE'S HOW

› Make a test track out of the books or other objects.

› Test the truck to see how well it can drive over the obstacles.

› Look closely to see what happens to the vertical axle when the wheels turn.



WHAT'S HAPPENING?

All-wheel drive is a huge advantage relative to a front- or rear-wheel drive system when driving a vehicle over difficult terrain. The decisive factor is the improved traction (static friction between tires and ground) that the system provides.

For all four tires to maintain contact with the ground and contribute to its forward motion, all-wheel-drive vehicles have a soft suspension with a lot of spring range. A Cardan drive shaft ensures transmission of the engine's power to all axles and wheels. In your model, it's the vertical axle that enables the motor to engage and drive both of the axles.

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