EXPERIMENT MANUAL

THE BIG Engineering Makerspace

THAMES & KOSMOS

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Safety Information

WARNING! Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled. Strangulation hazard — long cords and tubes may become wrapped around the neck.
Store the experiment material and assembled models out of the reach of small children.

Keep packaging and instructions as they contain important information.

For the hang glider: WARNING. Do not aim at eyes or face.

For the models intended to be used in the water: WARNING. Use only in shallow water under adult supervision. Never operate these models with a hair dryer or fan.

Disassemble models used in or with water after use and let them dry.

After use, allow excess air to escape from the pressurized air system.

Dear Parents and Adults,

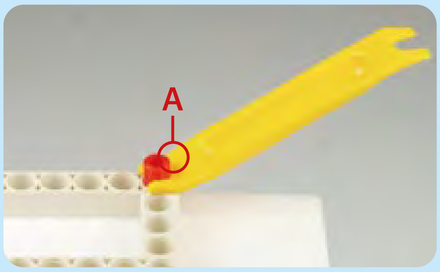
Before starting the experiments, read through the instruction manual together with your child and discuss the safety information. Check to make sure the models have been assembled correctly. Assist your child with the experiments, especially with reading the assembly diagrams and putting pieces together that may require more dexterity or hand strength than the child currently possesses.
We hope you and your child have a lot of fun with the experiments!

Tips and Tricks

Here are some tips for assembling the models. Read these tips closely before starting, so building is easier and your experiments are successful.

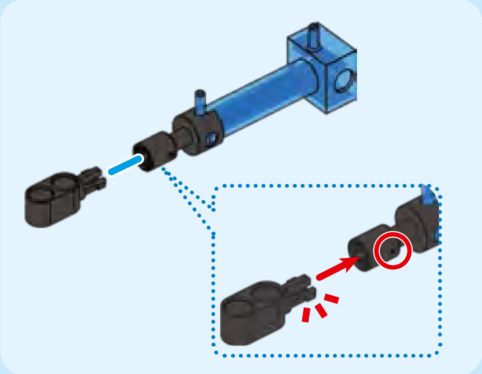
Anchor pin lever

When you want to take a model apart, you will need the anchor pin lever. Use the narrow end of the lever to remove the anchor pins. You can use the wide end to pry apart other small parts.

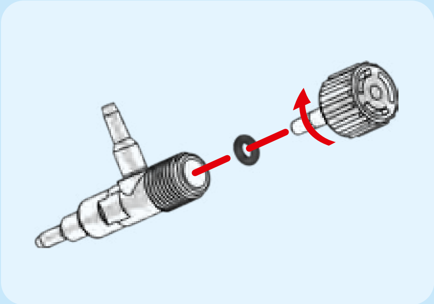


Initial assembly of some important components

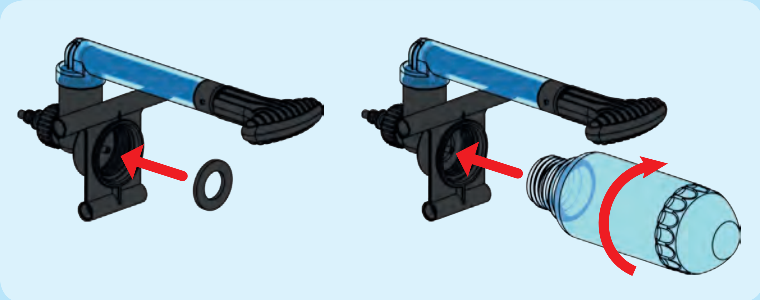
Pneumatic cylinder piston with piston handle assembly



Valve assembly

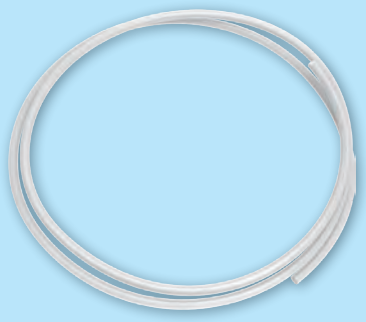


Pressurized air tank and pump assembly



Tire and wheel rim assembly

Cutting the tubes to length



In your kit, you'll find wo pieces of 120-cm tube. Cut these into the lengths specified be ow, so that you always have the right length at hand when you assemble each model. These tubes can be used over and over again.

Tube 1: 2 x 60 cm

Tube 2: 1 x 10 cm, 2 x 20 cm, 1 x 25 cm, 1 x 40 cm

Abbreviations used for physical quantities

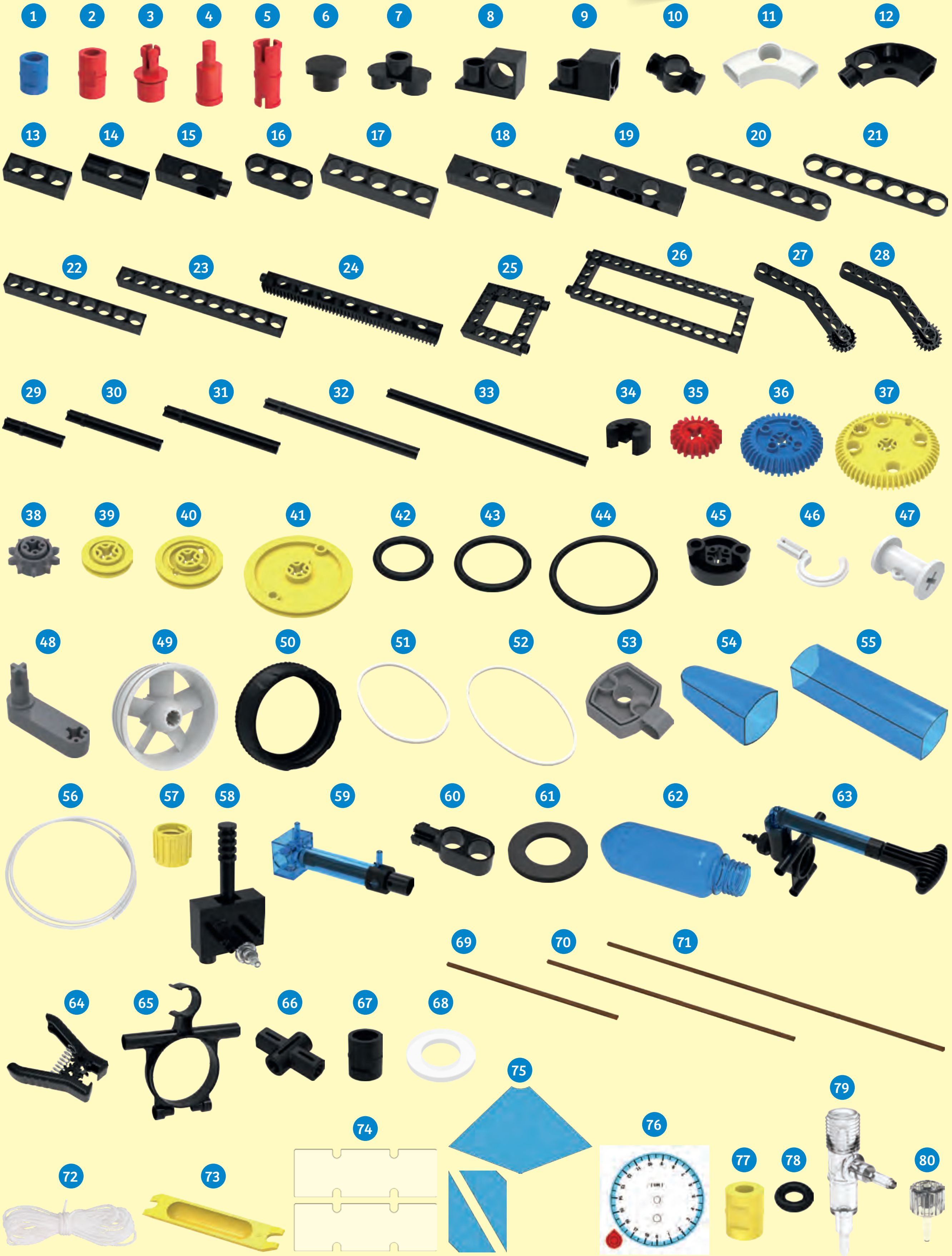
d		Distance to center of gravity
a, b, c, d		Various lengths
A		Area
F		Force
	F_{BL}	Buoyant/lift force
	F_E	Earth's gravitational force
	F_G	Gravitational force
	F_R	Rocket force
S		Stop point

H_2	Hydrogen
H_2O	Water
L	Length of lever arm
T	Torque
O_2	Oxygen
p	Pressure
C_G	Center of gravity
u	Flow velocity

GOOD TO KNOW! If you are missing any parts, please contact Thames & Kosmos customer service.
US: techsupport@thamesandkosmos.com
UK: techsupport@thamesandkosmos.co.uk

Any materials not included in the kit are indicated in *italics* in the "You will need" sections.

What's included in your experiment kit:



Checklist: Find – Inspect – Check o

✔	No.	Description	Qty.	Art. No.
❍	1	Short anchor pin (blue)	40	717 767
❍	2	Anchor pin (red)	20	702 527
❍	3	Shaft plug	2	702 525
❍	4	Shaft pin	1	702 526
❍	5	Joint pin	12	702 524
❍	6	Short button pin	6	716 676
❍	7	Two-to-one converter	6	716 889
❍	8	90-degree converter X	2	716 682
❍	9	90-degree converter Y	2	716 884
❍	10	1-hole connector	4	719 233
❍	11	Round curved rod, white	1	717 971
❍	12	Curved rod, black	7	716 310
❍	13	3-hole rod	3	719 234
❍	14	3-hole cross rod, black	6	717 899
❍	15	3-hole dual rod, black	1	716 859
❍	16	3-hole rounded rod, black	4	716 872
❍	17	5-hole rod	4	716 876
❍	18	5-hole cross rod	4	716 677
❍	19	5-hole rod C, black	3	717 889
❍	20	7-hole wide rounded rod	4	716 878
❍	21	7-hole flat rounded rod	4	716 879
❍	22	9-hole rod	6	717 806
❍	23	11-hole rod	4	716 304
❍	24	Long rack gear	2	716 356
❍	25	Square frame	2	718 936
❍	26	5x15 frame	2	718 541
❍	27	Crankshaft gear A	2	719 212
❍	28	Crankshaft gear B	2	719 213
❍	29	35-mm axle	3	716 861
❍	30	60-mm axle	2	718 278
❍	31	70-mm axle	2	713 490
❍	32	100-mm axle	3	716 901
❍	33	150-mm axle	2	703 518
❍	34	Axle lock	2	702 813
❍	35	Small gear, red	6	710 062
❍	36	Medium gear, blue	2	716 179
❍	37	Extra large gear, yellow	2	715 047
❍	38	Small sprocket	2	720 232
❍	39	Small pulley wheel	2	707 011
❍	40	Medium pulley wheel	2	707 010
❍	41	Large pulley wheel	2	710 197

✔	No.	Description	Qty.	Art. No.
❍	42	Small O-ring	2	703 250
❍	43	Medium O-ring	2	703 251
❍	44	Large O-ring	2	703 809
❍	45	Bar connector	2	718 543
❍	46	Hook	1	706 533
❍	47	String spool	1	706 854
❍	48	Crank	1	719 237
❍	49	Wheel rim	4	720 236
❍	50	Tire	4	720 235
❍	51	Small rubber band	2	702 596
❍	52	Large rubber band	2	703 241
❍	53	Flange	6	714 012
❍	54	Cap for air-and-water tank/ pontoon	4	714 011
❍	55	Air-and-water tank/ballast tank	2	714 010
❍	56	Tube, 1200 mm	2	710 129
❍	57	Small security nut	1	710 137
❍	58	Switch	1	710 126
❍	59	Pneumatic piston cylinder	1	719 214
❍	60	Pneumatic piston handle	1	719 215
❍	61	O-ring	1	710 135
❍	62	Air tank	1	719 207
❍	63	Pump	1	719 208
❍	64	Clamp	1	720 237
❍	65	Air tank bracket	1	719 219
❍	66	Straight connector	1	716 685
❍	67	Short anchor pin (black)	4	715 744
❍	68	Washer	1	703 242
❍	69	Bamboo dowel, 150 mm	2	715 746
❍	70	Bamboo dowel, 220 mm	2	715 747
❍	71	Bamboo dowel, 300 mm	3	720 233
❍	72	White string	1	714 240
❍	73	Anchor pin lever	1	702 590
❍	74	Microscope bracket piece	2	720 238
❍	75	Plastic sheets	1	720 239
❍	76	Cut-out counting wheel	1	720 240
❍	77	Short anchor pin, yellow	2	720 234
❍	78	Small O-ring for valve	1	720 241
❍	79	Valve	1	720 242
❍	80	Valve controller	1	720 243

You will also need:

Scissors, adhesive tape, measuring tape, small objects (e.g. toy cars or building blocks), objects that you can grasp (e.g. small ball), kitchen scales, a board, books, small coins or stones, large water container (e.g. filled bathtub, wading pool), tall water container (e.g. tall bucket, plastic tub), 125 grams of weight such as metal washers or quarter coins (22 in total), chair, smartphone, flashlight or bicycle light or head-lamp, small transparent items (leaves, petals, etc.)

Trial run

Before getting ucked into model building, let's start by testing the main parts included in your kit!

WANT TO FIND OUT MORE?
Get ready to explore the fascinating world of engineering...

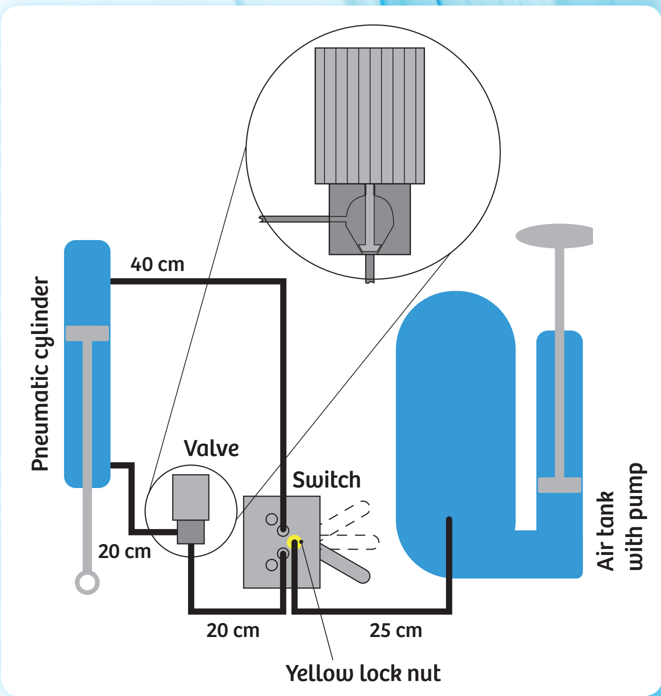
Air power

YOU WILL NEED

- **Tube** 56
- **Small security nut, yellow** 57
- **Switch** 58
- **Pneumatic cylinder piston** 59 **with piston handle a ached** 60
- **Air tank and pump assembly** 61 62 63
- **Valve assembly** 78 79 80
- *Scissors*
- *Measuring tape*

HERE'S HOW

1. Pick out the following tube lengths: 20 cm (2 x), 25 cm, and 40 cm (see Tips and Tricks, page 1).
2. Next, assemble the parts as shown in the diagram. If you have not yet assembled the pneumatic cylinder piston with piston handle, the valve assembly, or the air tank and pump assembly, see the Tips and Tricks section on the inside front cover and page 1.
3. Move the lever on the switch to the center position.
4. Pump air into the pressurized air tank (pump between 30 and 50 times).
5. Next move the lever back and forth — the piston in the cylinder will now move in and out.
6. You can use the controller on the valve to adjust how fast the piston moves.



WHAT'S HAPPENING?

When you operate the air pump, you are pushing air into the pressurized air tank. When you then move the lever on the switch, the air ows through the tubes and the valve into the cylinder. The degree to which the valve is open will determine how quickly or slowly this happens. Opening the valve reduces ow resistance, which means the air flows be er. This also means that more air ows into the cylinder at the same time, which pushes the piston out more quickly. When you move the lever in the other direction, the piston will start moving in. Because the air needs to pass through the valve again, this occurs at the same speed.

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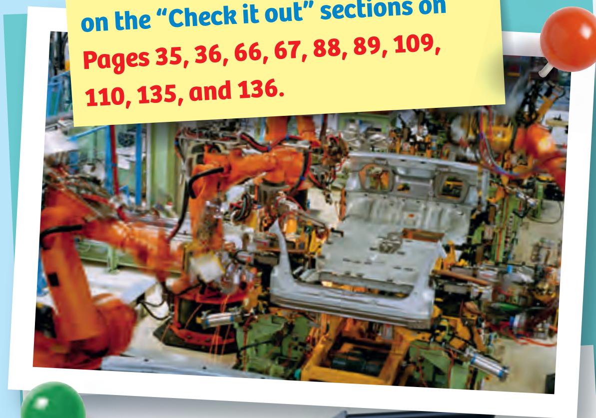
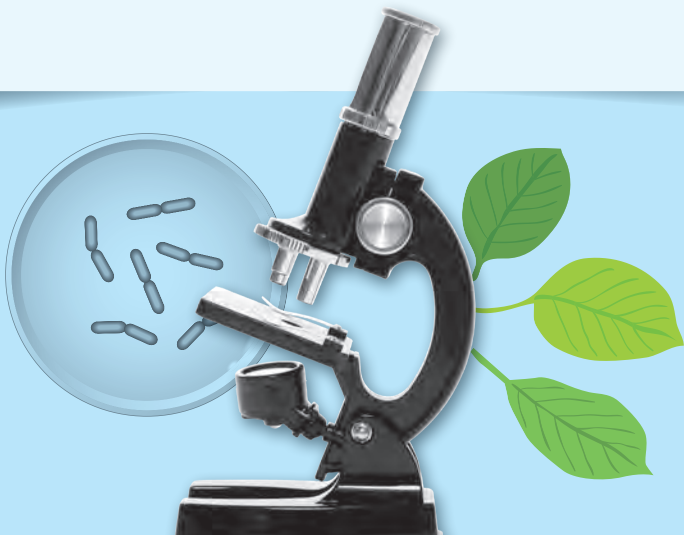
TIP!
You will find additional in ormation on the "Check it out" sections on Pages 35, 36, 66, 67, 88, 89, 109, 110, 135, and 136.



TIP!
Above each set of assembly instructions, you'll find a ed bar.
››› This bar shows the level of diffic ty of each model:

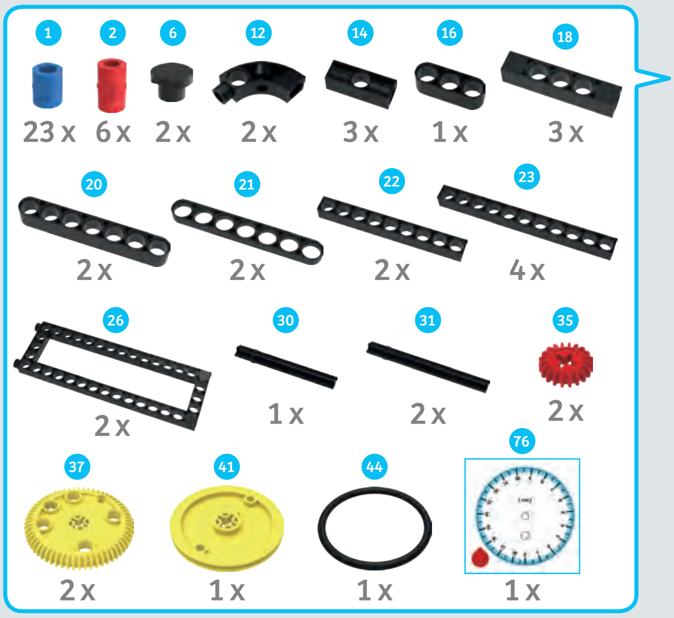
Easy   Medium   Diffic t



Man Versus Machine

Since the beginning, humankind has always sought to use tools to make life easier. We've come a long way from the invention of the first hand ax to the complex machinery we know today. Let's try out some of the machines that people work with nowadays. They help us to grasp, lift, and measure things, and also to find our bearings.

SURVEYOR'S WHEEL



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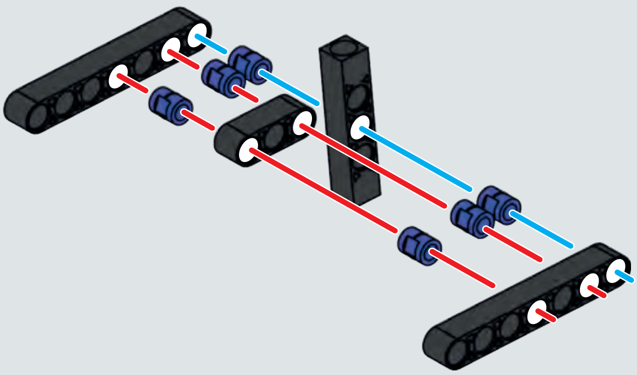

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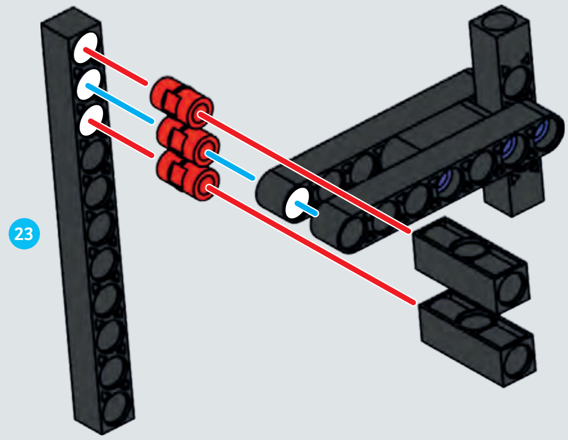

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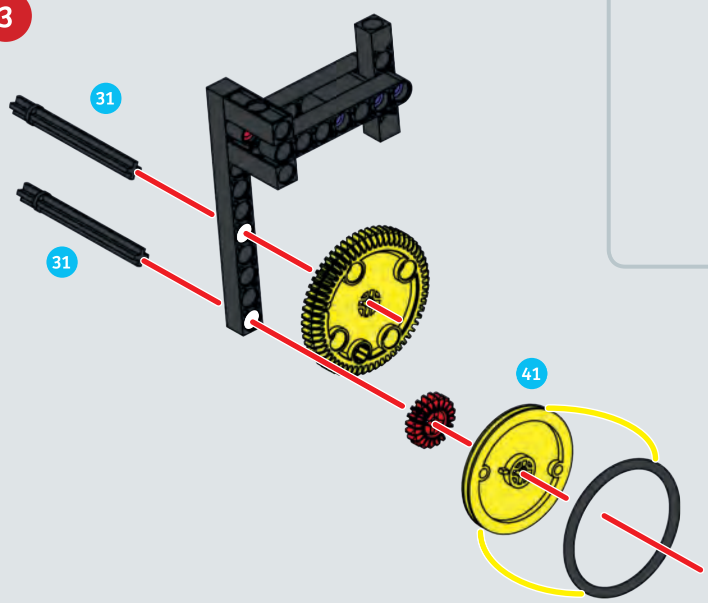

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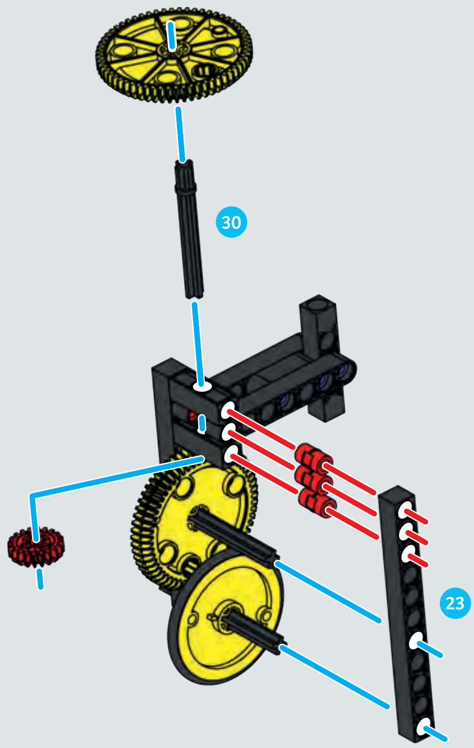

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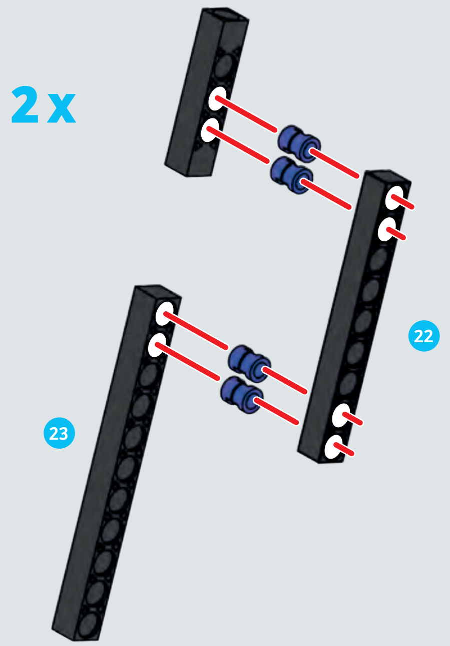

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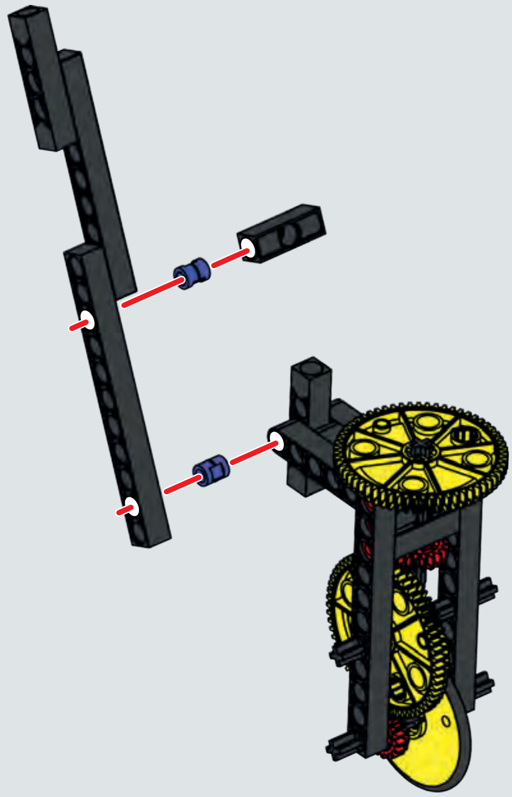

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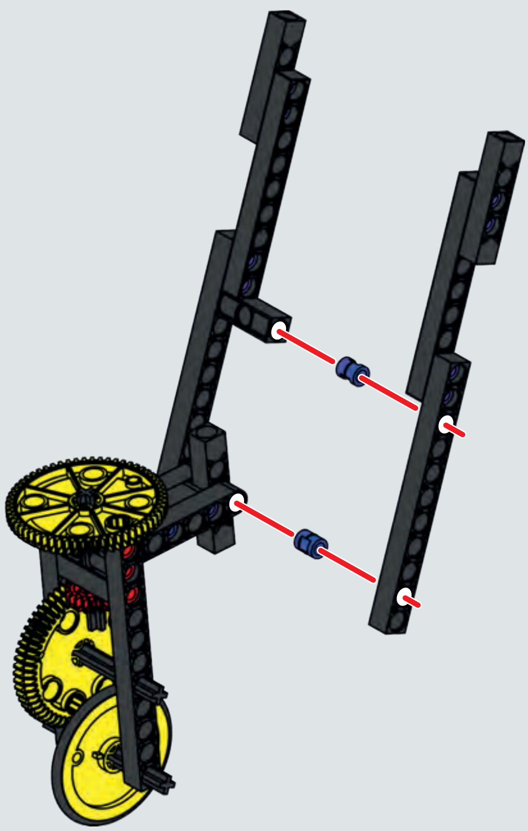

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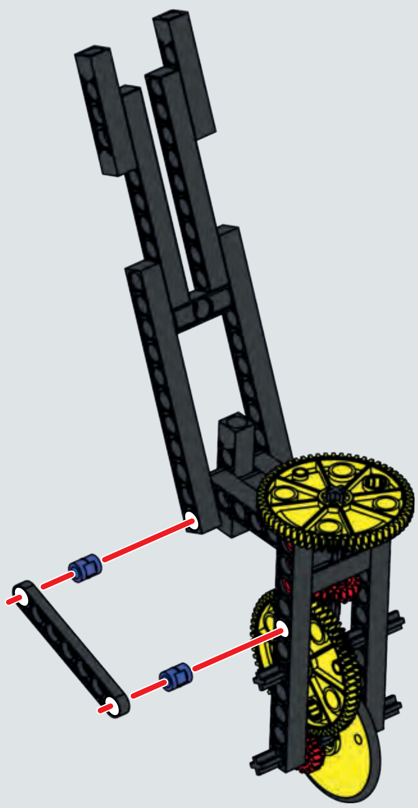

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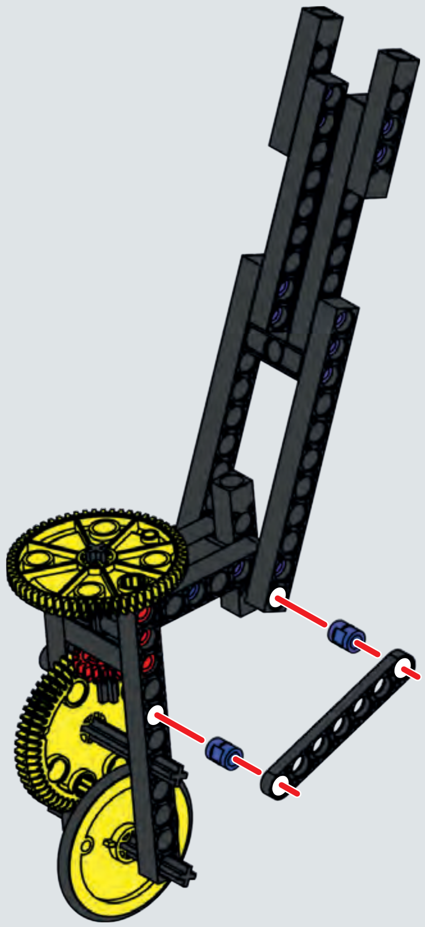

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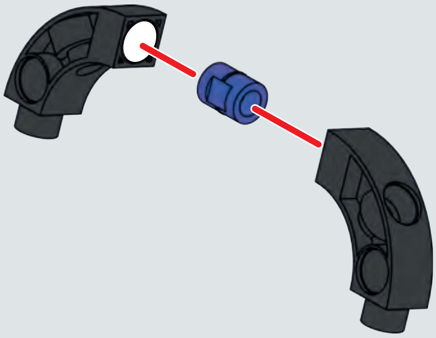

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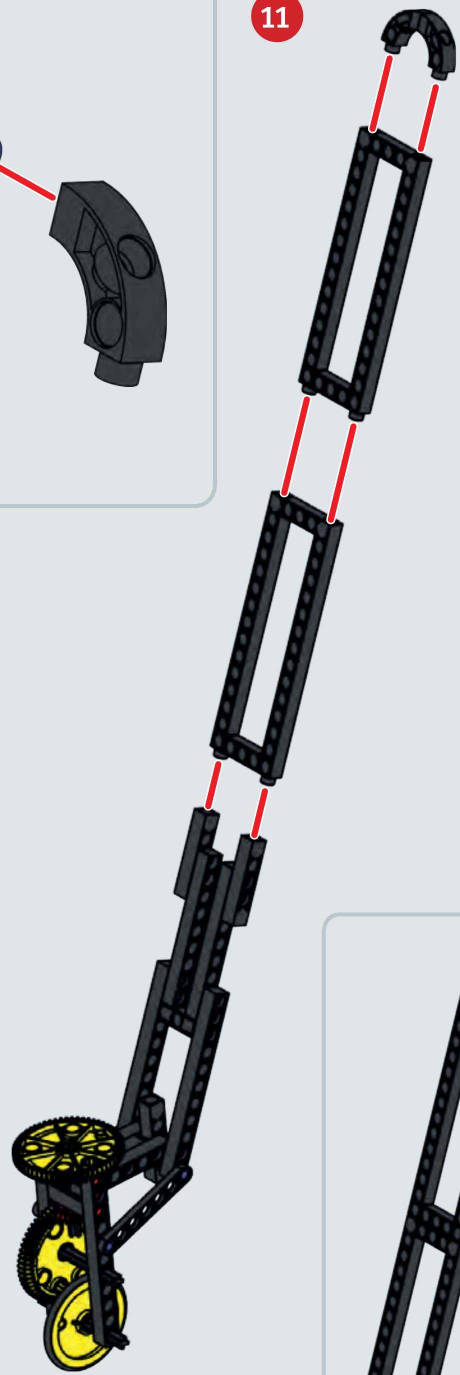

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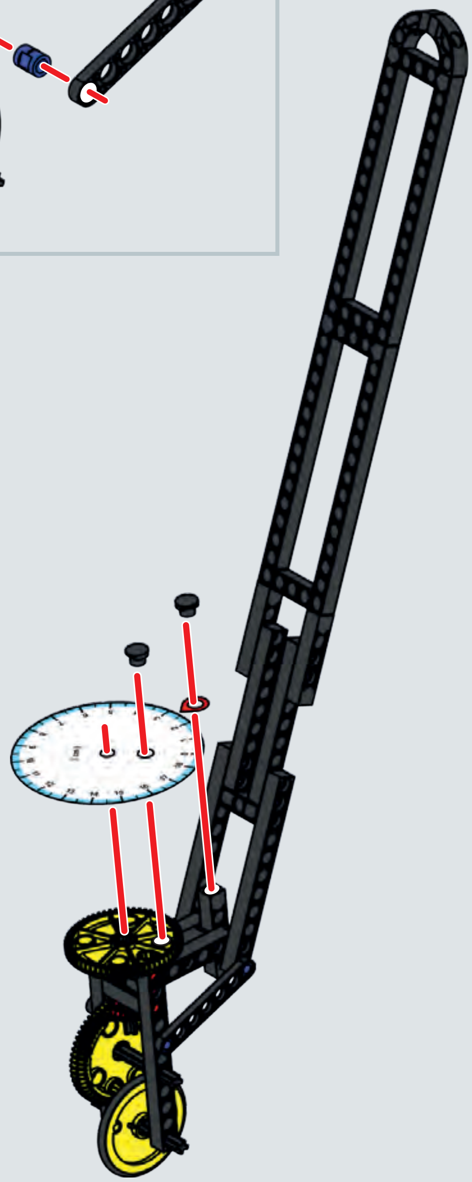
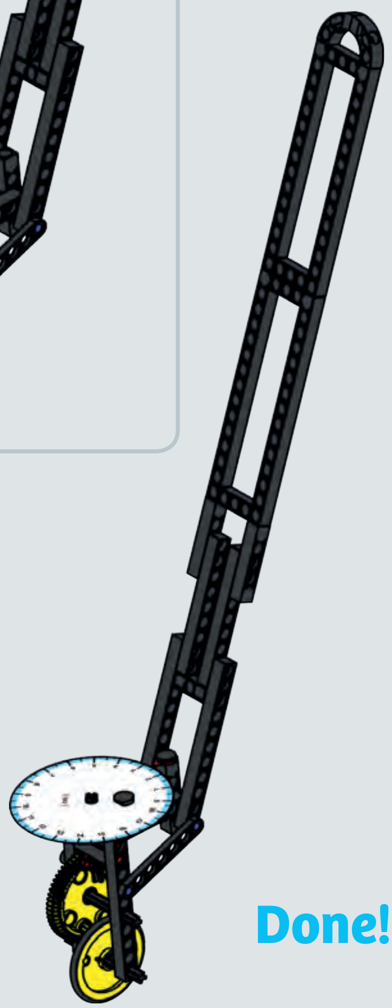




Done!

EXPERIMENT 1

Surveyor's wheel

YOU WILL NEED

› **The assembled surveyor's wheel**
› *Various distances you can measure*

HERE'S HOW

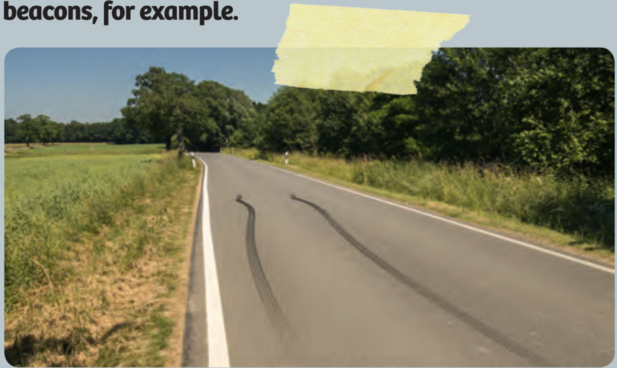
1. Turn the measuring wheel until the pointer is set to zero.
2. Push the wheel slowly along the oor a certain distance and count the number of full revolutions.
3. Multiply the number of full revolutions by 19 and then add this figu e to the value indicated on the cut-out counting wheel. This corresponds to the distance in centimeters. To get the corresponding distance in meters, just divide this value by 100.

WHAT'S HAPPENING?

When you push the surveyor's wheel along a certain distance, the wheel turns. This rotation is transferred to the cut-out counting wheel by means of a bevel gear. The axes of bevel gear wheels typically intersect at a 90° angle. This allows the direction of rotation to change, from vertical to horizontal in this case.

DID YOU KNOW?

This type of measuring wheel is used by police to measure the length of brake marks in the event of a car accident, for example. They can then use this information to calculate the speed that the car involved was traveling at. Measuring wheels like these are also used in road building and landscaping to measure the length of paths and the distance between warning beacons, for example.



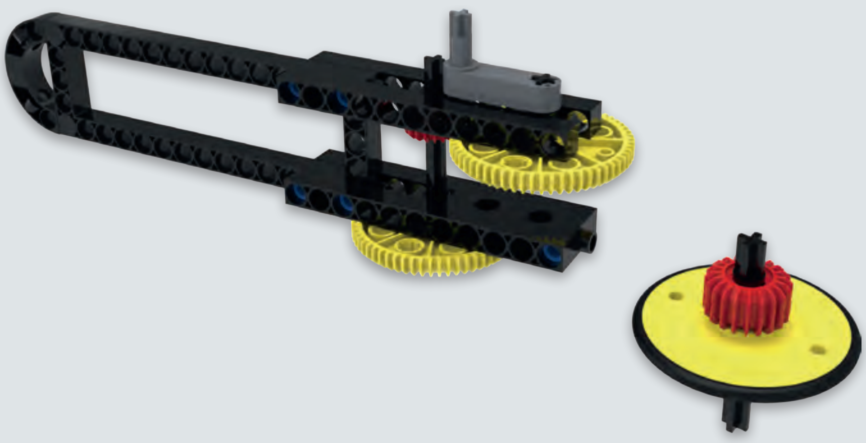
WANT TO FIND OUT MORE?

You can use the surveyor's wheel to create a measuring tape from a long piece of string. You can then use this measuring tape in the next experiment. To create the measuring tape, use the surveyor's wheel to measure out 10 cm of string and then tie a knot in the string at this point. You can make your measuring tape even more precise by tying a knot every 5 cm.

KEY CONCEPT: WARNING BEACONS

A **warning beacon** is a road sign that's used to alert road users to the location of the side of the road or an obstruction on the road. For extra visibility, they're designed with diagonal stripes in two contrasting colors.

SPINNING TOP



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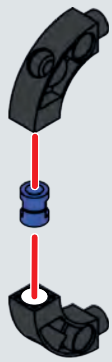

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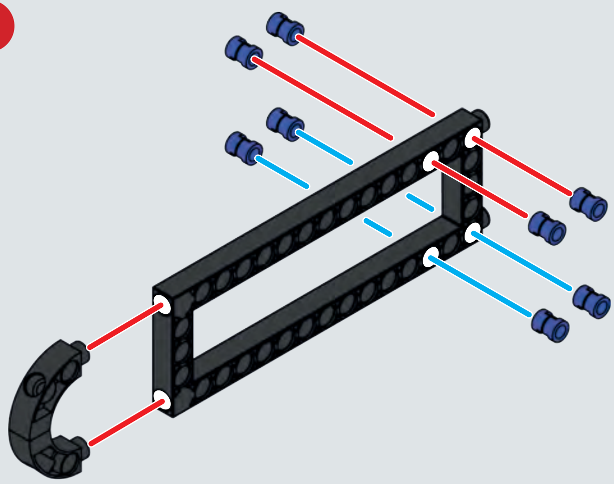

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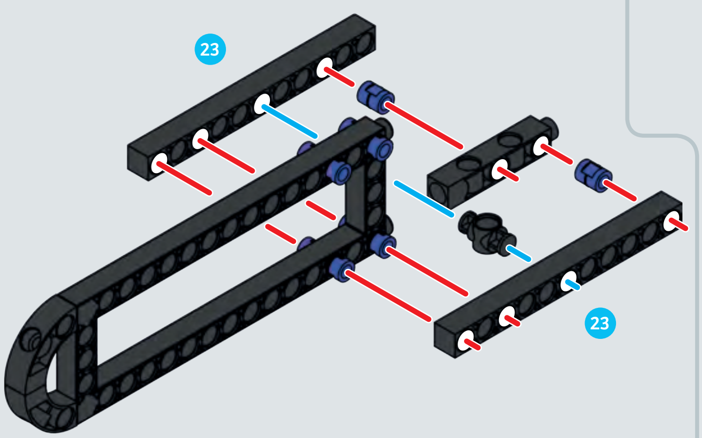

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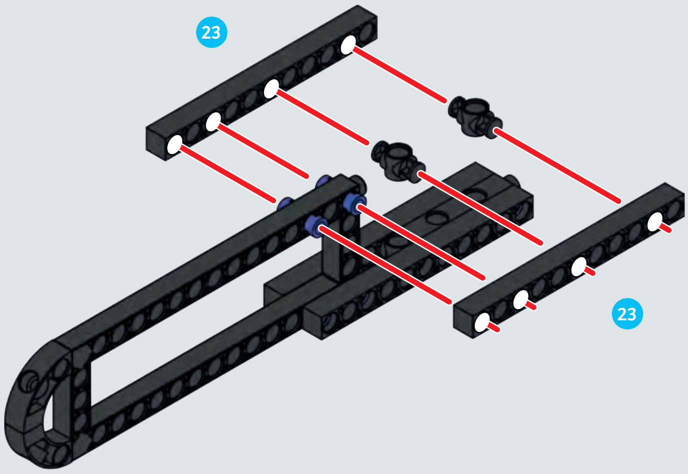

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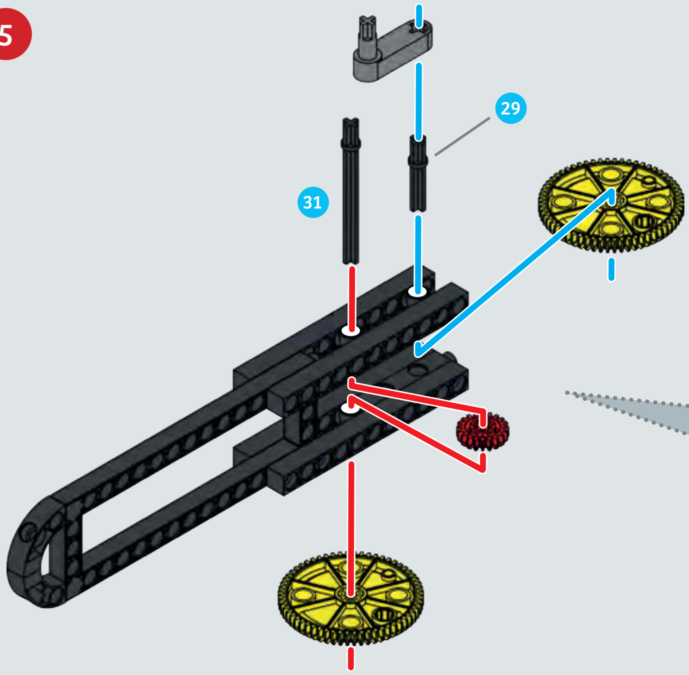

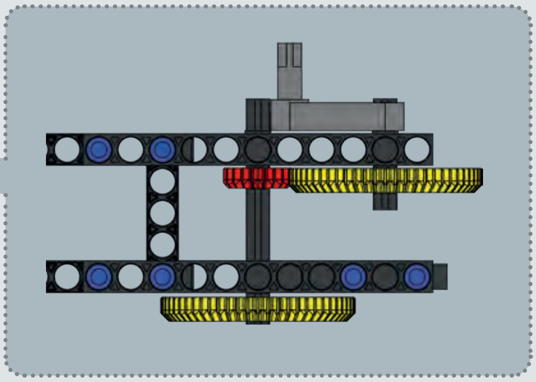

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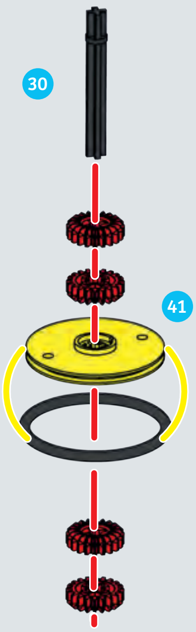
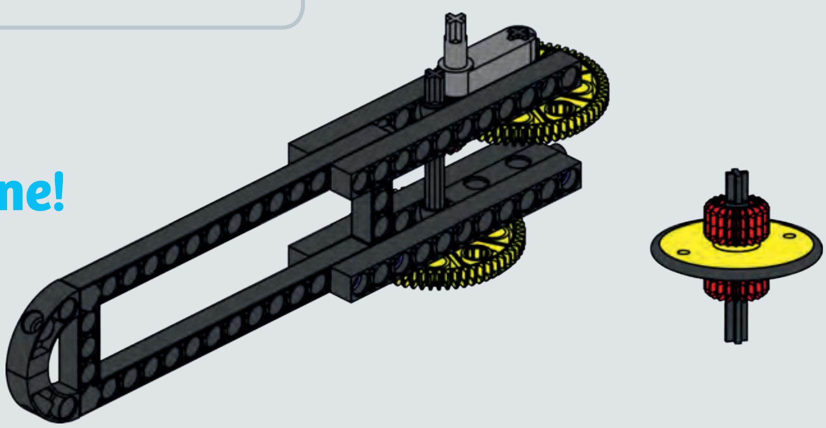
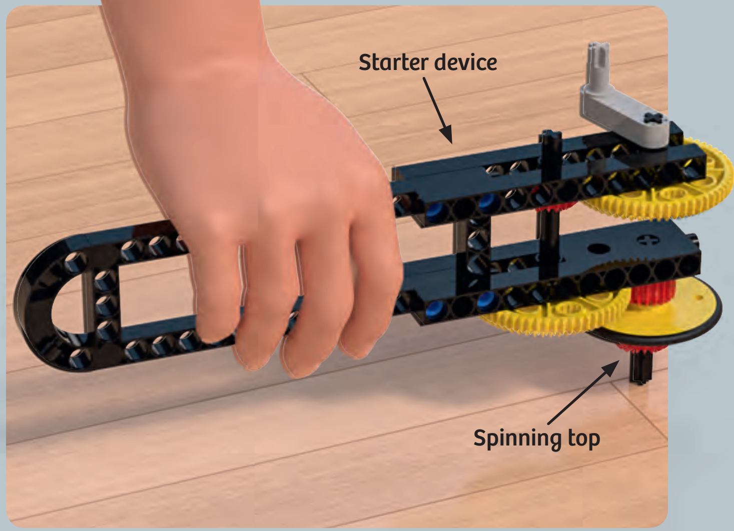


Done!



EXPERIMENT 2

Spinning top



YOU WILL NEED

› The spinning top
› The assembled starter with crank

HERE'S HOW

1. Hold the spinning top upright on the a est oor surface you can find
2. Insert the spinning top into the starter device.
3. Turn the crank so that the top starts to spin.
4. Once the top is spinning fast enough, remove the starter device.

WHAT'S HAPPENING?

The rotation from the crank is transferred to the spinning top via two gears. In this case, the gear a ached to the crank is larger than the gear a ached to the spinning top. This means that you can turn the crank slowly and the spinning top will rotate quickly. As long as it is spinning, the top will remain upright. Balancing forces and the law of conservation of angular momentum ensure that the spinning top does not topple over. It's only when it loses speed and is no longer spinning fast enough that it begins to wobble, and eventually topples over.

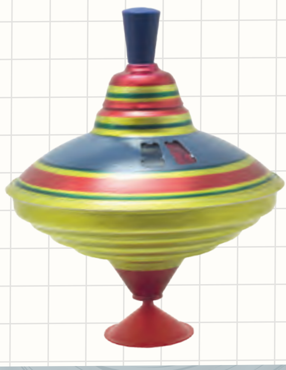
DID YOU KNOW?

Spinning tops are used in airplanes and in small drones to detect the position of the aircraft during complicated maneuvers, for example. They spin around at really high speeds, but always maintain an upright position, even when the plane is rotating. This particular type of spinning top is called a gyroscope. In the past, spinning tops were also used in ships to ensure that gyrocompasses remained completely horizontal at all times, even in heavy swells. This was the only way for sailors to navigate accurately.

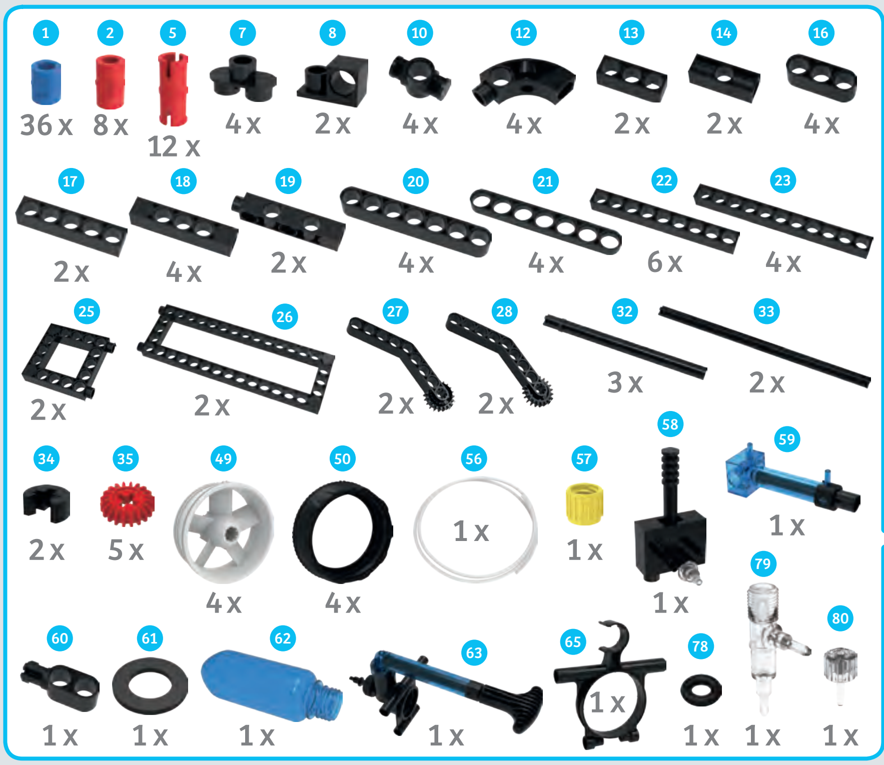
WANT TO FIND OUT MORE?

Take a board or large book and place it onto another book at an angle, to make a ramp. What happens if you start the spinning top on a sloped surface like this? The spinning top will travel sideways up the slope in curved or cycloid-shaped movements.

Moving up the slope in this way requires a lot of energy, which means the spinning top decelerates a lot more quickly than it would if it were on a at horizontal surface.



HYDRAULIC LIFT



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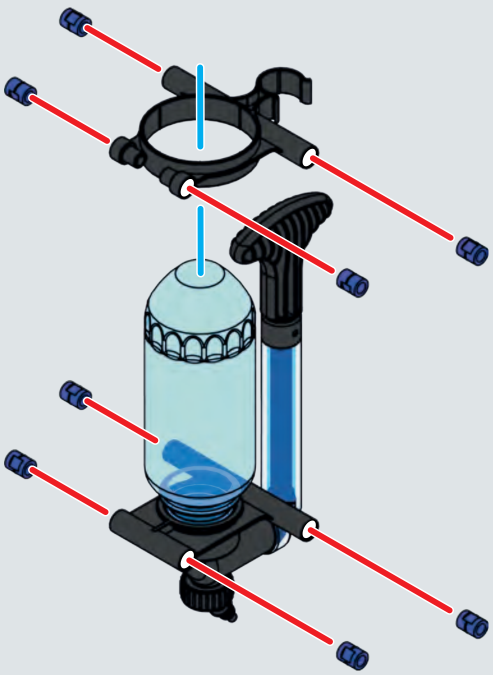

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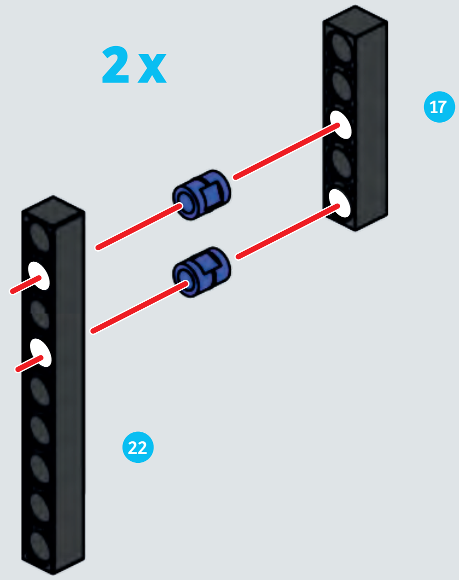

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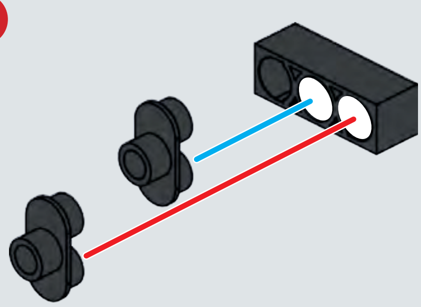

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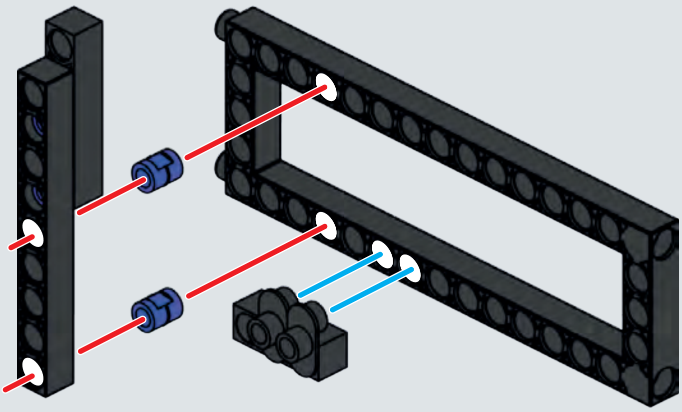

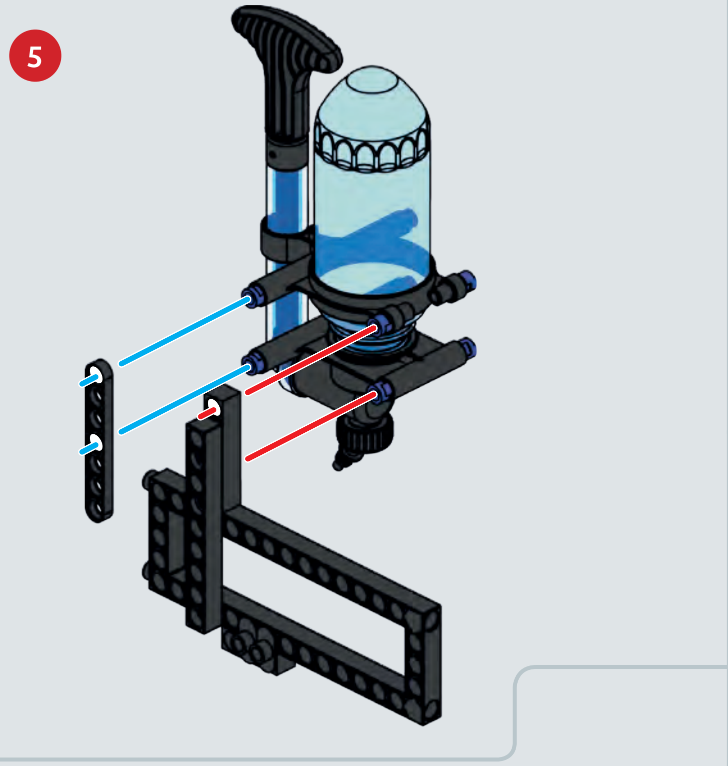
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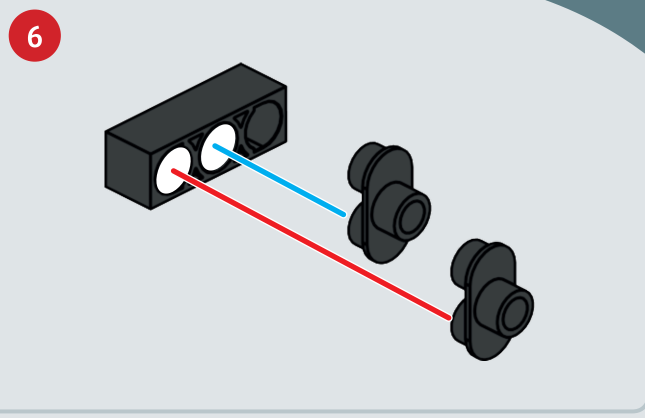
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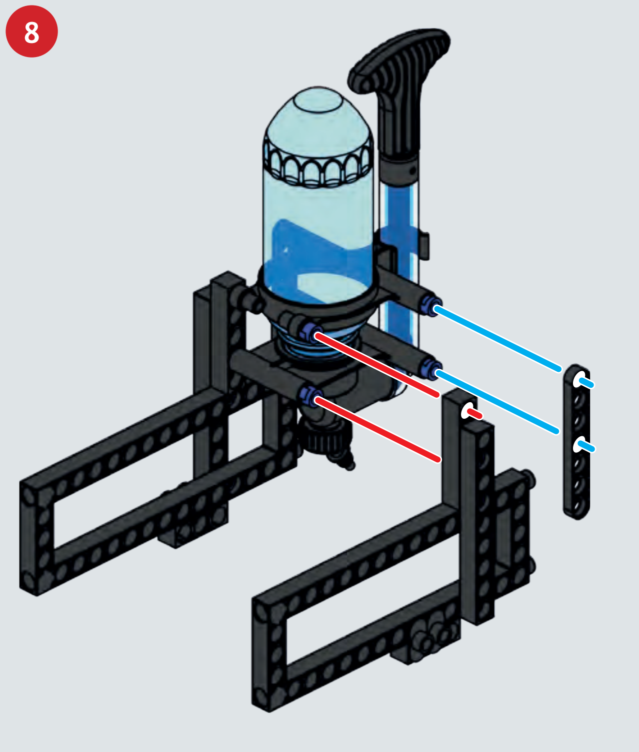
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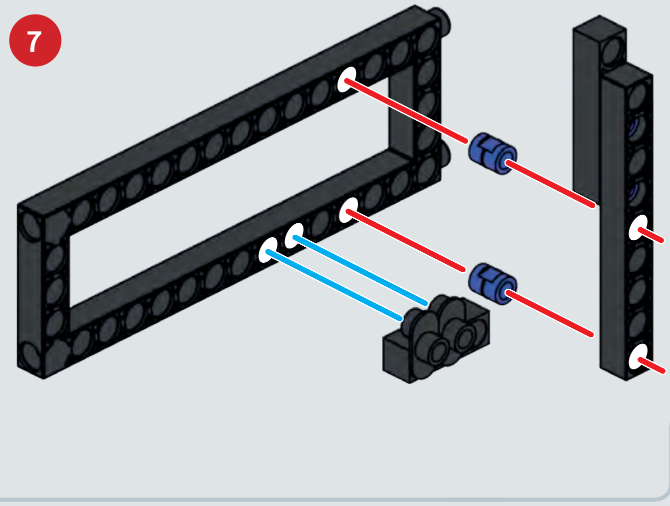
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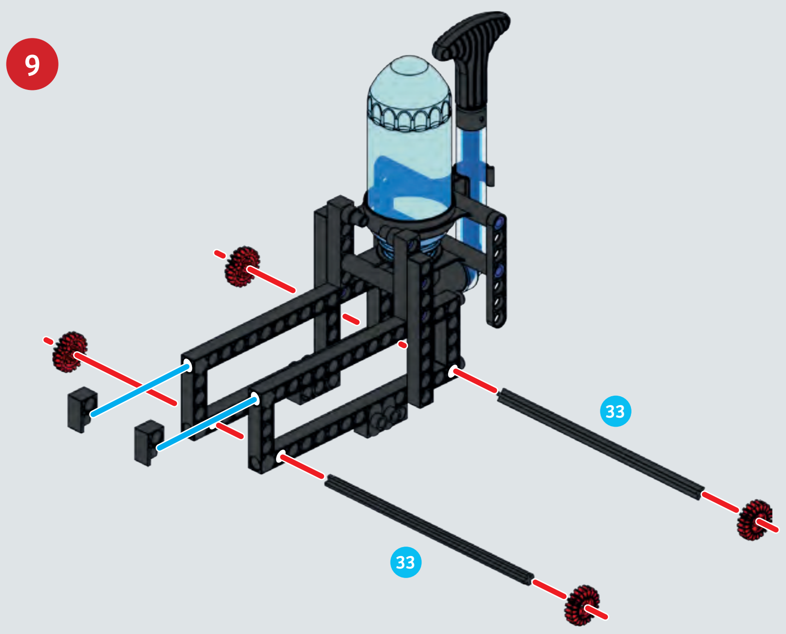
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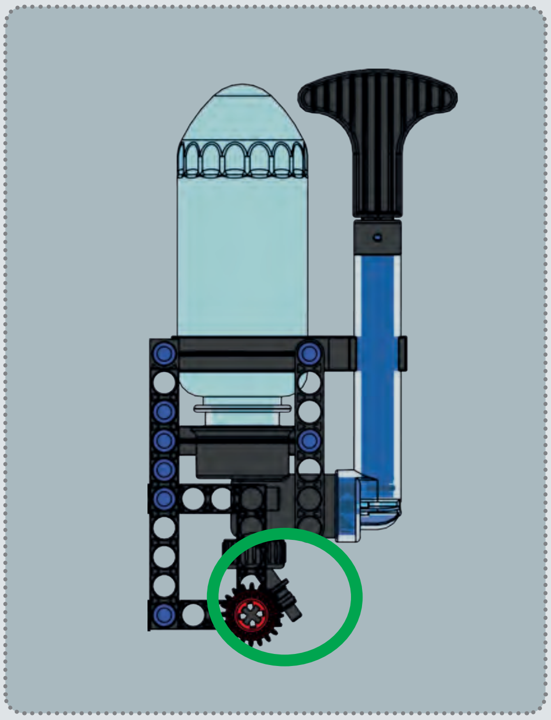

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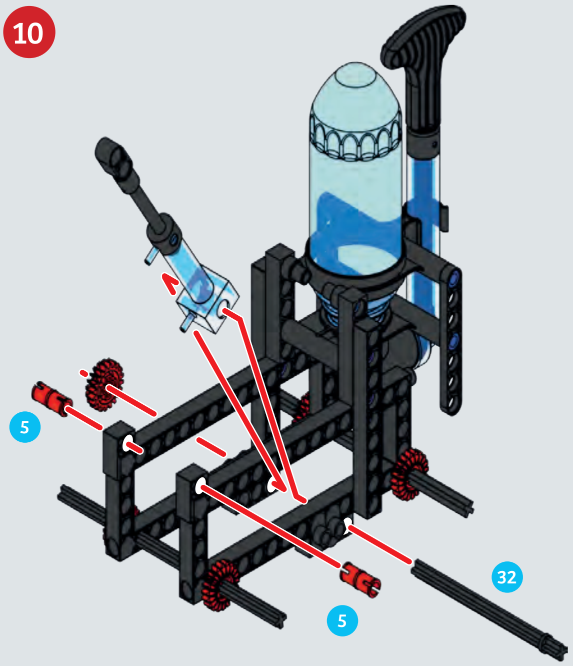

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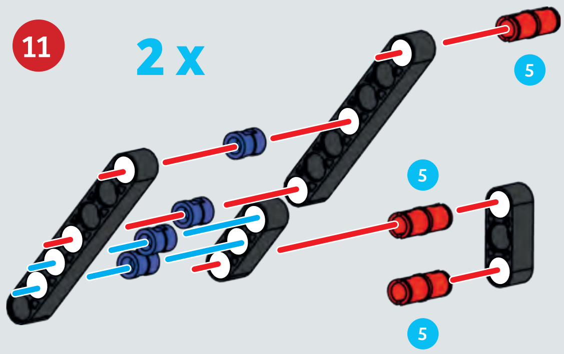

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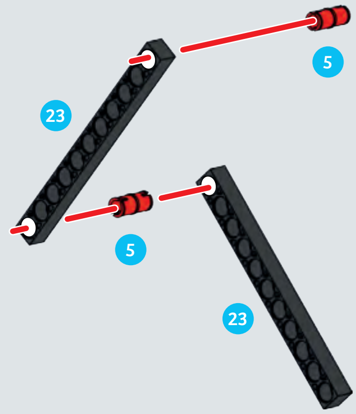

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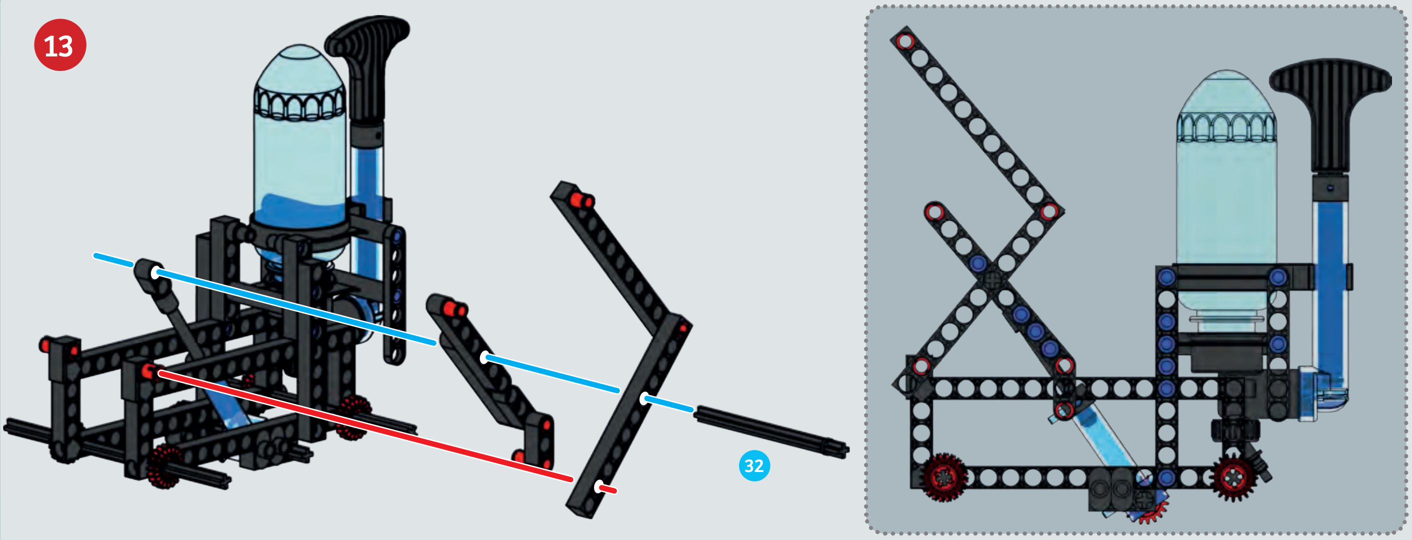

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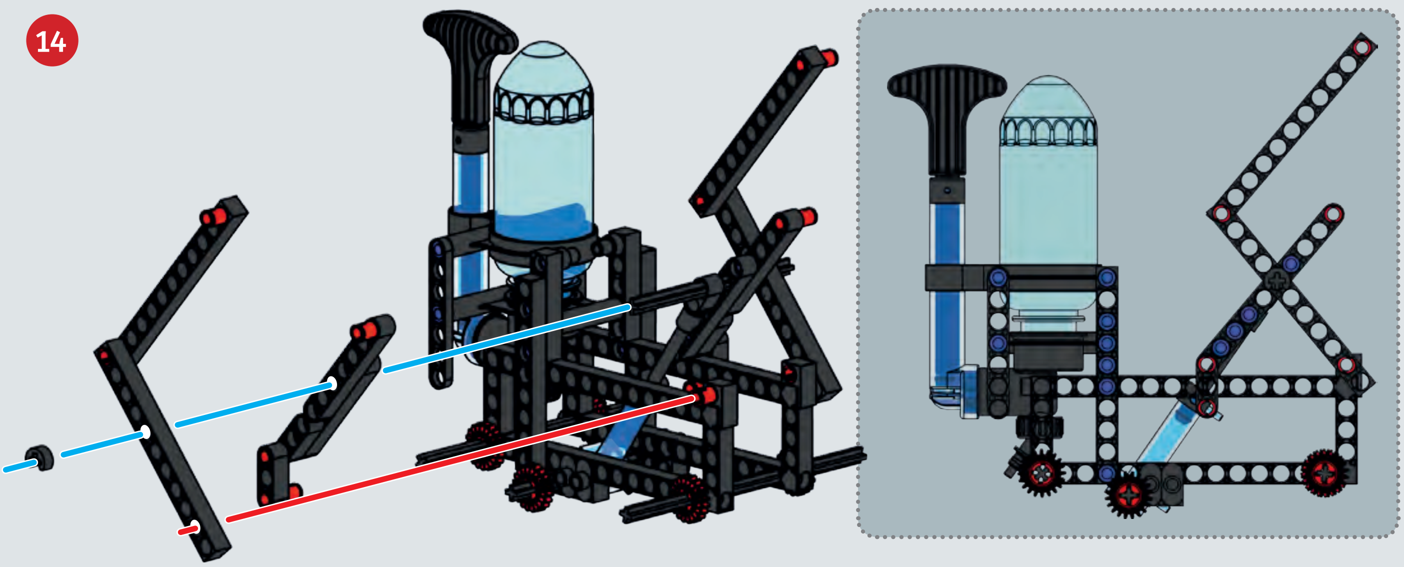

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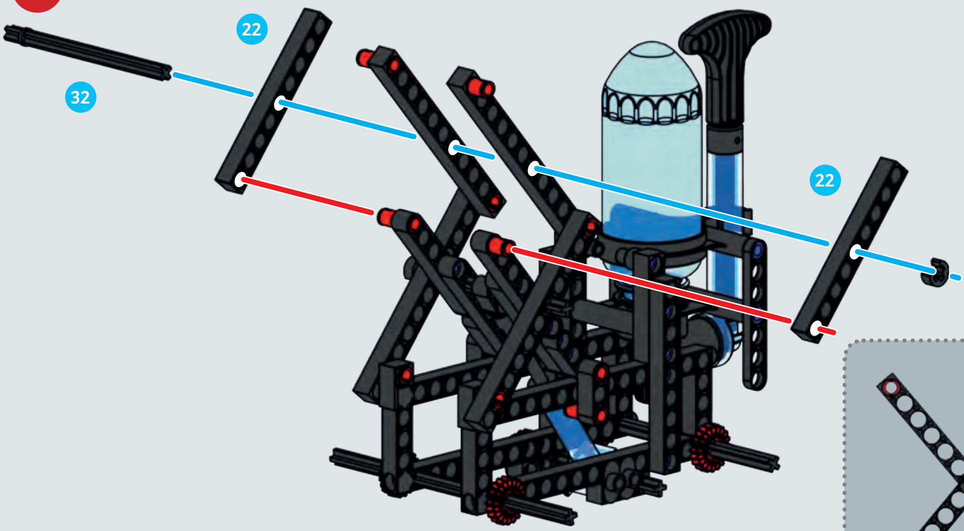

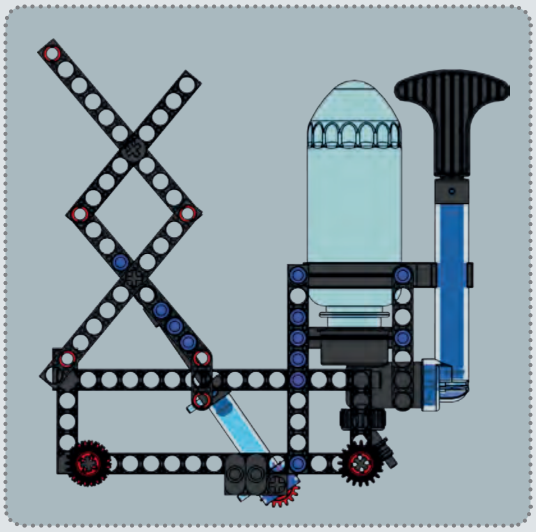

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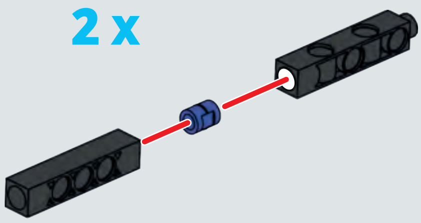

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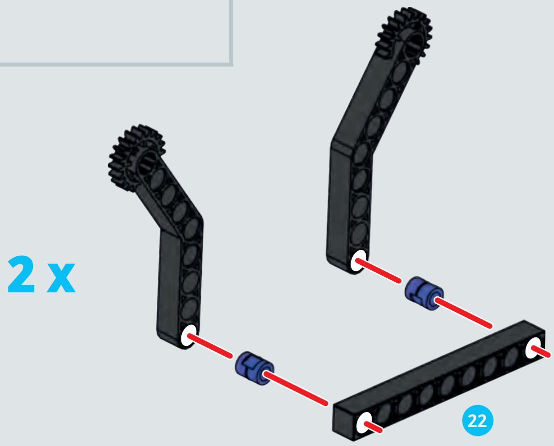

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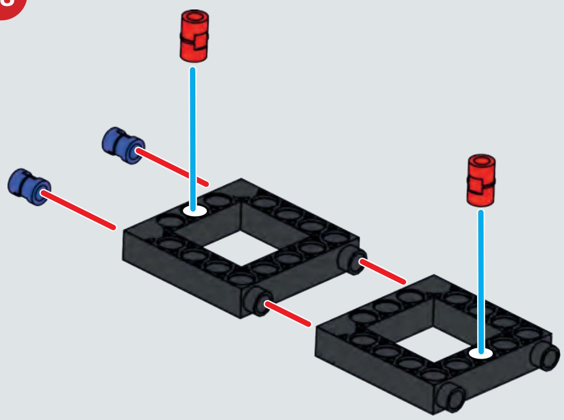

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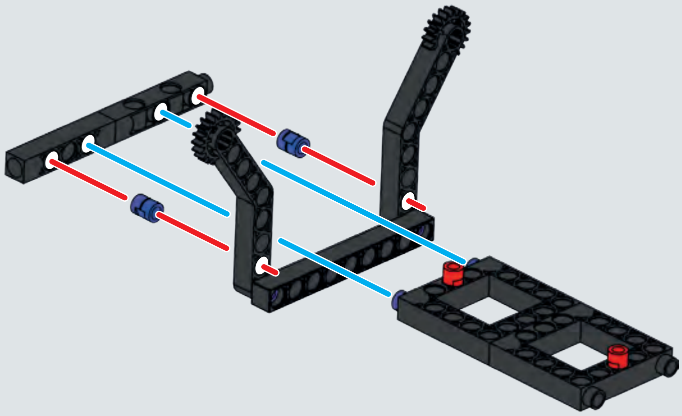

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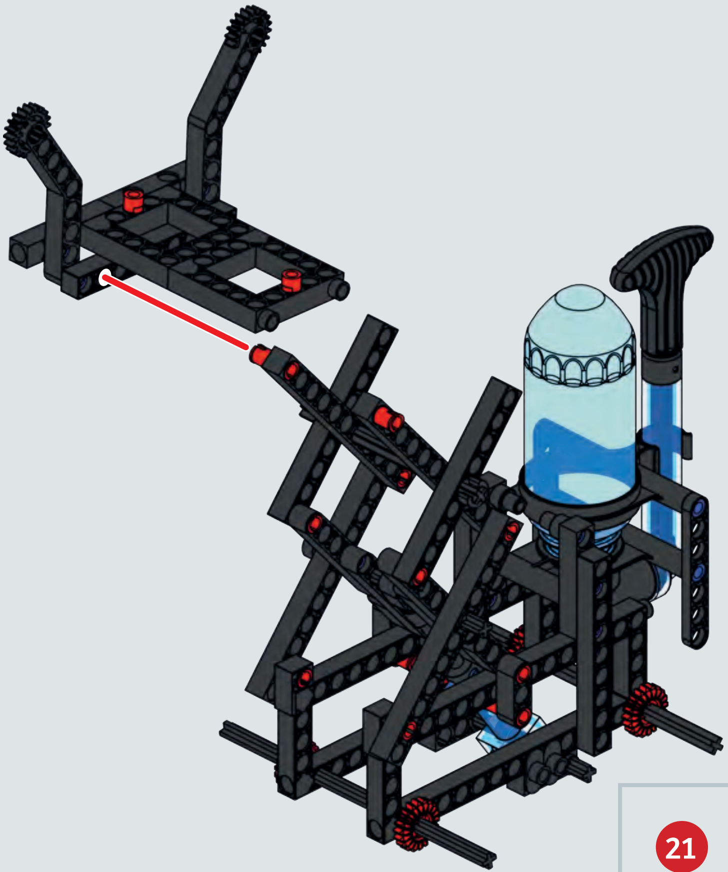

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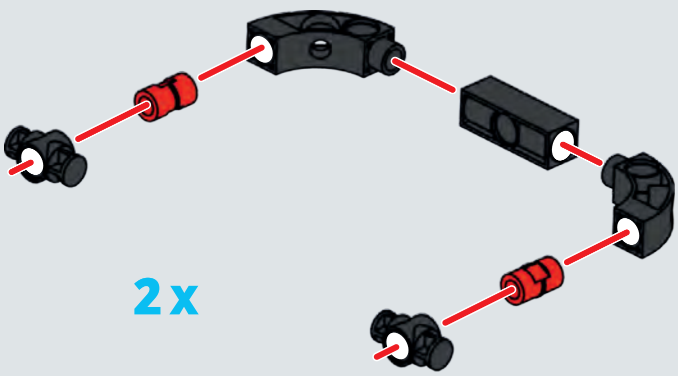

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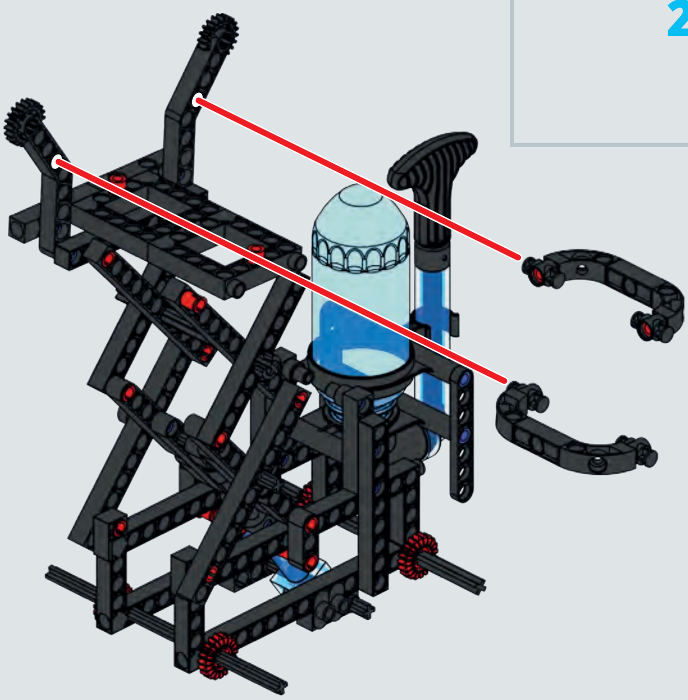

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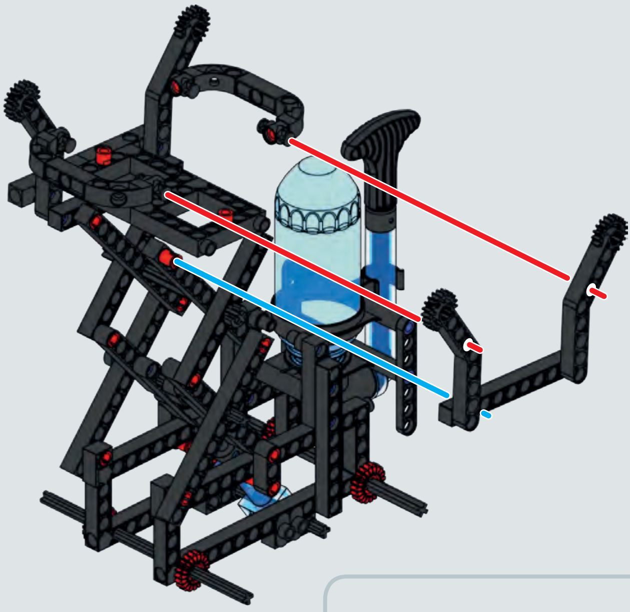

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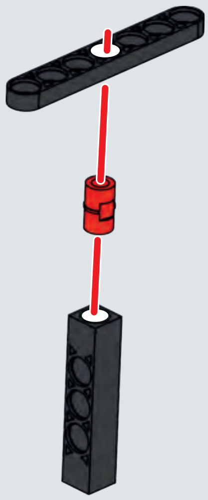

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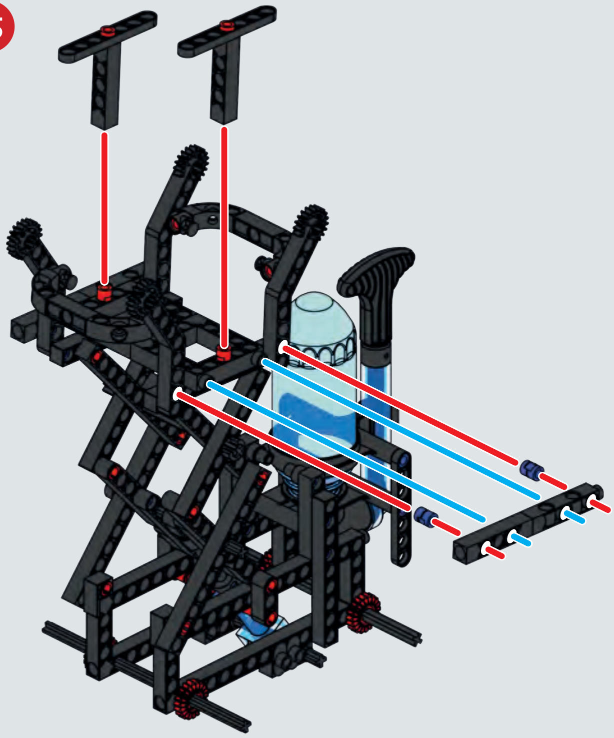

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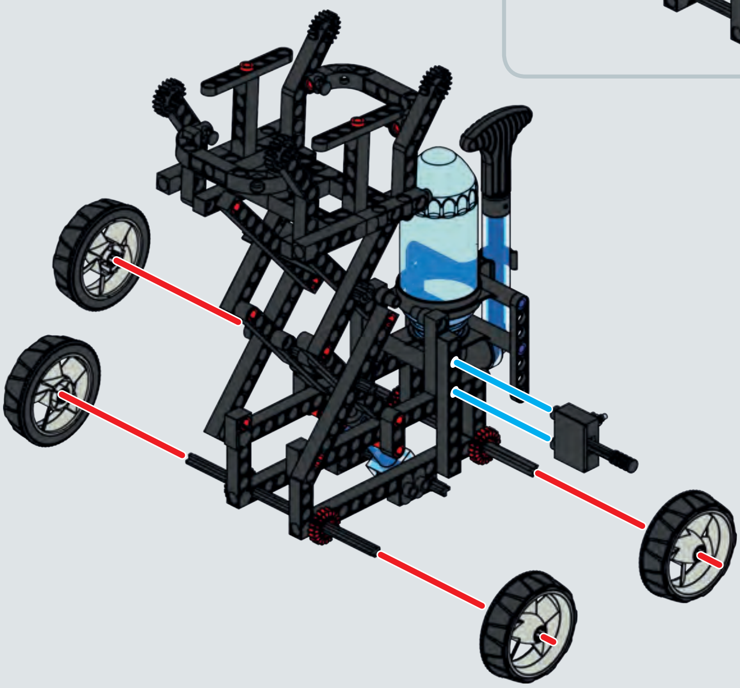

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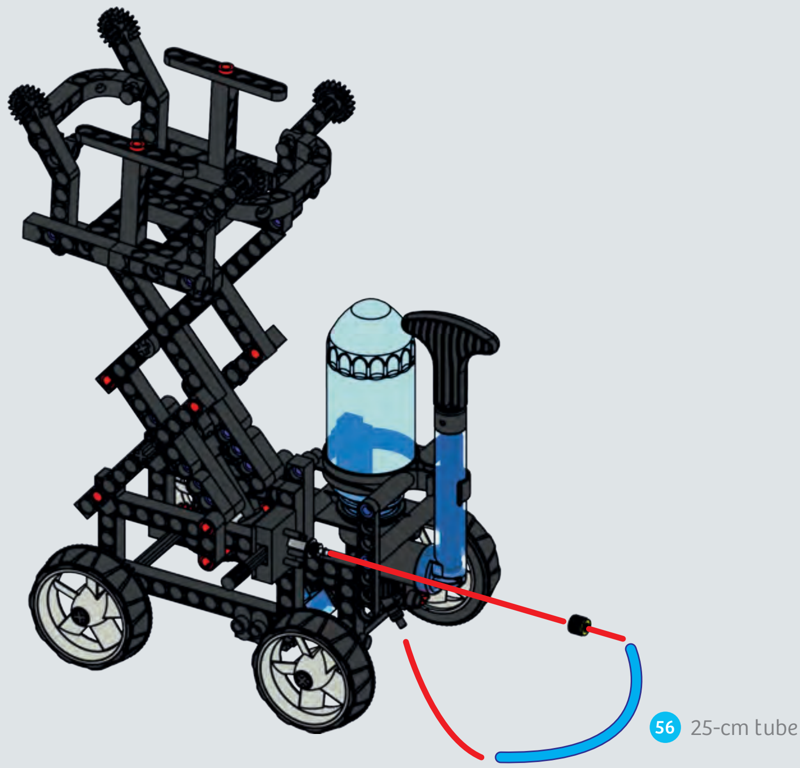

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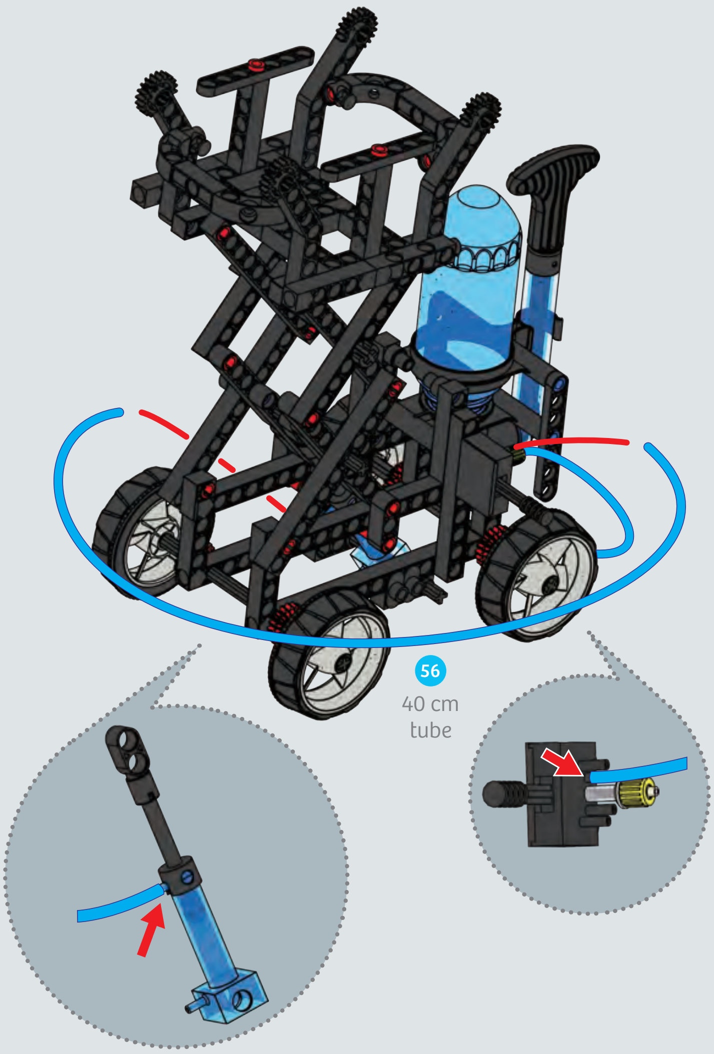

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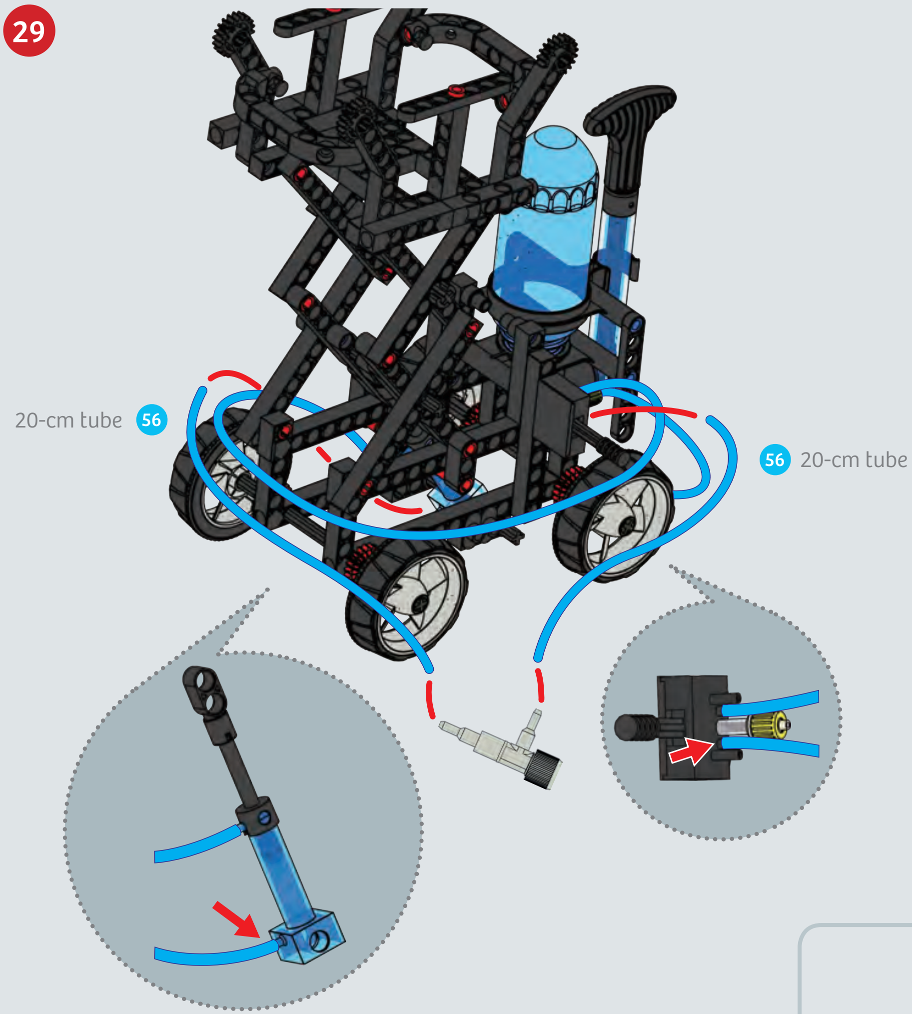
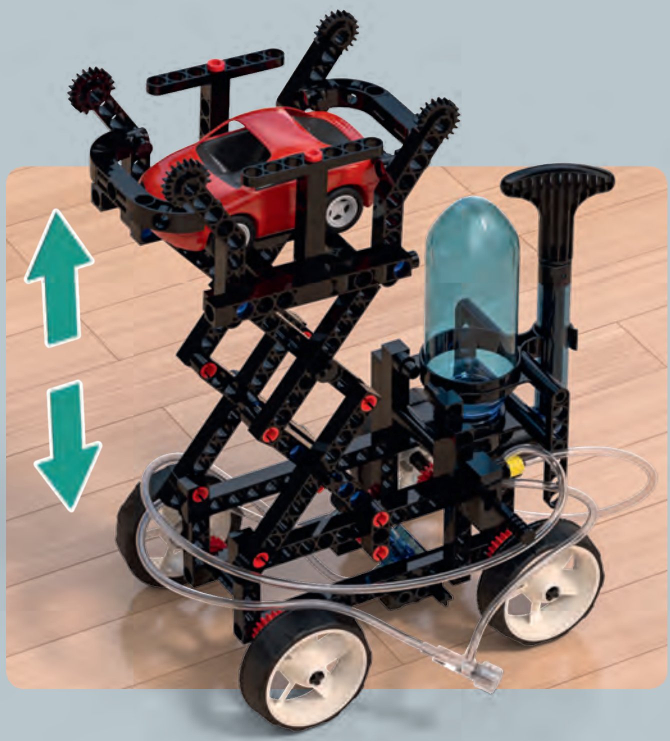


Done!

EXPERIMENT 3

Hydraulic lift



YOU WILL NEED

› **The assembled hydraulic lift**
› *Some small objects, e.g. toy cars, blocks, etc.*

HERE'S HOW

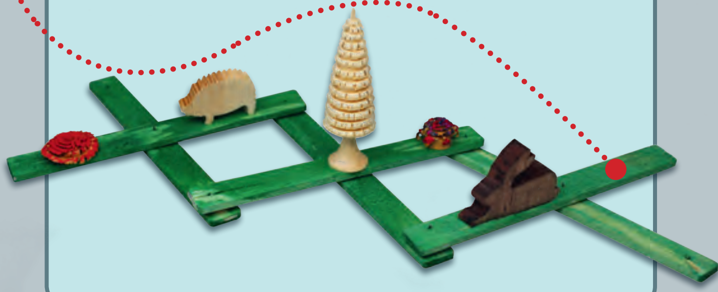
1. Move the lever on the switch to the center position.
2. Pump air into the pressurized air tank (pump between 30 and 50 times).
3. Next move the lever back and forth — the hydraulic lift will move up and down.
4. You can use the valve to adjust how fast the hydraulic lift moves.
5. Now place some small objects onto the hydraulic lift, and then raise them up and lower them down.

WHAT'S HAPPENING ?

The air contained in the pressurized air tank ows through the valve and pushes the piston out of the cylinder. The movement is transferred to the scissor-like linkage and raises the hydraulic lift. This leverage action allows very heavy loads to be transported. The work performed here, i.e. the gravitational force multiplied by the height di erence, is equal to the potential energy supplied. When the lift is lowered, this energy is released again and converted into heat by friction.

KEY CONCEPT: PANTOGRAPH

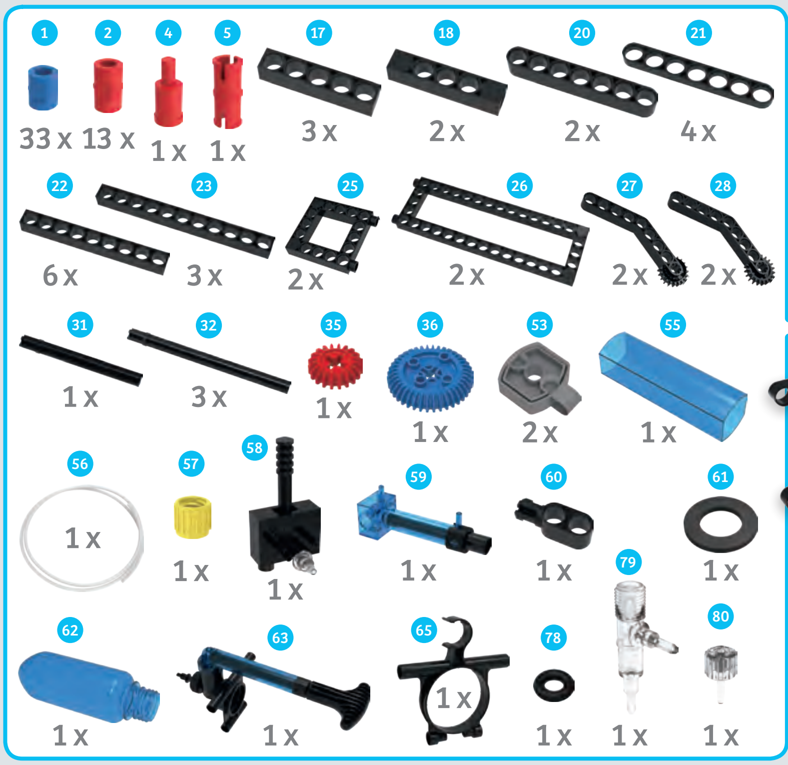
The hydraulic lift uses the same principle as the **"pantograph."** A very similar principle was used for a wooden toy that was once very popular. Li le figurines we e fi ed onto a series of interconnected wooden slats that could be moved in and out in unison. This allowed the structure to be opened and closed in the same way as a scissors.

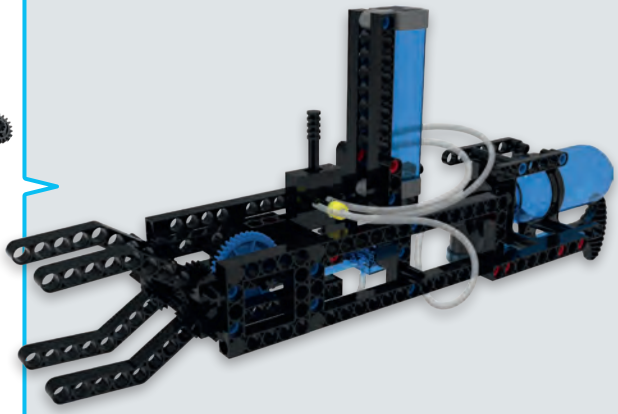


DID YOU KNOW?

Hydraulic lifts are used for various tasks. For example, fi e services and technical emergency services use hydraulic lifts to hoist equipment and people. They are also useful in building construction in cases where ladders are not stable enough or the erection of proper sca olding is too costly.

ROBOTIC ARM





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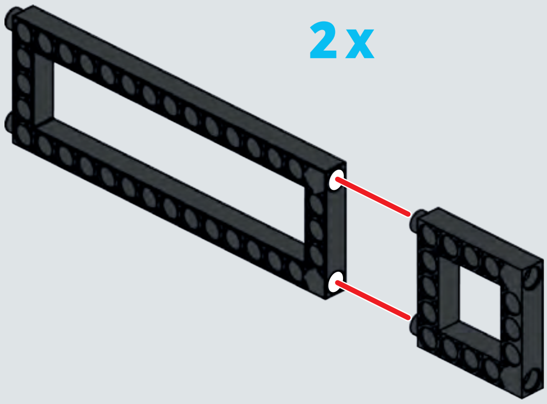

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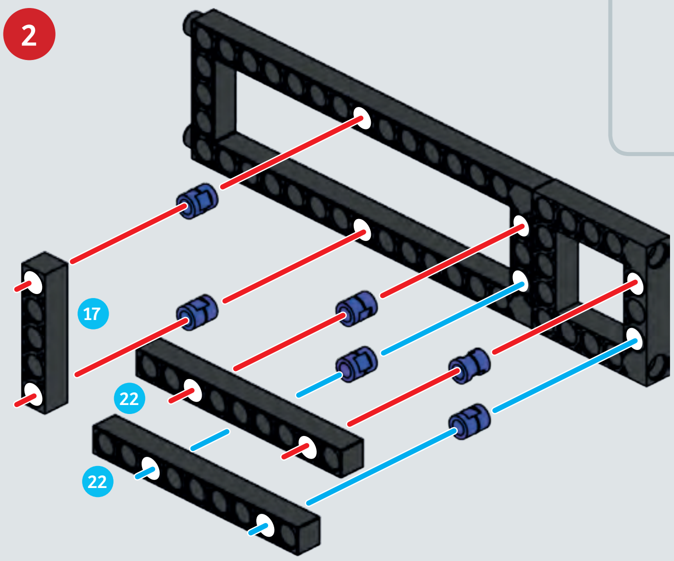

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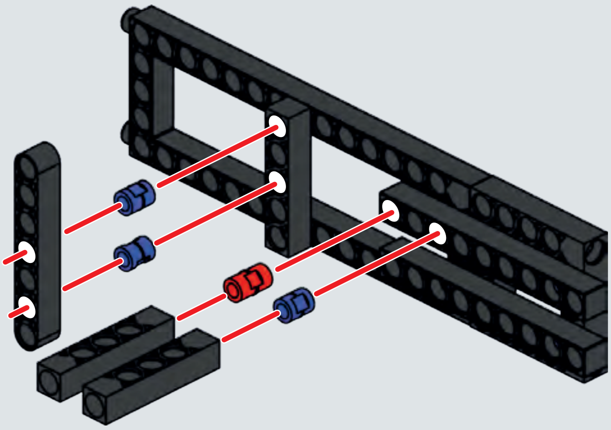

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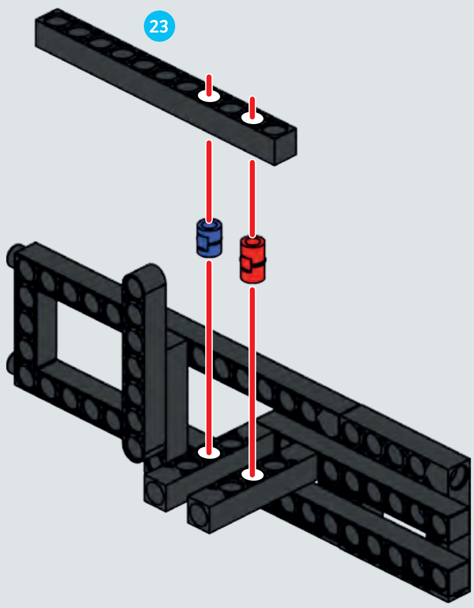

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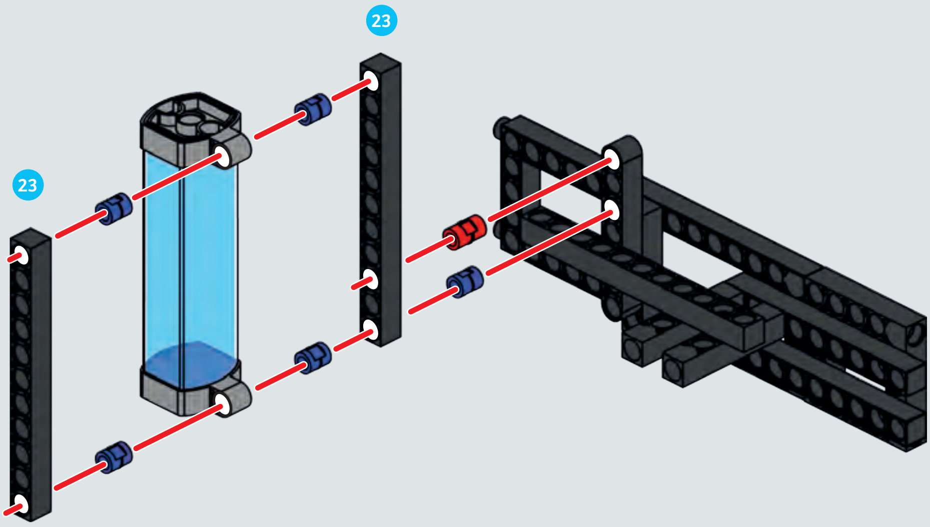

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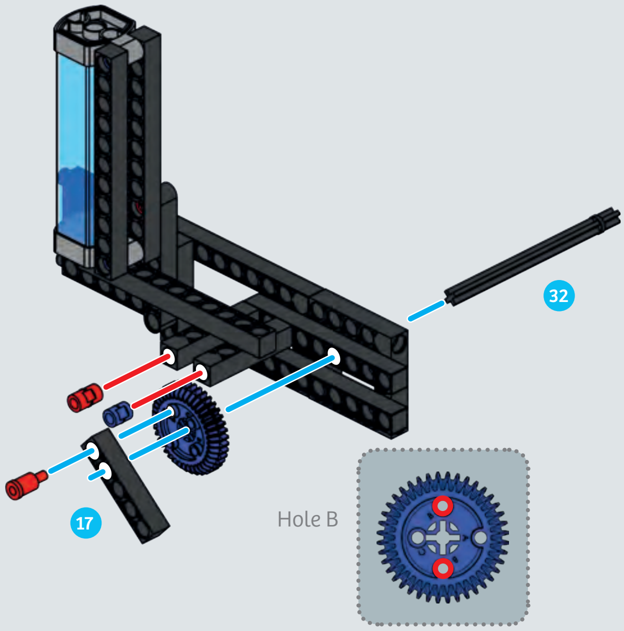

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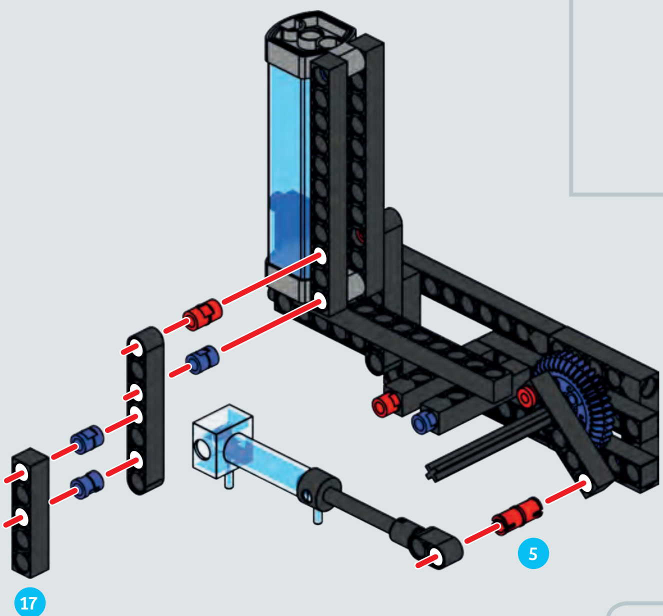

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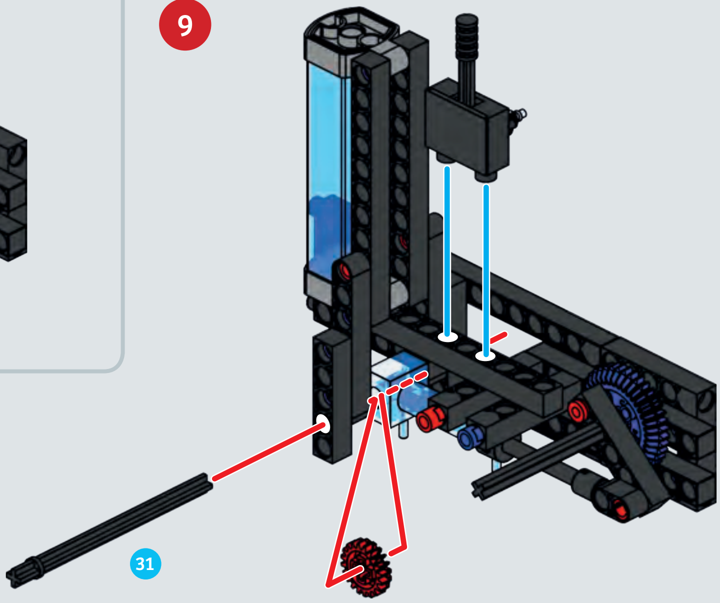

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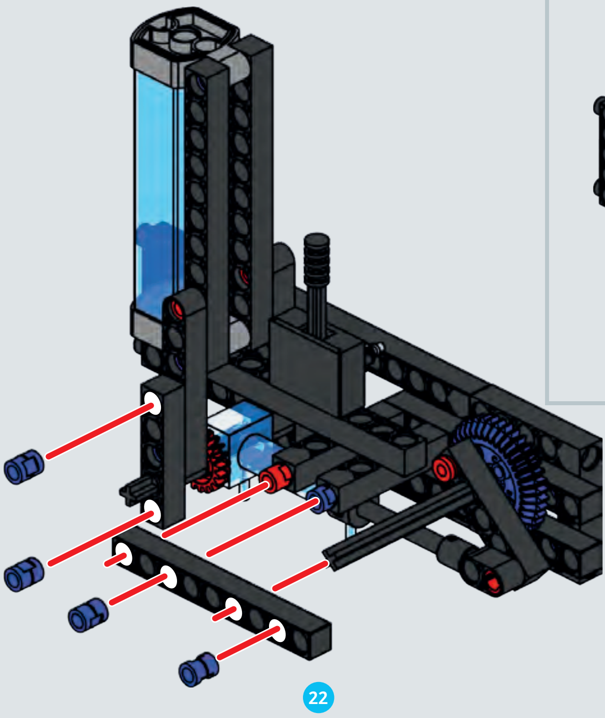

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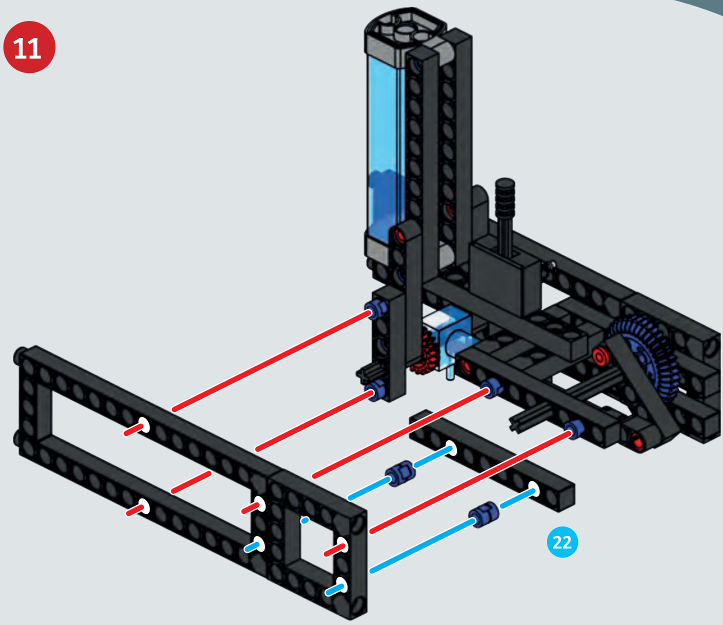

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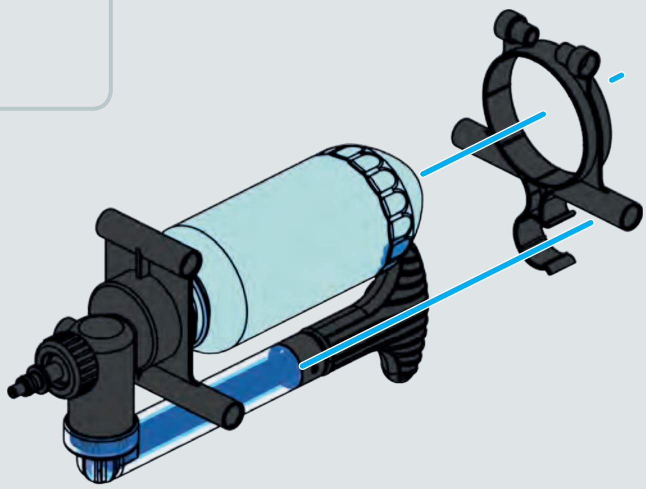

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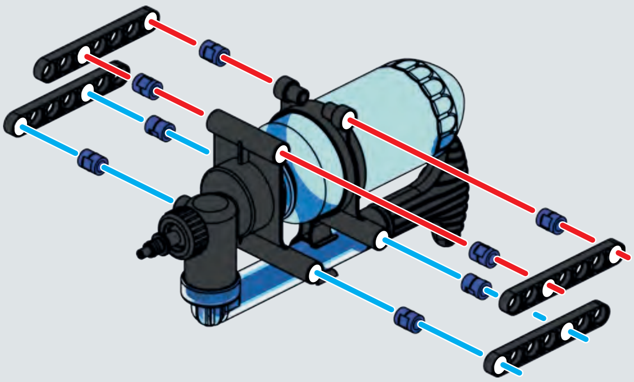

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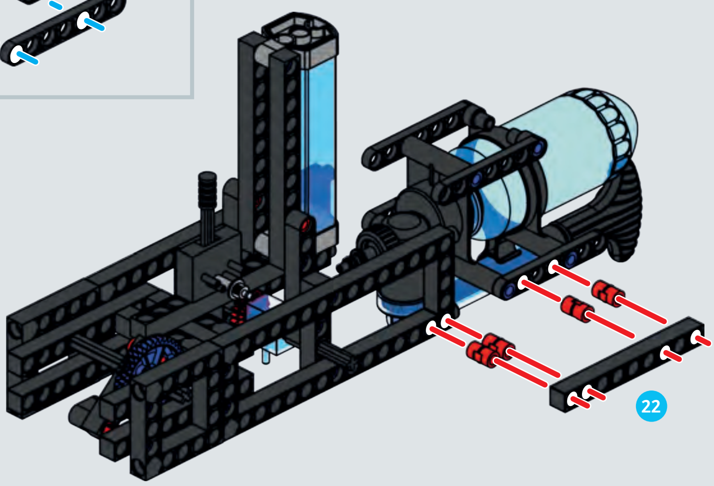

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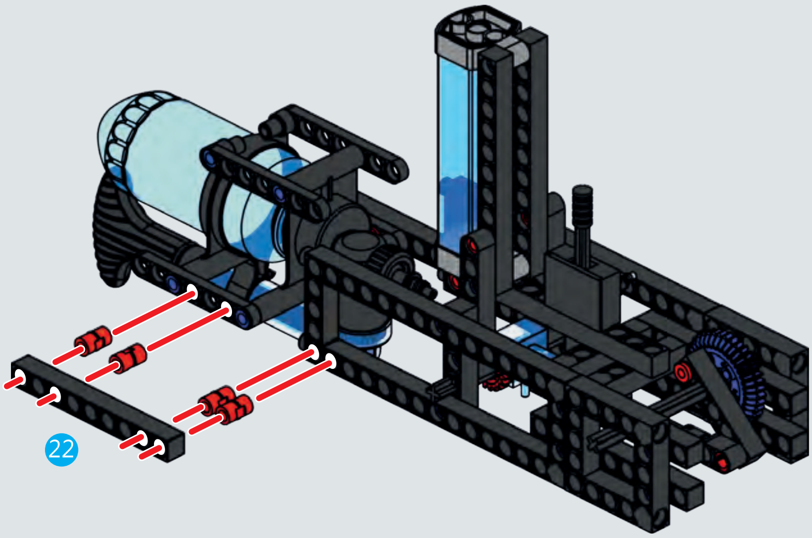

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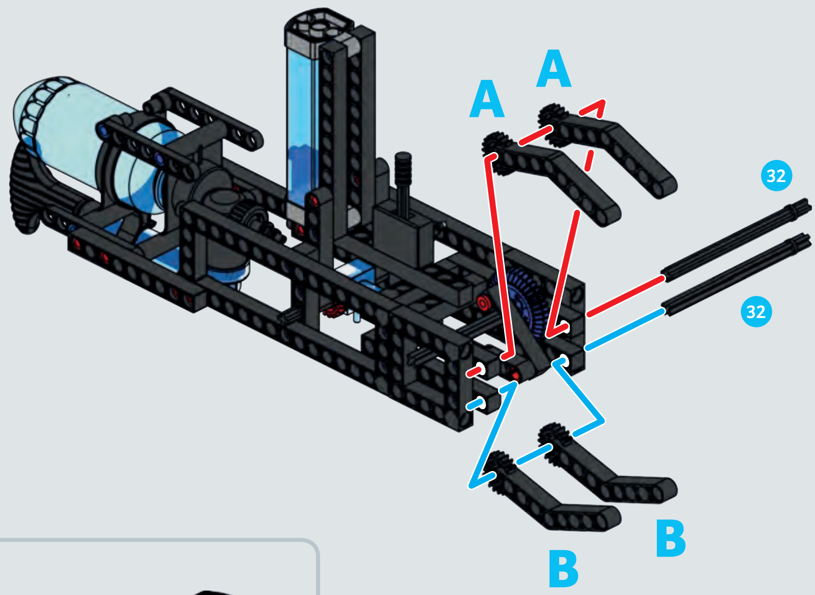

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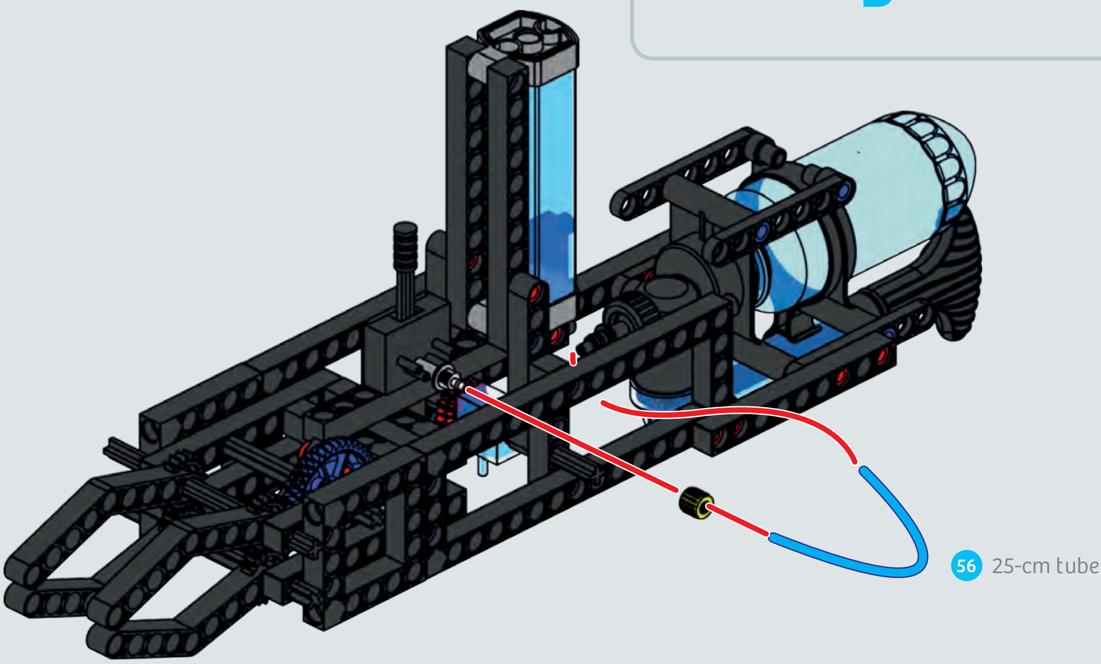

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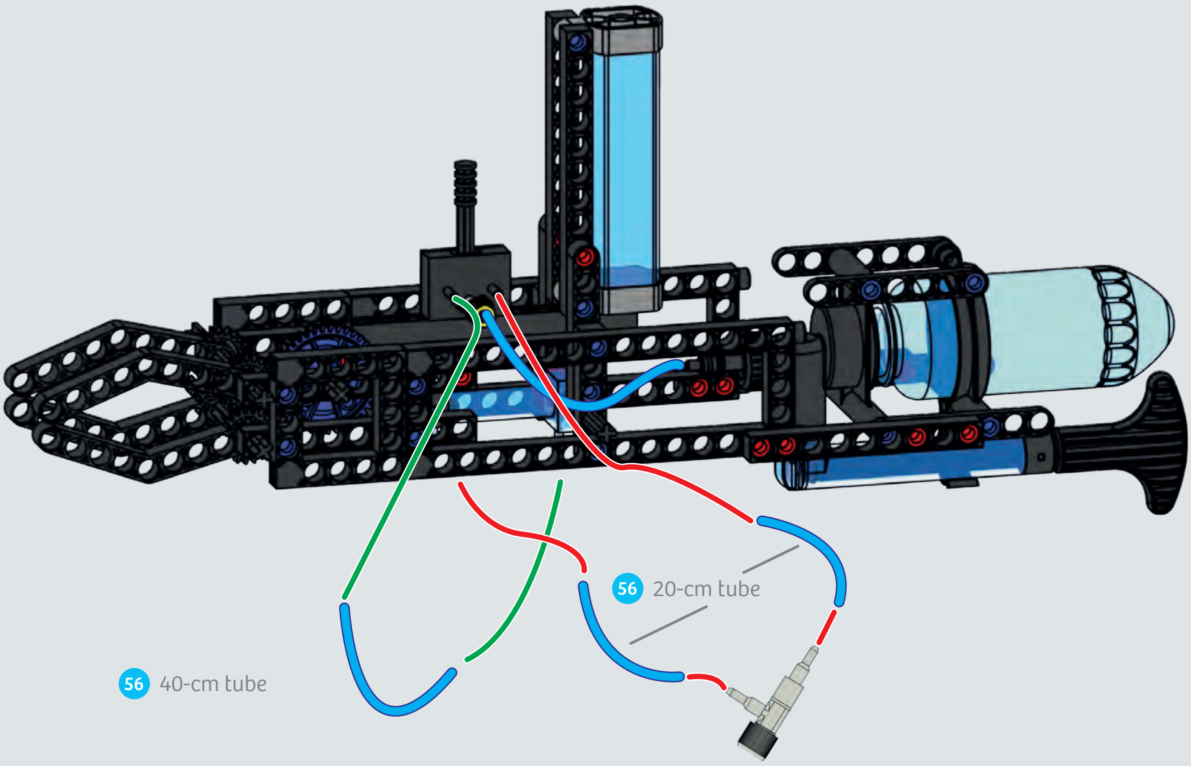
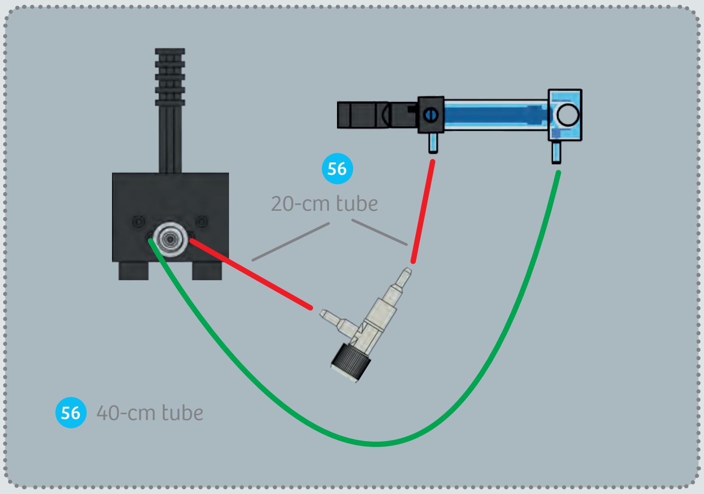
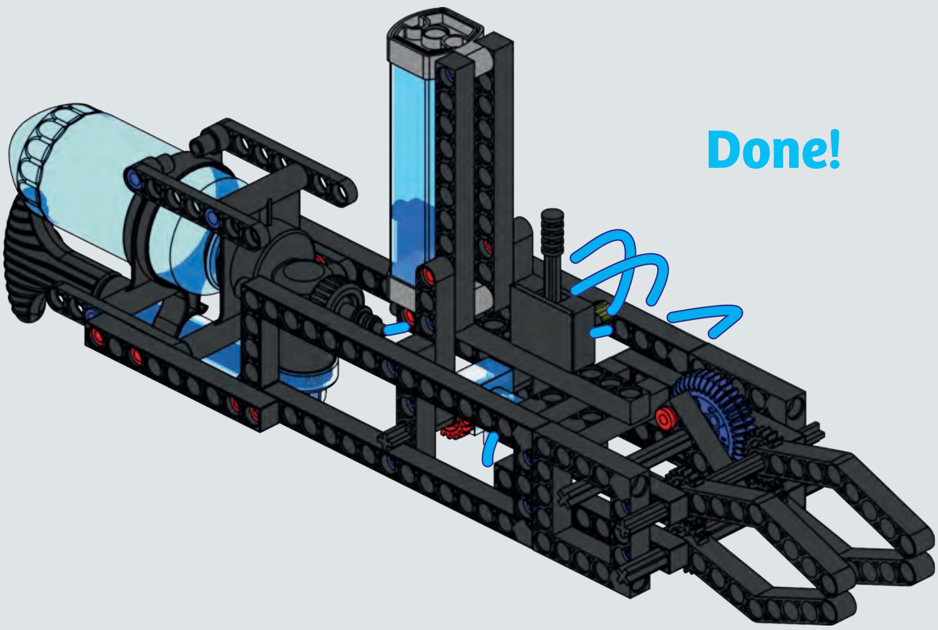
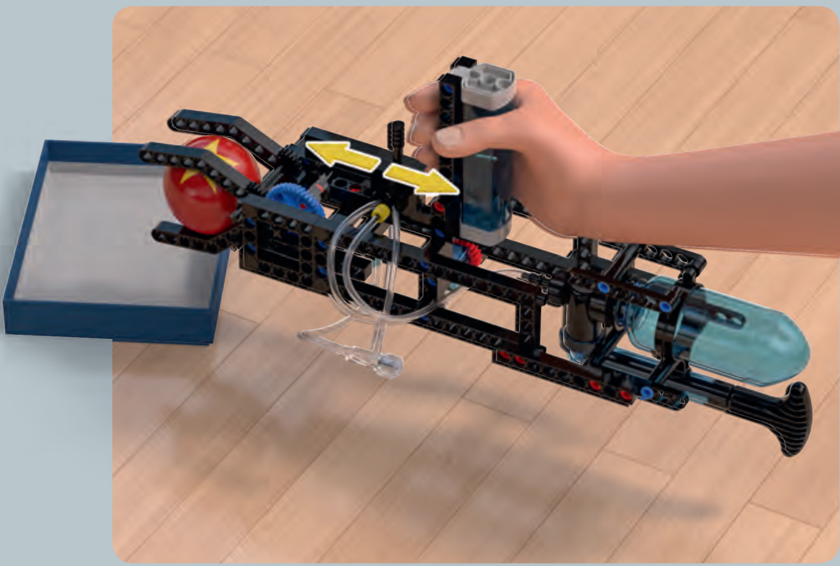






Done!

Robotic arm



YOU WILL NEED

› **The assembled robotic arm**
› *Various small objects for the robotic arm to grasp*

HERE'S HOW

1. Move the lever on the switch to the center position.
2. Pump air into the pressurized air tank (pump between 30 and 50 times).
3. Next, move the lever back and forth.
4. Using the gripper arm, try grasping an object, carrying it a short distance, and then releasing it again at a specific spot

WHAT'S HAPPENING ?

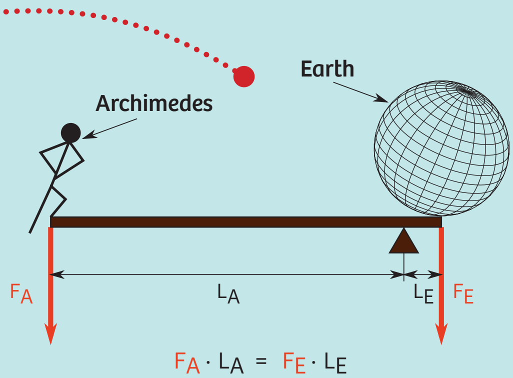
When the air from the pressurized air tank ows through the tube into the cylinder, the piston gets pushed out. A linkage mechanism transfers the force to the robotic arm's gripper device. The principle used here is the lever principle (see the key concept). When the object is released again, the air ows against the piston from the other side, and pushes it in the opposite direction. You can keep playing with the arm like this until all of the excess pressure built up in the pressurized air tank by the pump has been released.

WANT TO FIND OUT MORE?

If you rotate the gripper device on the robotic arm, so that its arms curve outward, you can transform your robotic arm into a rescue spreader. A rescue spreader tool is used by the fi e services in cases where the door of a car could no longer be opened as a result of an accident. In this case, the rescue spreader is used to physically bend open the door. You can experiment with this on a smaller scale by using your spreader to open a drawer or door that's been left slightly ajar.

KEY CONCEPT: LEVER PRINCIPLE

The origins of the **lever principle** can be traced back to the Greek mathematical scholar Archimedes. He is credited with saying, "Give me a lever and a place to stand, and I will move the entire Earth." We're all familiar with the classic seesaw situation in which a lighter child sittin at one end of a **seesaw** is able to lift a heavier child at the other end simply by sitting further back on their side This is because force times the length of the lever arm must be equal on both sides. This is referred to as the conservation of angular momentum.



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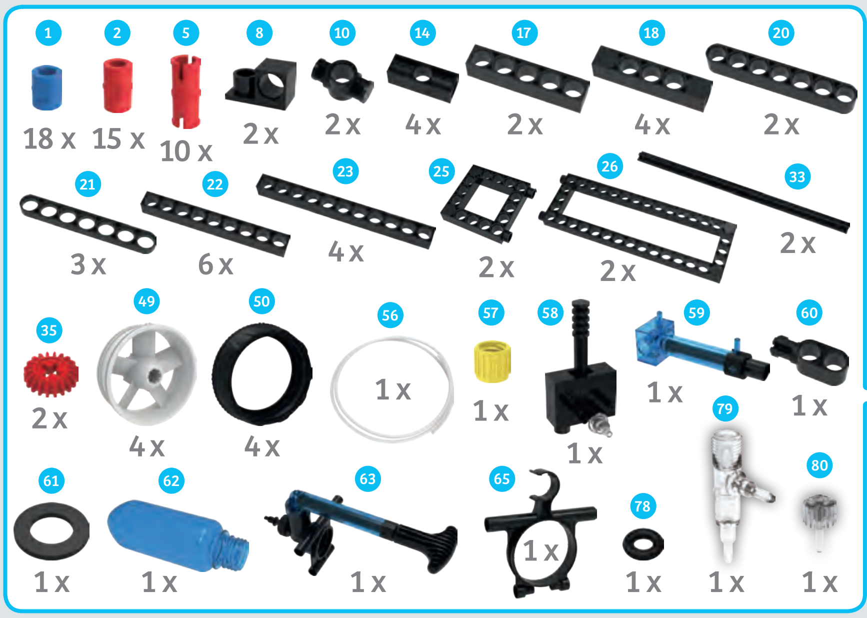

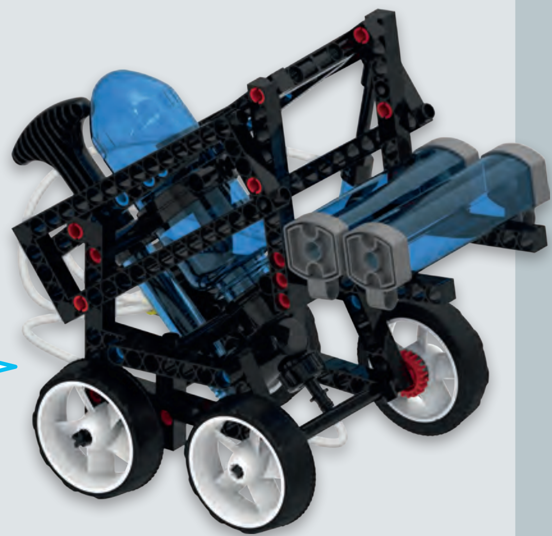

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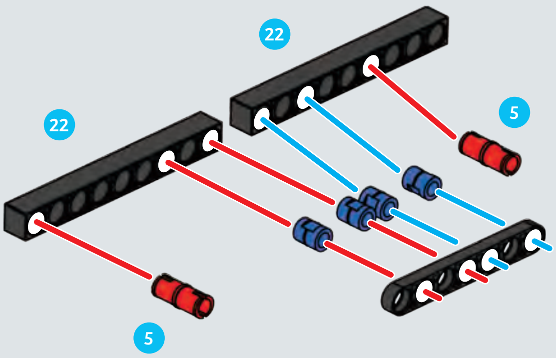

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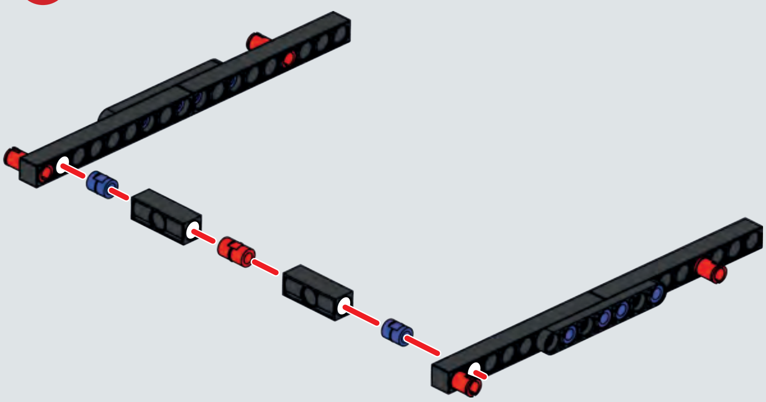

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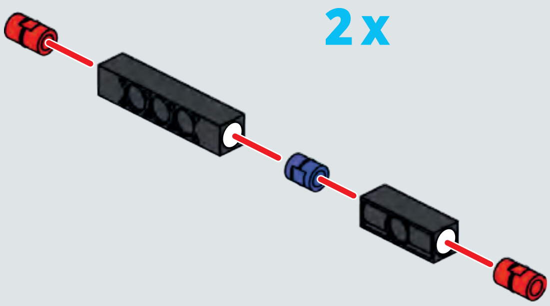

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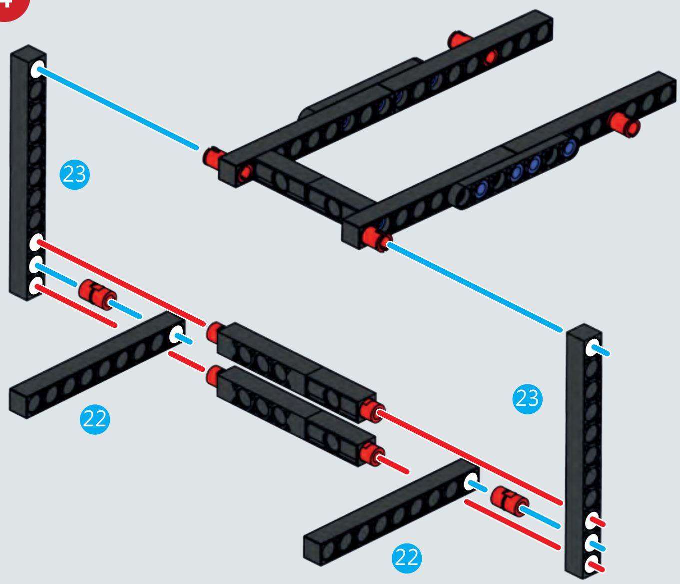

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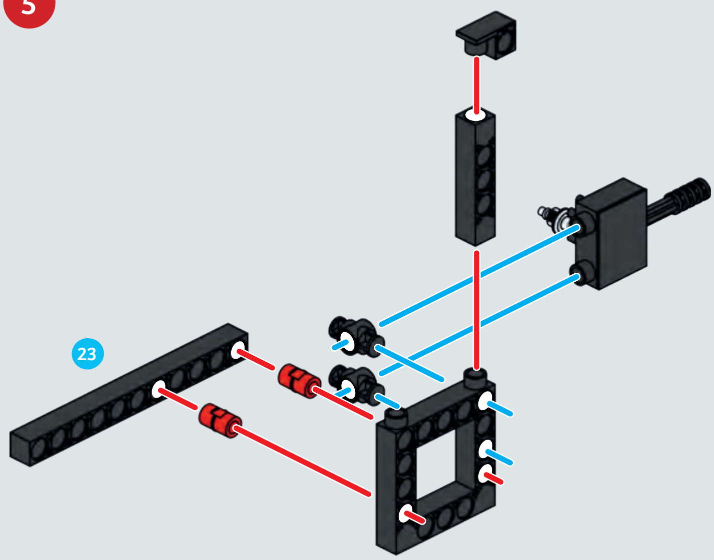

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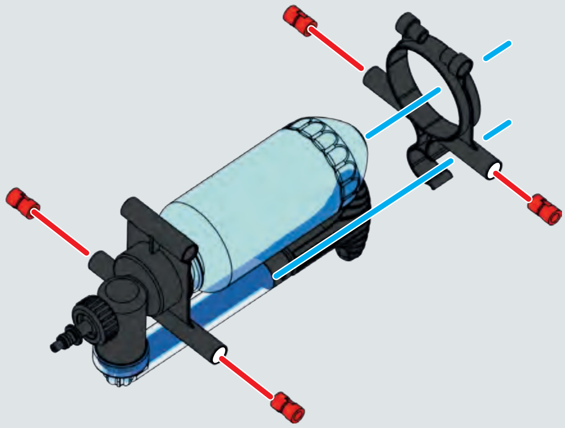

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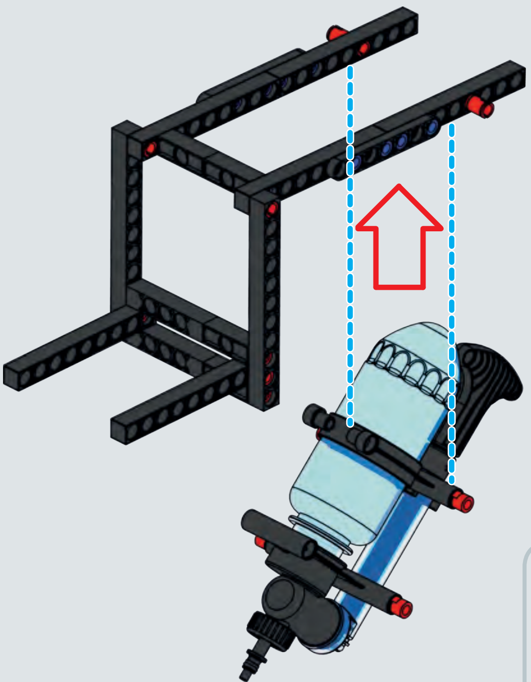

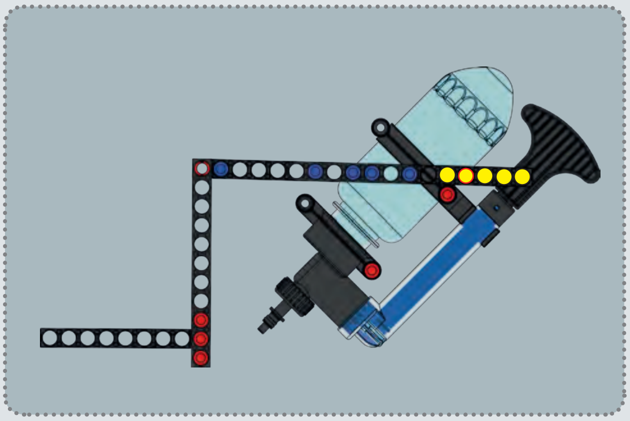

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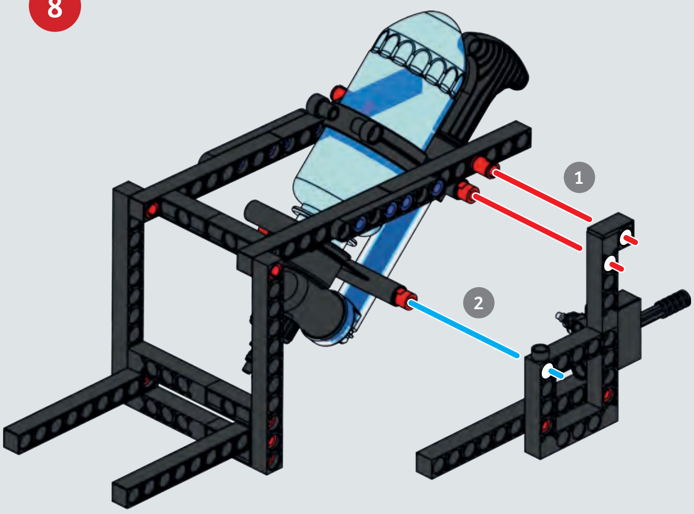

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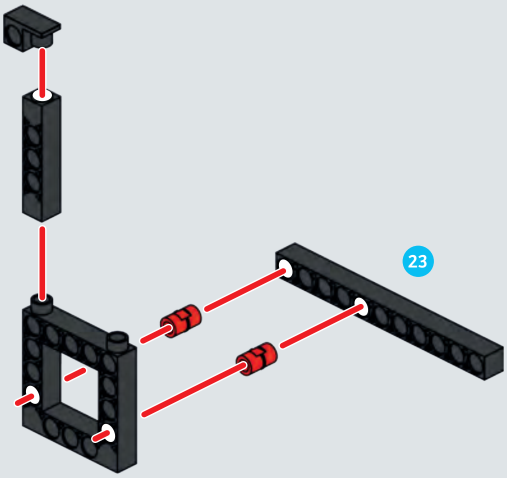

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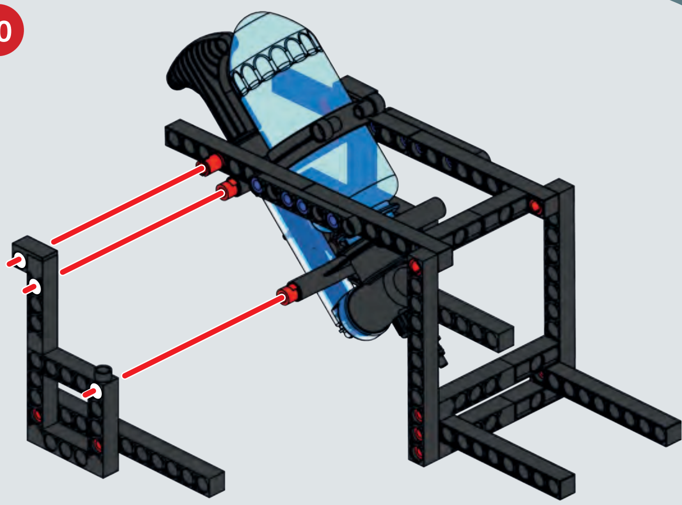

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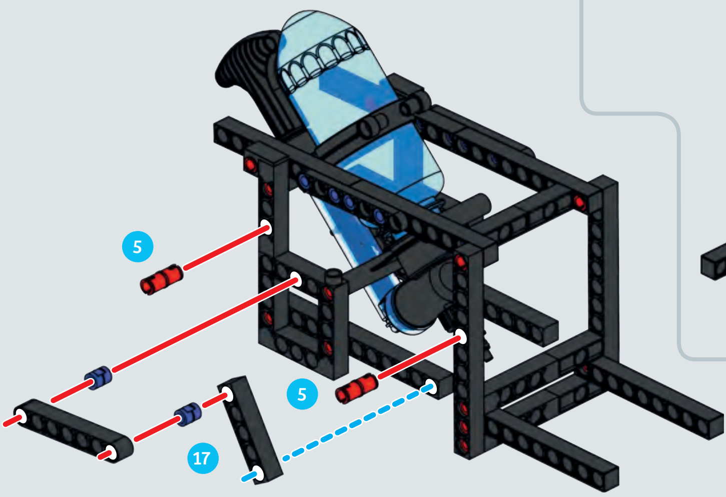

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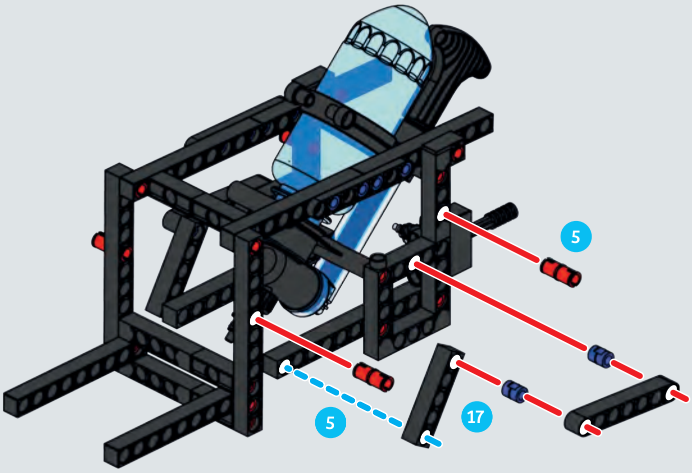

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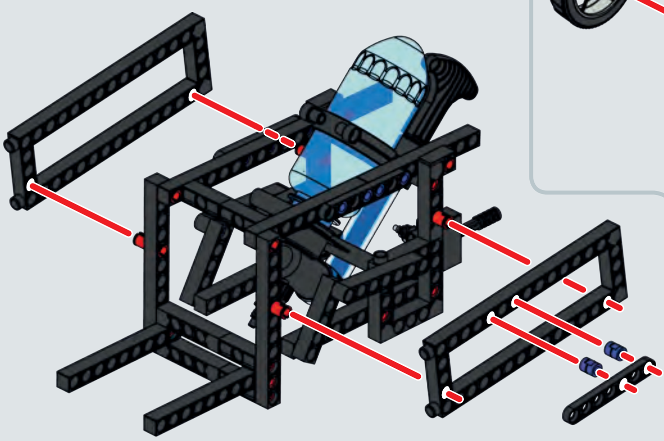

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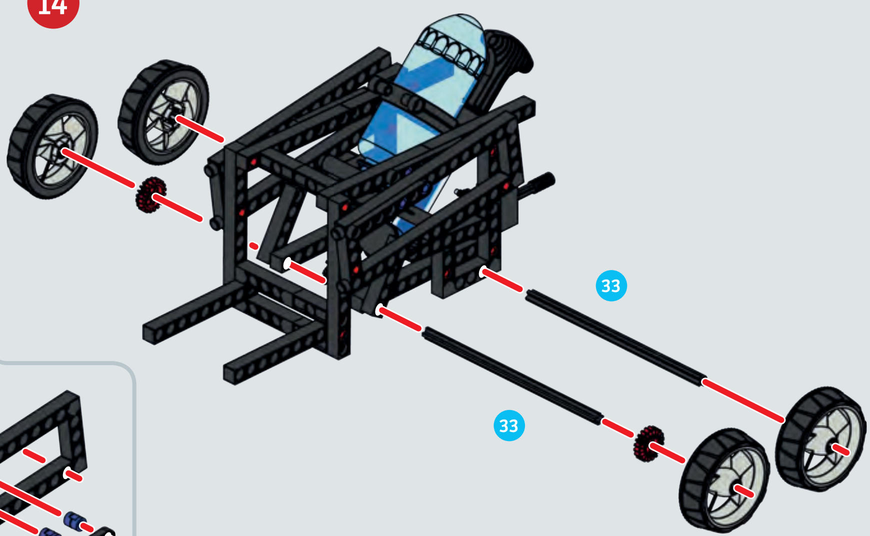

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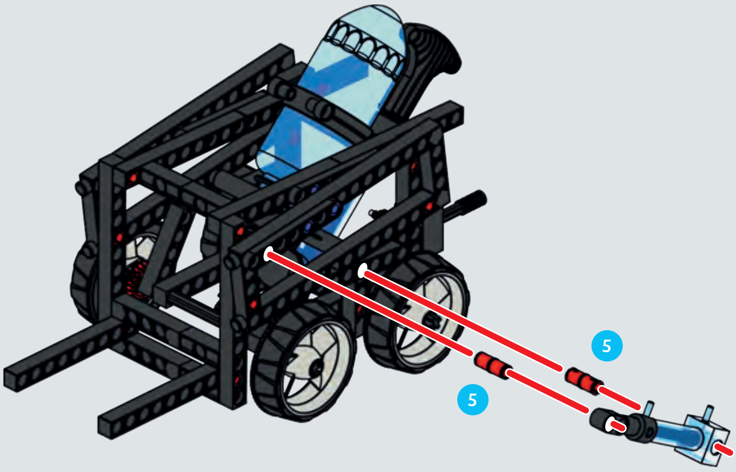

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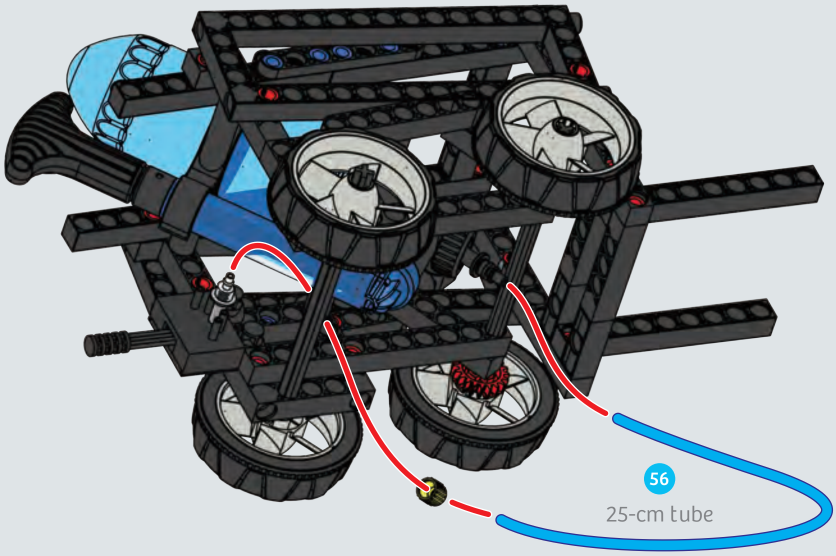

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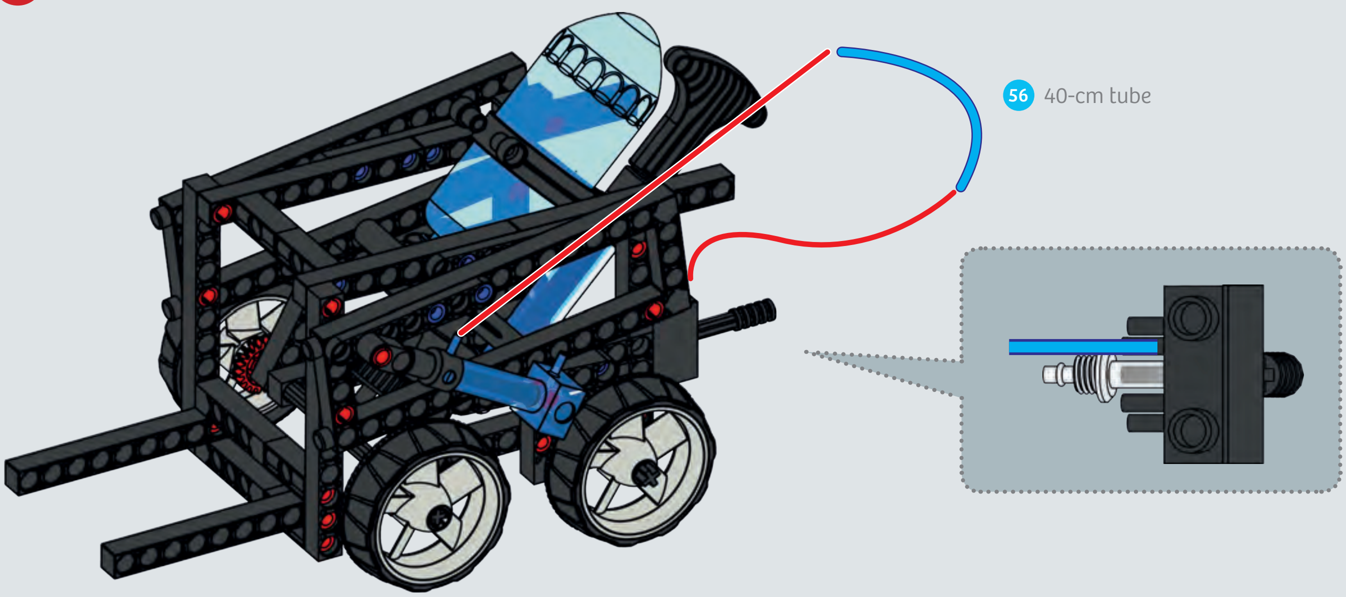

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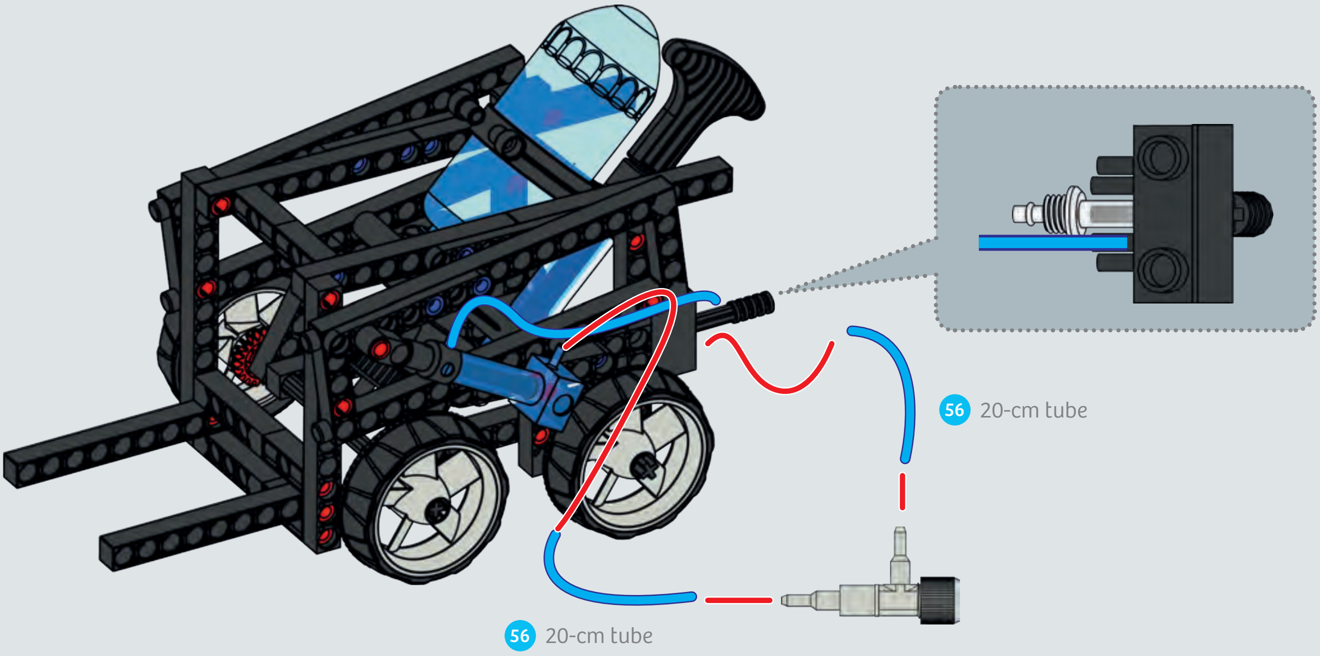

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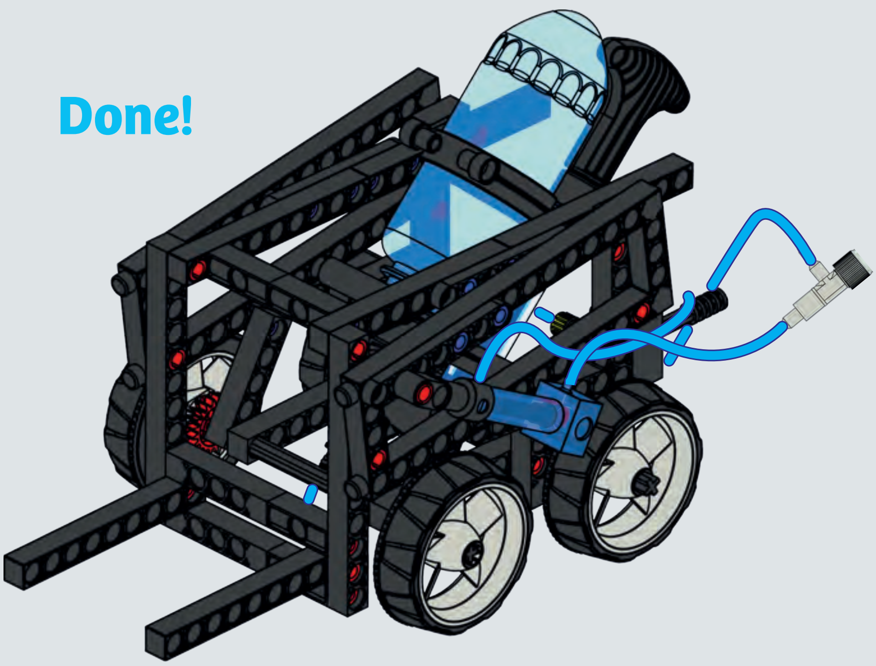
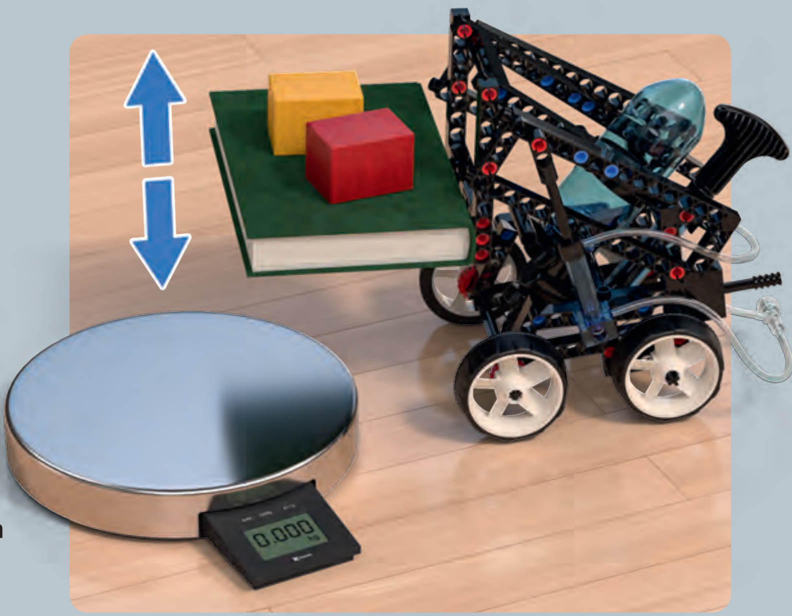


Forklift



YOU WILL NEED

- **The assembled forklift**
- *Various objects that can be placed on the forks of the forklift (such as small books, toys, etc.)*
- *Weighing scales*

HERE'S HOW

1. Move the lever on the switch to the center position.
2. Pump air into the pressurized air tank (pump between 30 and 50 times).
3. Next move the lever back and forth — the forks of the forklift will move up and down.
4. Place various objects onto the forks of the forklift, lift them, and then lower them again.
5. Using the kitchen scales, weigh each of the individual objects, place them onto the forks one by one, and then raise the forks. At what object weight is the pneumatic mechanism no longer able to raise the forks on the forklift?
6. Now experiment to see if you can determine the heaviest weight that the forklift can lift before it topples forward.

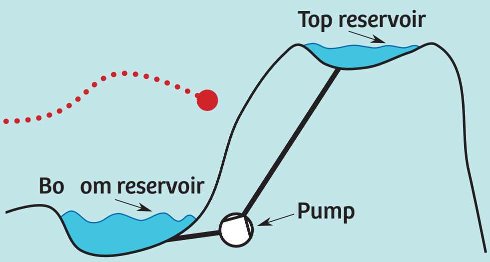
WHAT'S HAPPENING?

When air from the pressurized air tank flows through the tube into the cylinder, the piston is pushed out. The force is transferred to the forks of the forklift via the linkage. The mechanism here is designed to ensure that the forks remain horizontal. This is important because otherwise your objects would fall off. However, if the load is too big or positioned too far forward on the forks, the counterweight of the forklift itself will no longer be sufficient to maintain balance, so the forklift topples over.

During the lifting process, the energy stored in the compressed air is transformed into kinetic energy, which is what raises the load. The load therefore receives potential energy. It's not until the forks are lowered again that this potential energy is released and converted into kinetic energy.

KEY CONCEPT: PUMPED STORAGE STATION

Just as energy is stored in the raised load of a forklift, there is also energy stored in the raised reservoirs used by **pumped storage plants.** A pumped storage plant consists of two water reservoirs positioned at different heights and connected by means of a pipe. Whenever there is an excess of electric energy, water is pumped from the bottom reservoir to the top reservoir, during which the potential energy of the water increases. When electric energy is needed at a later time, the water flows back down again and this movement transforms the potential energy back into kinetic energy, and then into electric energy.



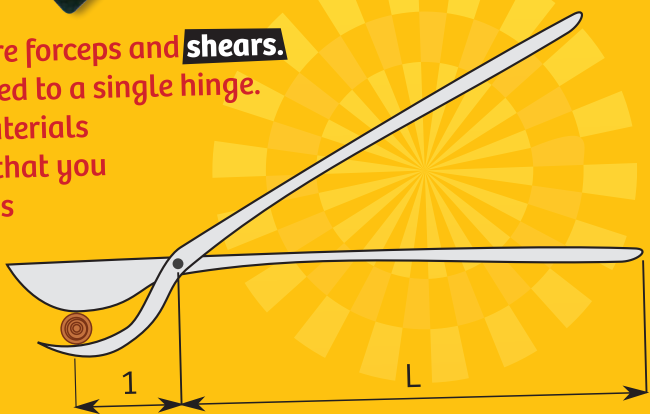
CHECK IT OUT

Pure power

Whenever you have to carry a **heavy load,** such as a full bag of groceries, for example, it's always important to hold the bag close to your body. This causes less pressure on the spine and the bag will feel less heavy.

LEVER PRINCIPLE

A few common examples of the lever principle are forceps and **shears.** Hinged shears consist of two lever arms connected to a single hinge. With shears that are used to cut very diffic t materials (such as metal sheets or branches), the handles that you grip are much longer than the actual blades. This allows the force to be transferred more e ectively, which in turn makes it easier to cut the material properly.



HARDWORKING HELPERS

In the vast warehouses of online retailers, we're seeing an ever-increasing number of autonomous, electrically operated robots. Controlled by a centralized computer, these robots receive requests to retrieve or store items. They do this using forklifts, but many also use ***hydraulic lifts*** (see page 14) and ***robotic arms*** (see page 23).

CHECK IT OUT

You can use an air pump to ...

... pump air into the tire tubes on your bike. When you do this, you are pushing a piston in the cylinder, and this piston then pushes air through a one-way valve into the tube. This one-way valve ensures that the air does not escape back out of the

tube. After pumping for a while, you'll notice that the **air pump** starts to heat up. This is perfectly normal, as air naturally warms up when compressed.

FROM VERY LITTLE TO VERY LARGE

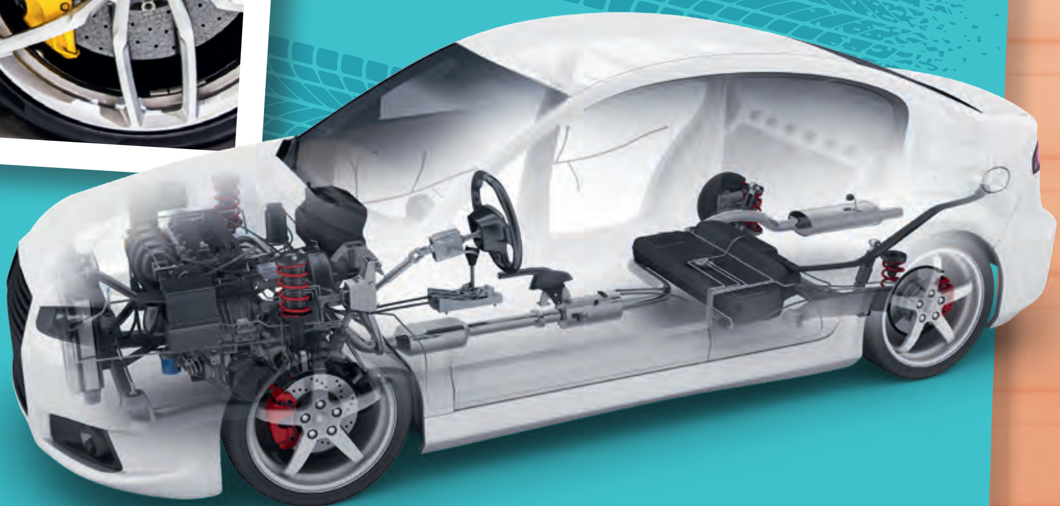
Gears come in every conceivable shape and size. Very tiny gears are used in mechanical watch movements to ensure that the minute hand turns more quickly than the hour hand. On a **bicycle**, the **sprocket** and chain mechanism ensure that the force that is created by turning the pedal cranks is transferred to the back wheels. It's possible to adjust the gear ratio by changing gears. The gear ratio is the ratio between the rotational speed of the back wheel and the rotational speed of the pedal crank.

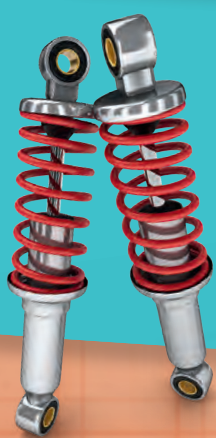
INDUSTRIAL ROBOTS

In modern factories, robots are used to ease the workload of factory workers. They are especially useful in cases where workers are required to carry out very dangerous work or very repetitive menial tasks. These robots are able to grasp, screw, drill, paint, **weld**, and much more.

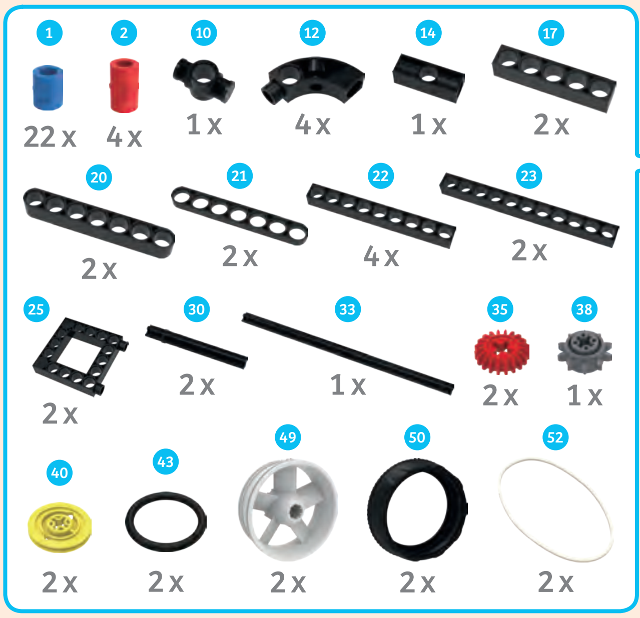
On the Road

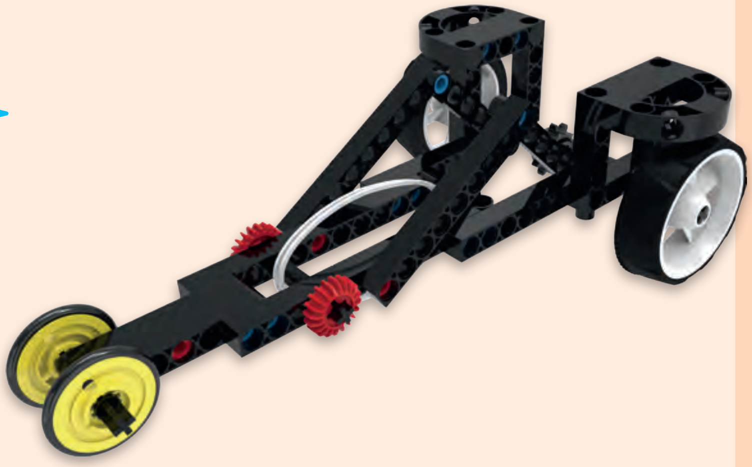
Since its invention in Mesopotamia over 6,000 years ago, the wheel has contributed tremendously to the development of civilization. It allowed our ancestors to transport items and people over long distances by road, much in the same way we do today. In the following experiments, you'll see there's a whole range of exciting things to discover about today's modern wheeled vehicles.





DRAGSTER





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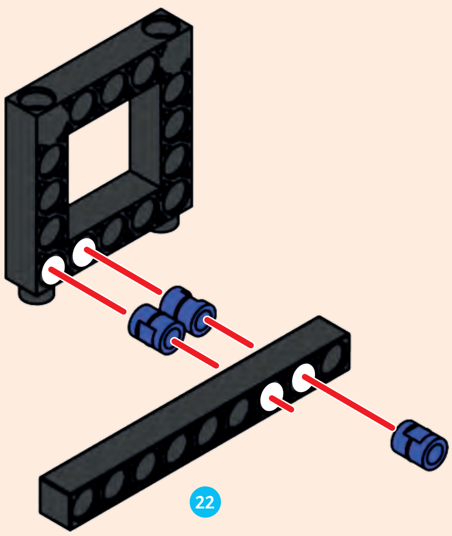

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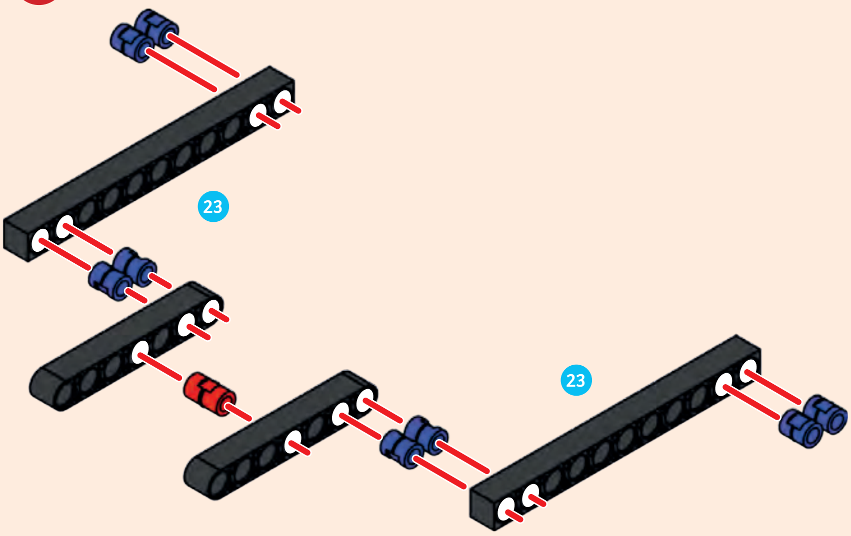

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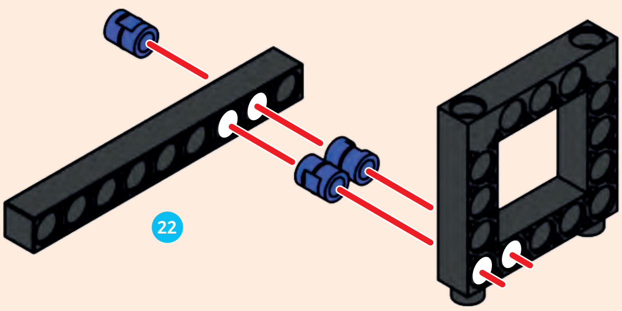

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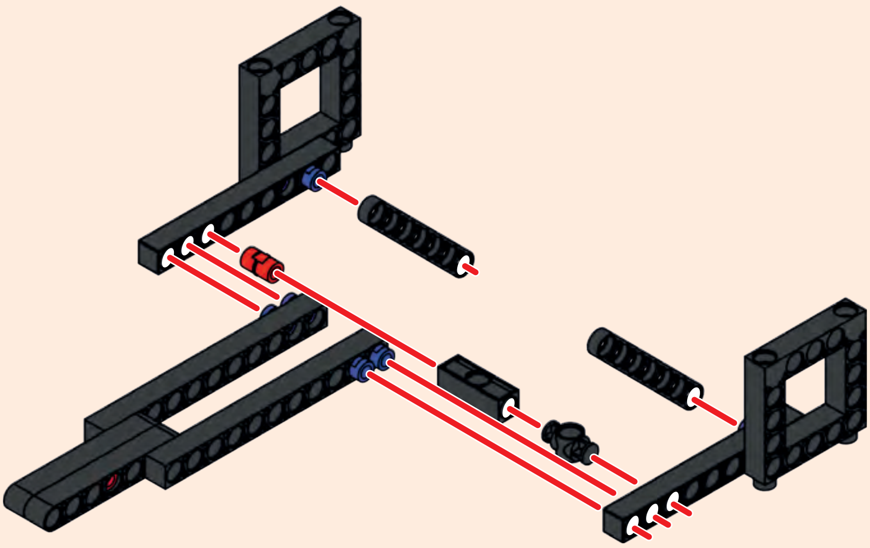

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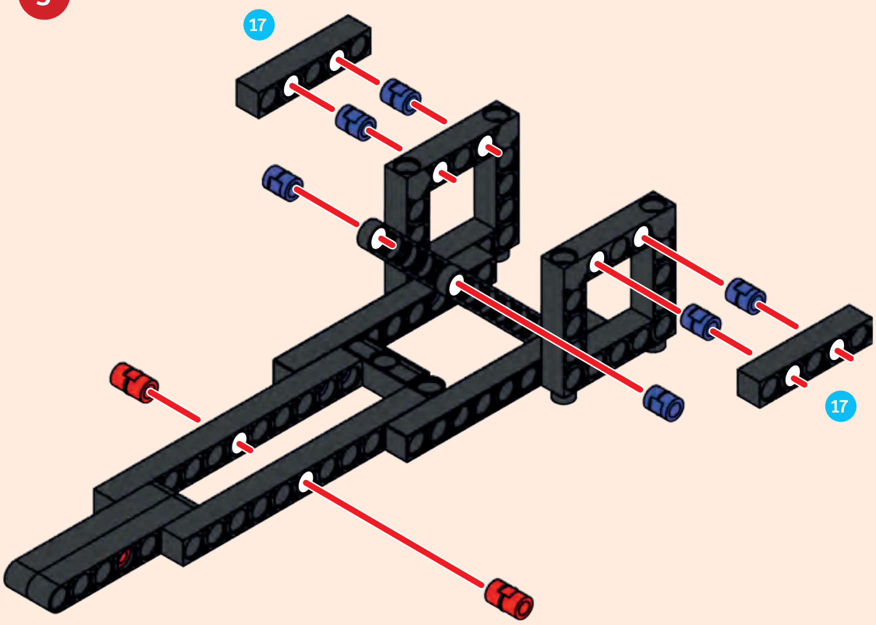

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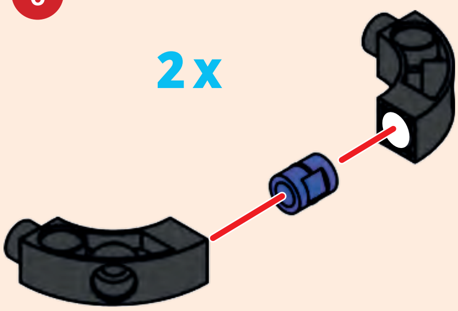

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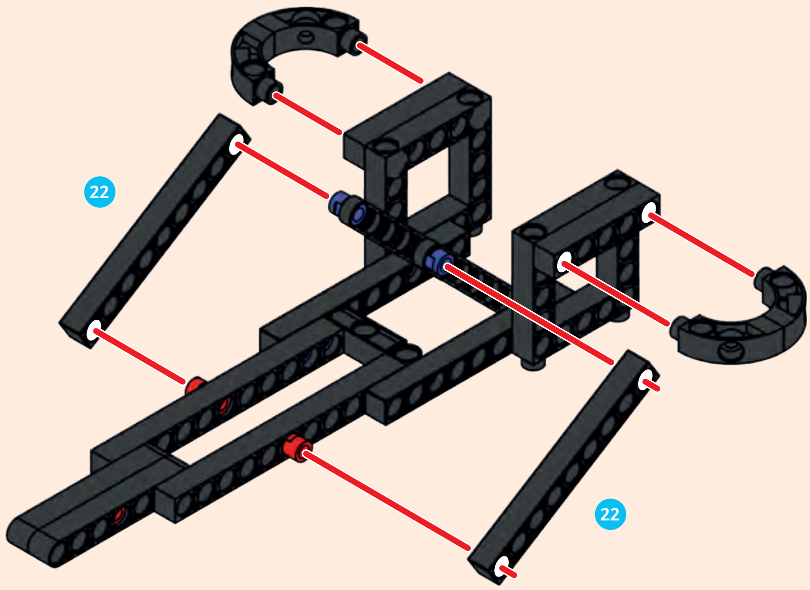

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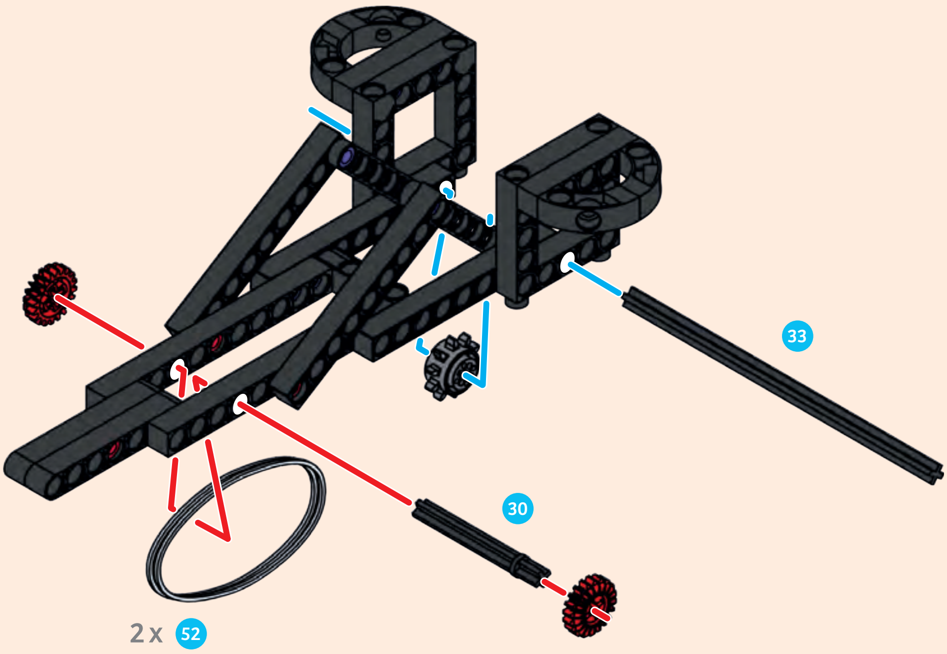

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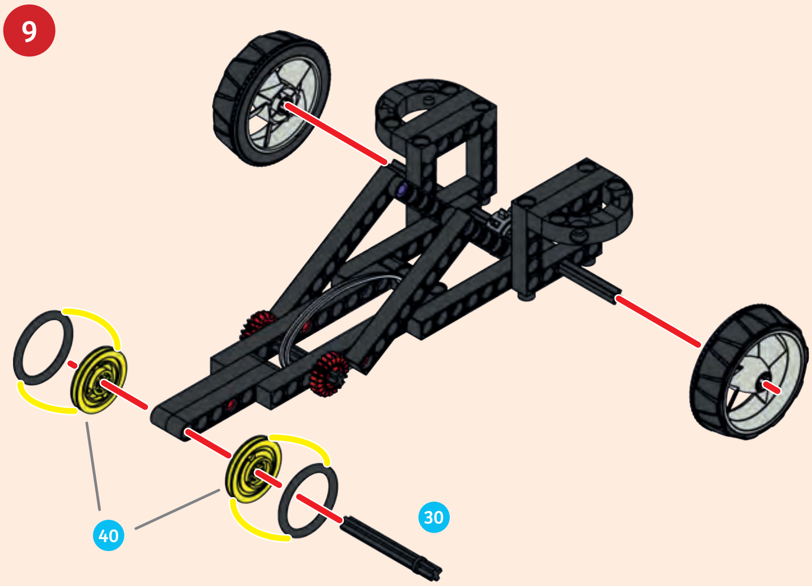

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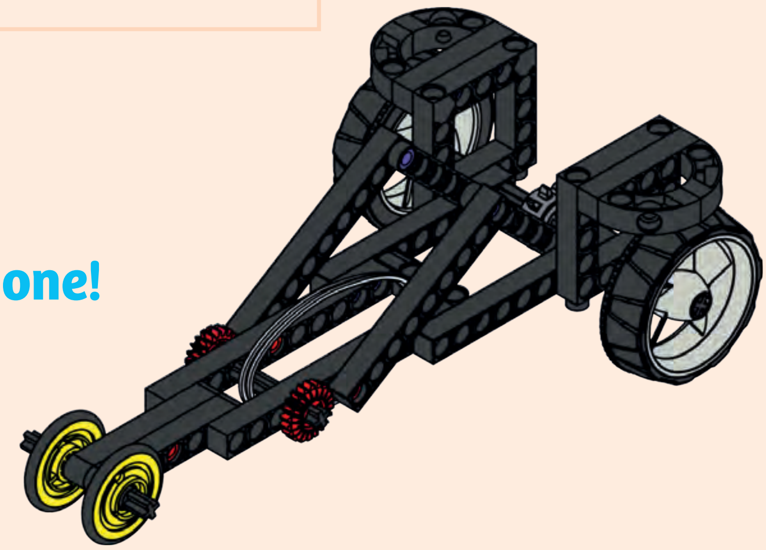
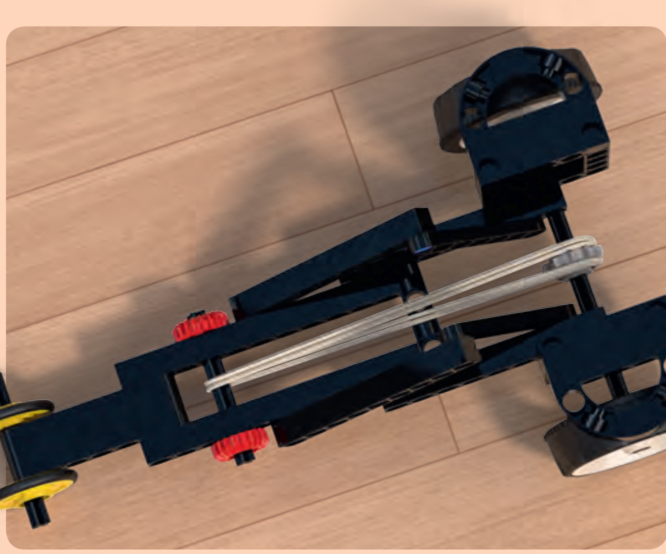


EXPERIMENT 6

Dragster



YOU WILL NEED

› **The assembled dragster**
› *Measuring tape (e.g. the measuring tape you created as part of the surveyor's wheel experiment)*
› *A long corridor or large room with smooth flooring*

HERE'S HOW

1. Draw the rubber bands back and place them over the teeth of the sprocket on the shaft attaching the two back wheels.
2. Now drag the dragster backward until the rubber bands are sufficiently taut. If you're using two rubber bands, this will correspond to a distance of roughly 1 to 1.5 meters.
3. Keep a firm grip on the back wheels so that they don't spin.
4. Line up the dragster so that the path ahead is clear of obstacles.
5. Now let go of the dragster.
6. How far did it go? Measure the distance with your measuring tape.
7. Repeat the experiment again, but this time with just one rubber band.
8. How far will it go if you make the dragster go backward with the large wheels to the front this time? In this case, you'll need to place the rubber bands around the sprocket from below.

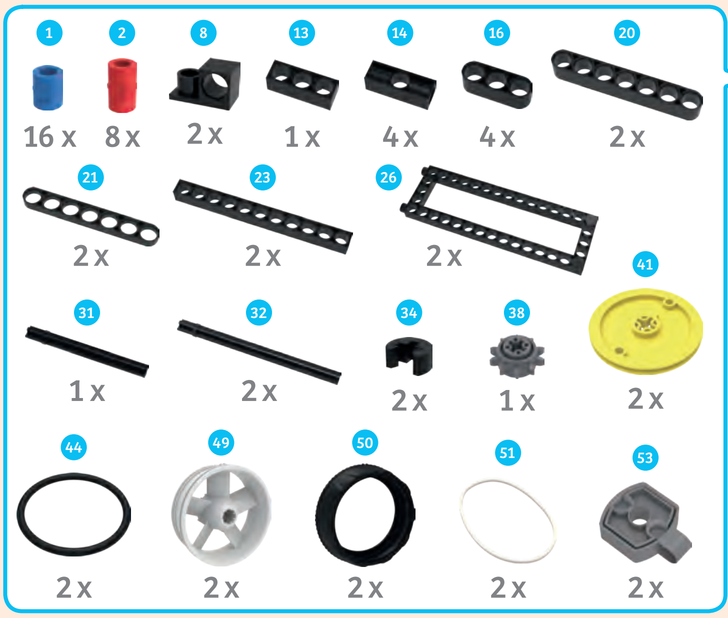
DID YOU KNOW?

When it comes to sports cars and racing cars, fast acceleration is critical. This is why they have rear-wheel drive. However, when taking a tight bend, they can sometimes go into a spin. This is because the back wheels are driving the car, so even though the driver has used the steering wheel to turn the front wheels, the back wheels are continuing straight on. If you're not expecting something like this to happen, it can get pretty dangerous pretty quickly.

WHAT'S HAPPENING?

The dragster's rubber band motor is driving the back wheels. This is referred to as rear-wheel drive. The tauter the rubber bands are stretched, the faster the dragster will accelerate. It will therefore travel faster and may even cover a longer distance. If you allow the dragster to travel backward, so that it's in front-wheel mode, you'll notice that the larger wheels have a tendency to spin. This happens because there's less force transferred to the surface of the floor and the dragster doesn't accelerate as much. With rear-wheel drive, however, acceleration causes the wheels to press harder into the floor because the car is being pushed down from the rear. The wheels therefore spin less and the force is transferred more efficiently.

TRICYCLE



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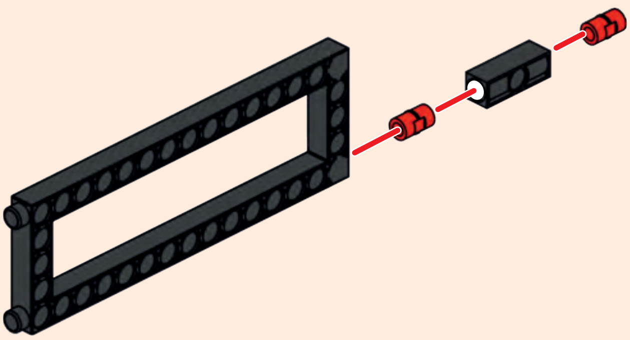

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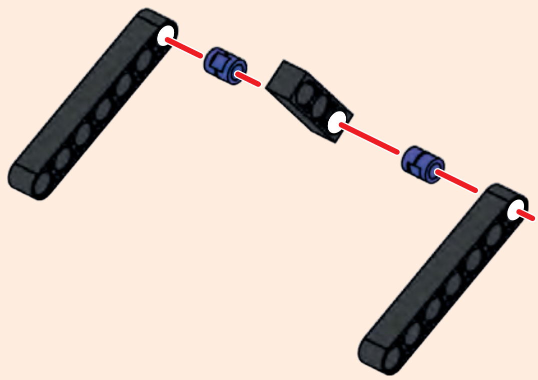

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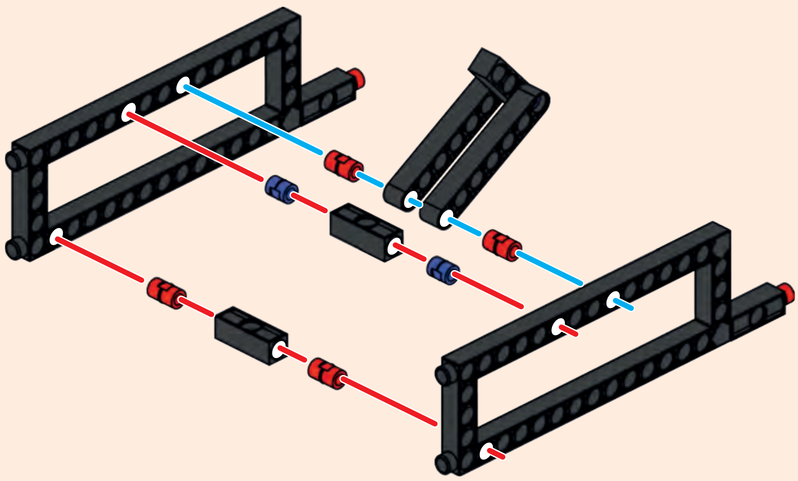

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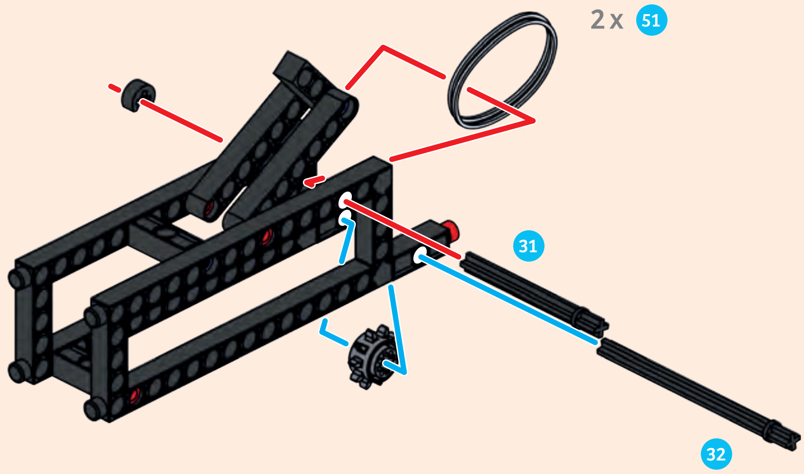

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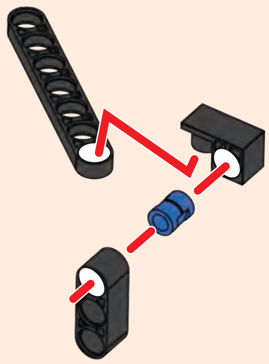

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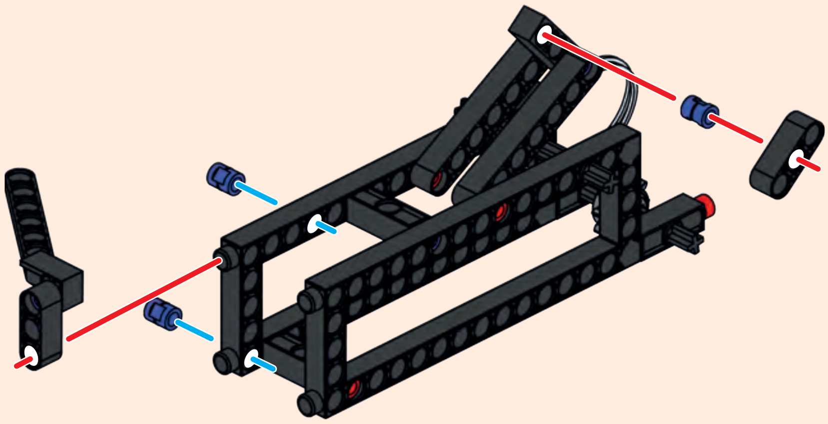

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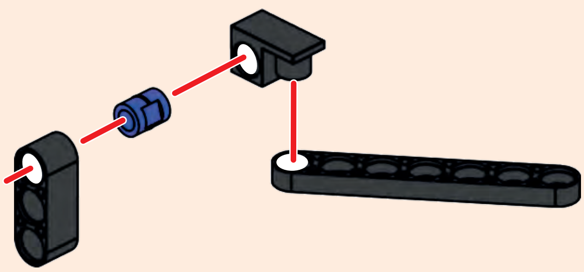

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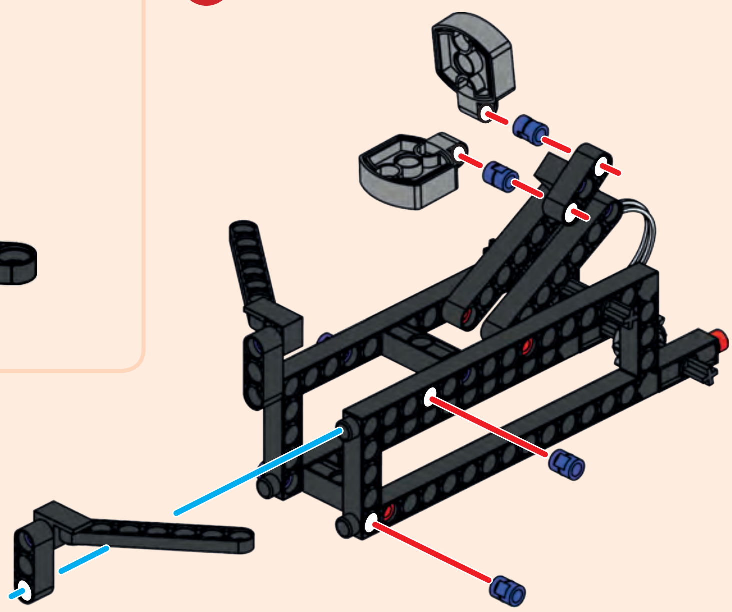

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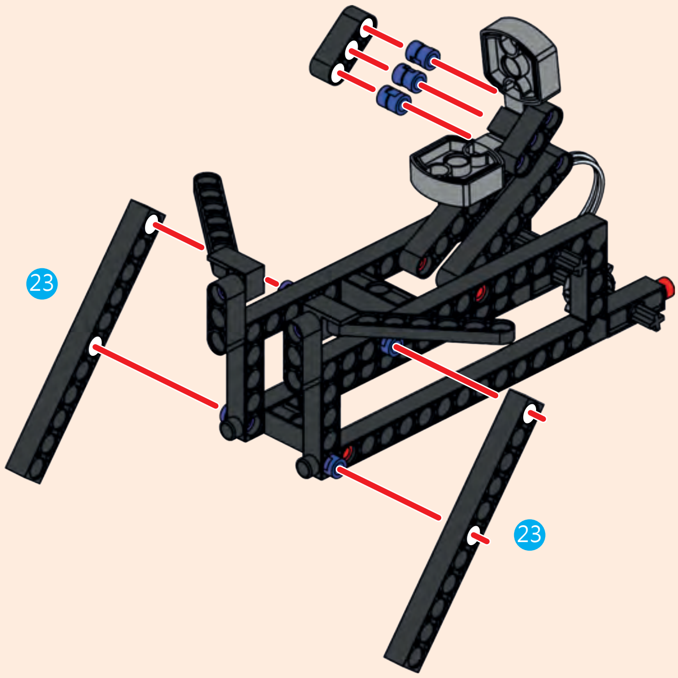

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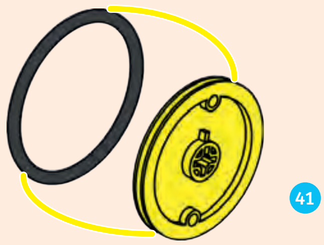

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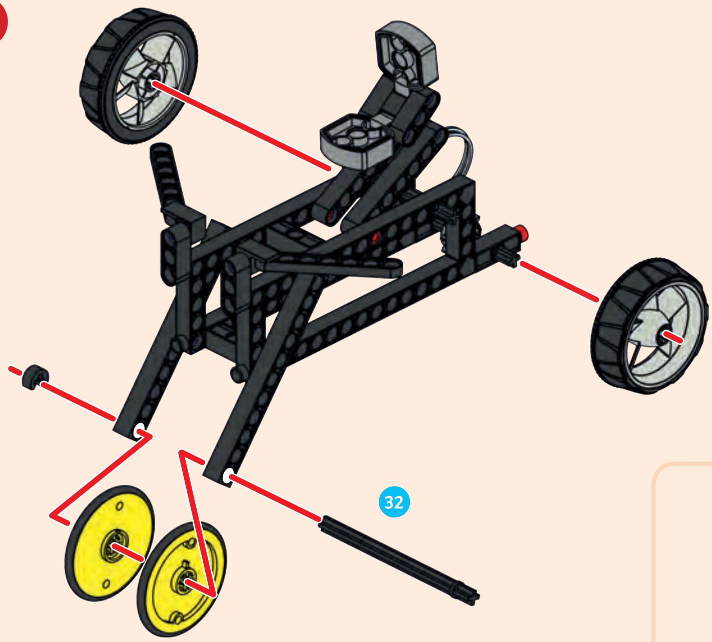


Done!

EXPERIMENT 7

Tricycle

YOU WILL NEED

› **The assembled tricycle**
› *Measuring tape (e.g. the measuring tape you created as part of the surveyor's wheel experiment)*
› *A long board and some books to lay the board on at an angle*

HERE'S HOW

1. Draw the rubber bands back and place them over and around the teeth of the sprocket on the back-wheel shaft.
2. Now drag the tricycle backward until the rubber bands are sufficie ly taut. If you're using two rubber bands, this will correspond to a distance of roughly 1 to 1.5 meters.
3. Keep a firm grip on the back wh els so that they don't spin.
4. Line up the tricycle so that the path ahead is clear of obstacles.
5. Now release the tricycle.
6. How far did it go? Measure the distance with your measuring tape.
7. Get your tricycle ready again and this time let it travel up and down the slope. How far did it go this time?
8. What happens when the tricycle is driven by its front wheels, i.e. in front-wheel-drive mode? In this case, you'll need to place the rubber bands around the sprocket from below.

WHAT'S HAPPENING?

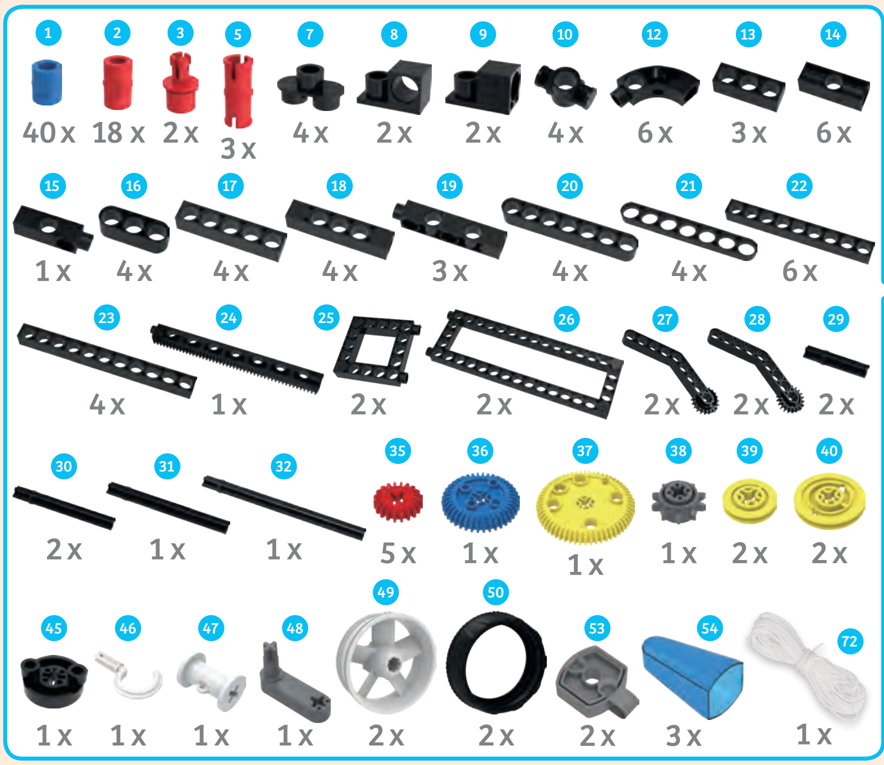
The tricycle functions in the same way as your dragster did in the previous experiment. However, the tricycle's center of gravity is a lot higher. This means that the wheels turn more easily in front-wheel drive.

After a few test runs, you'll notice that when traveling in an upward direction, the tricycle covers less distance than it does when traveling in downward direction. This can be explained by a principle of physics — the principle of conservation of energy. When you stretch the rubber bands, you are storing elastic energy. This is then converted into kinetic energy. When the tricycle travels down the slope, potential energy is also released, which allows the tricycle to travel farther. When traveling upward, potential energy needs to be applied, which means that the tricycle can't travel as far. The tricycle will keep going until its movement is stopped by friction. During this process, heat is generated, i.e. mechanical energy is converted into thermal energy.

WANT TO FIND OUT MORE?

Which one accelerates faster and travels farther? The dragster or the tricycle? You'll need assembled models of both the dragster and the tricycle and ideally, a helper. Wind up the rubber band motors for both models, then let them race on a at oor surface and also on an inclined plane.

CRANE



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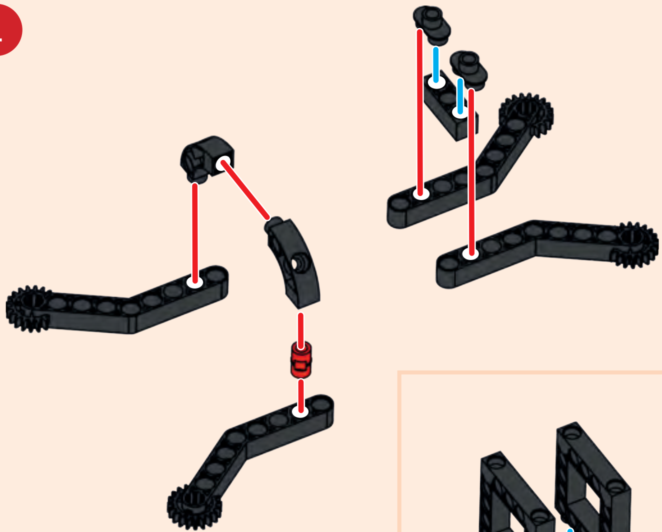

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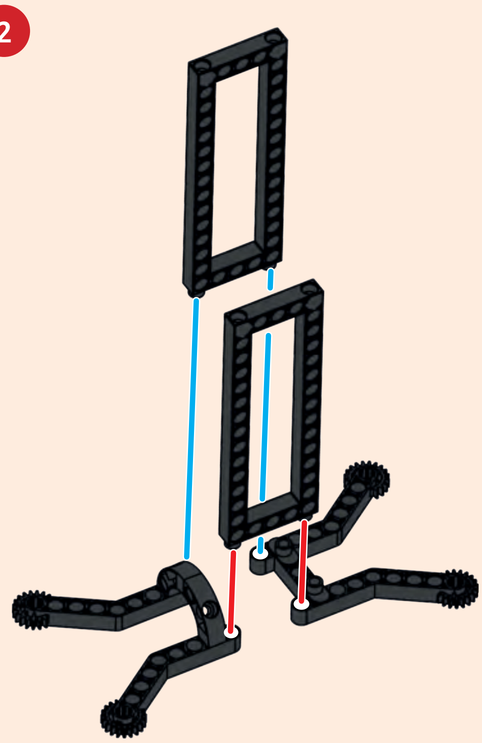

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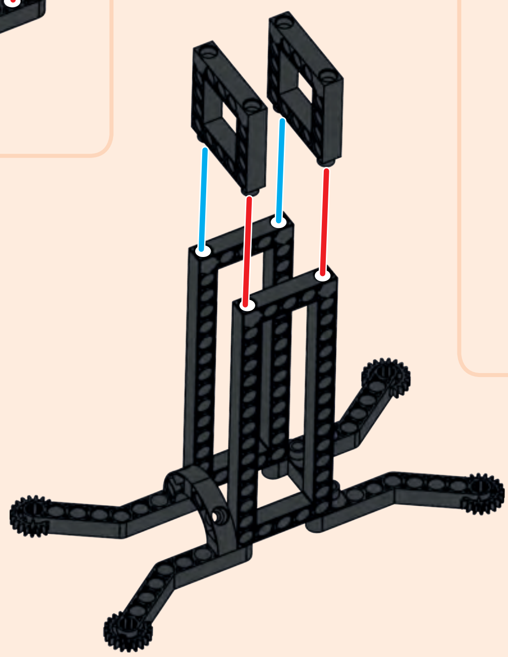

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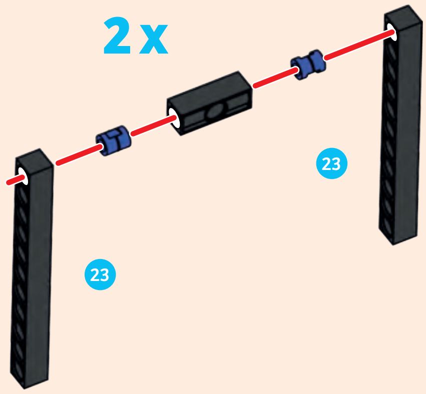

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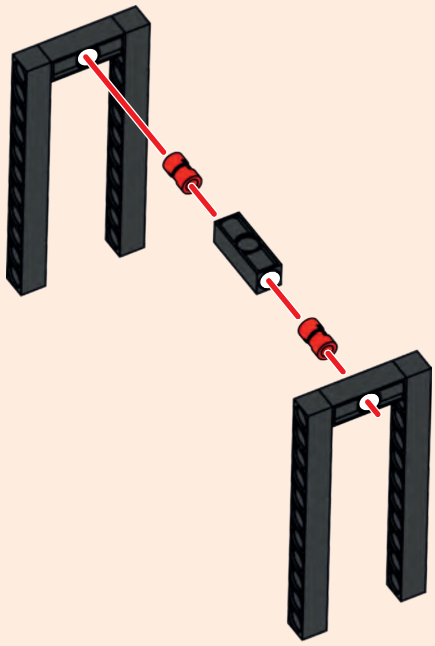

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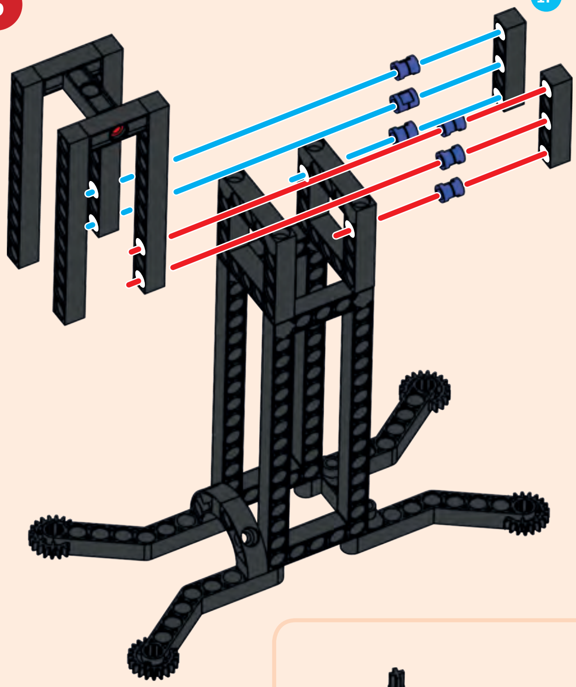

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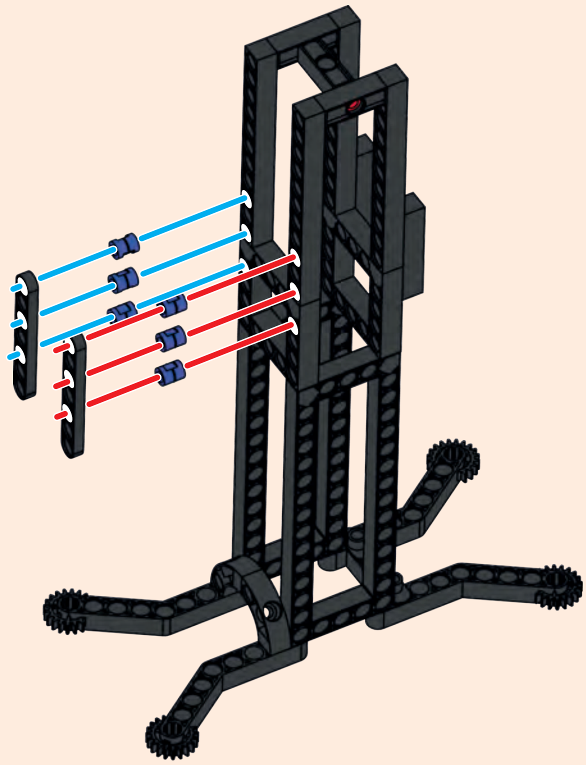

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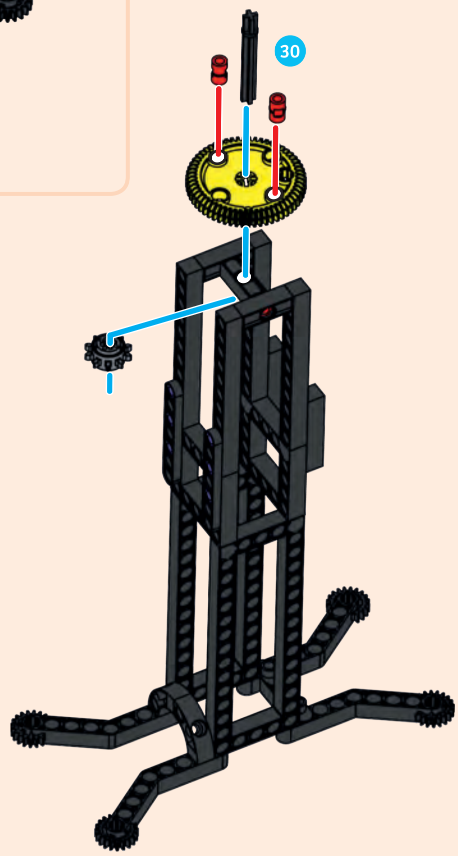

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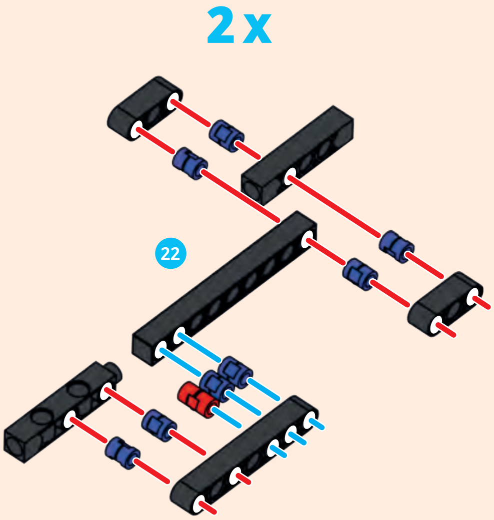

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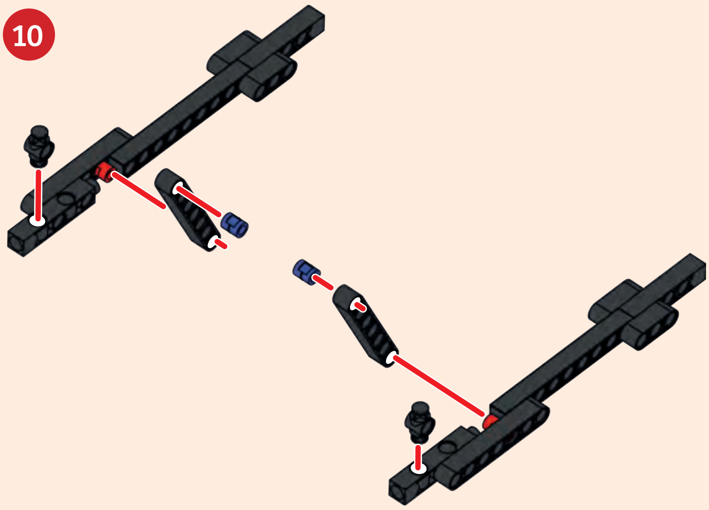

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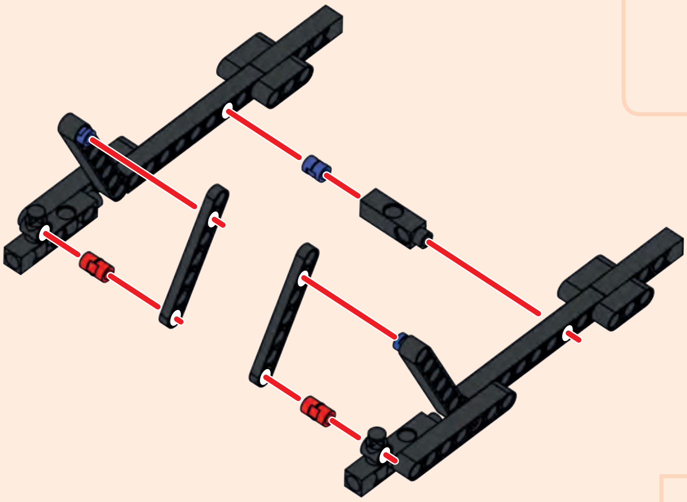

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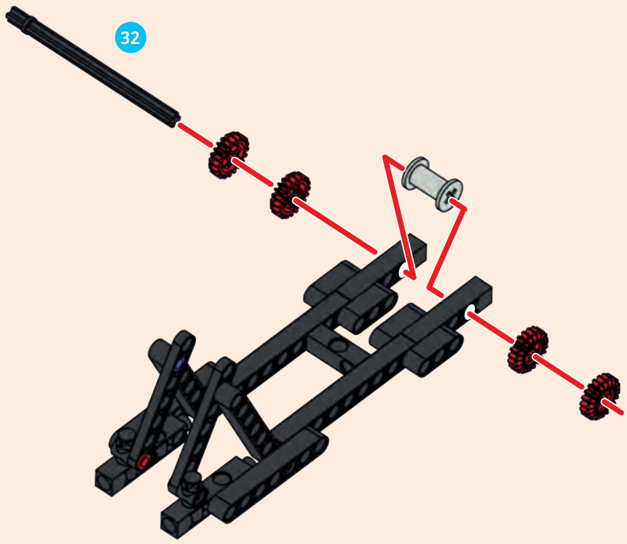

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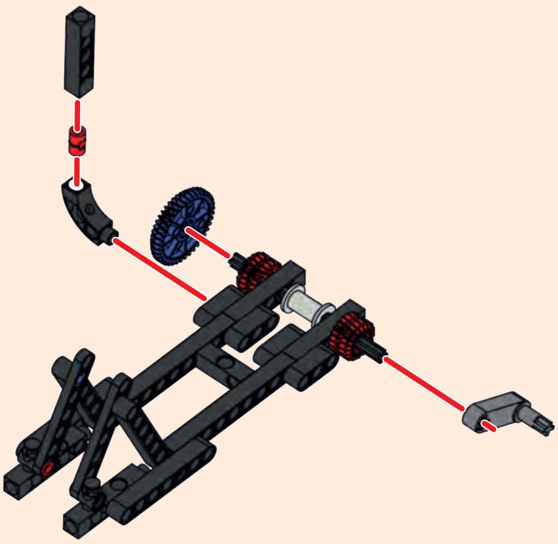

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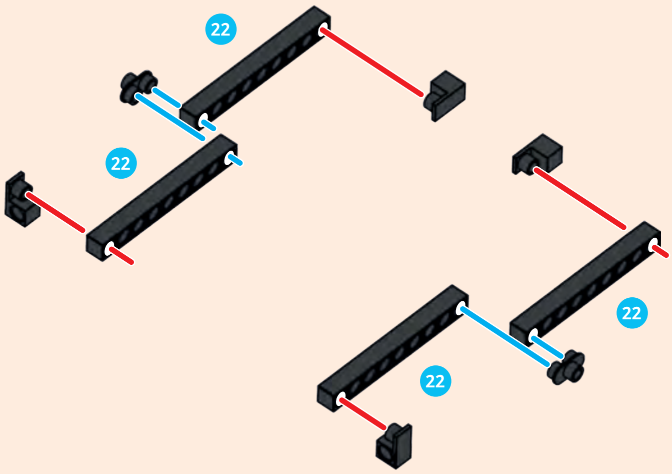

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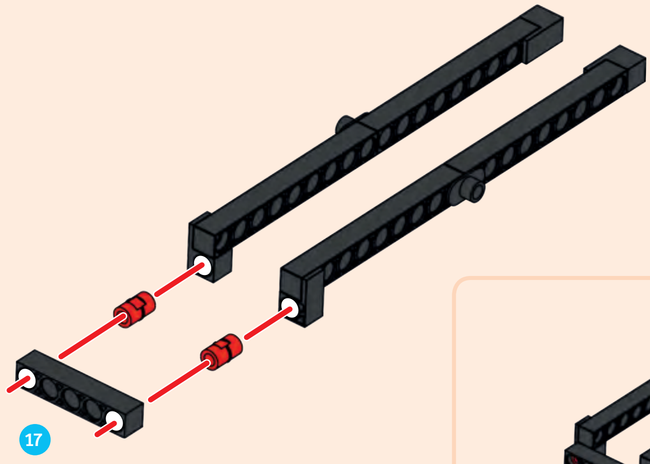

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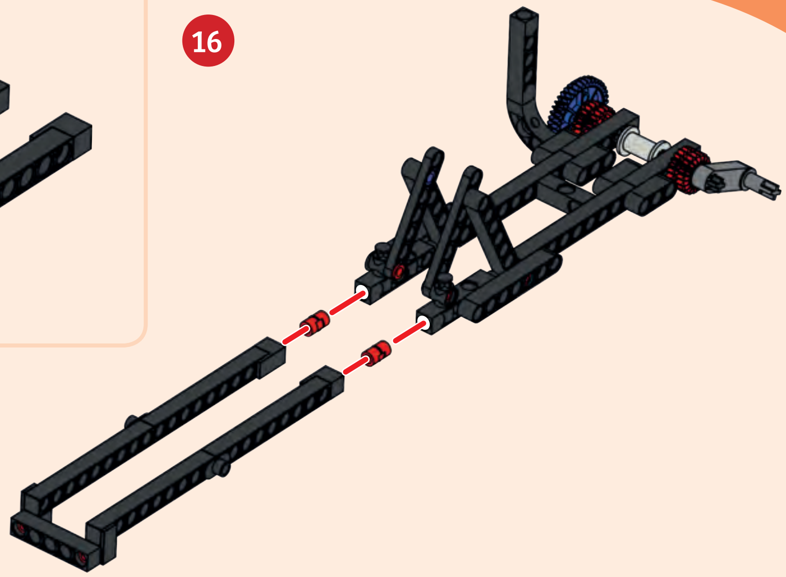

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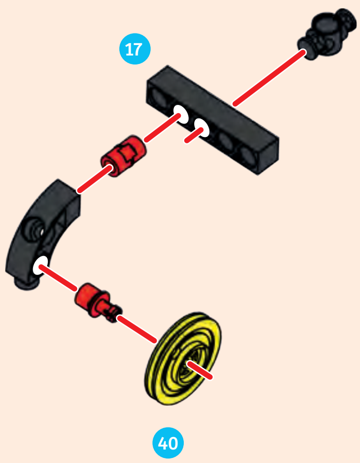

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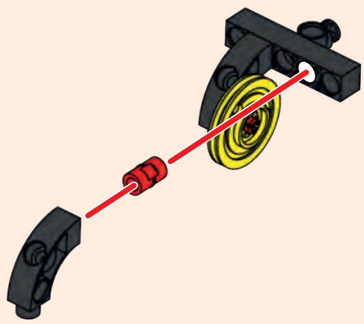

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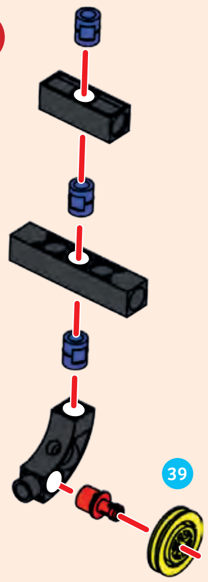

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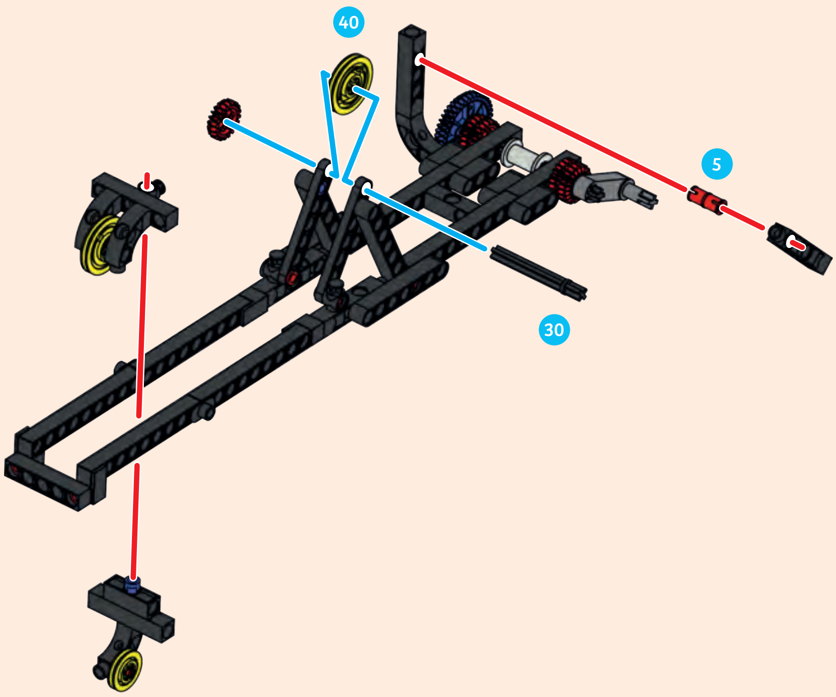

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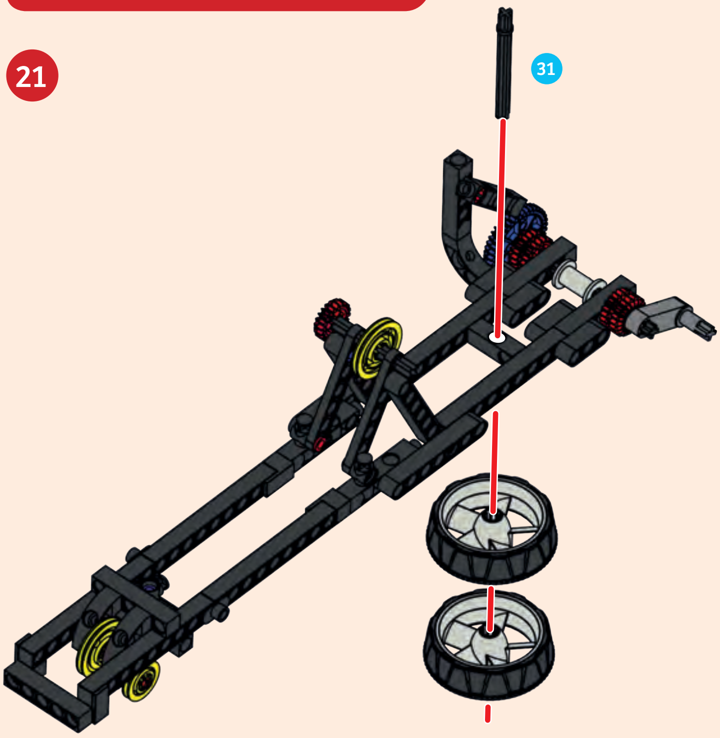

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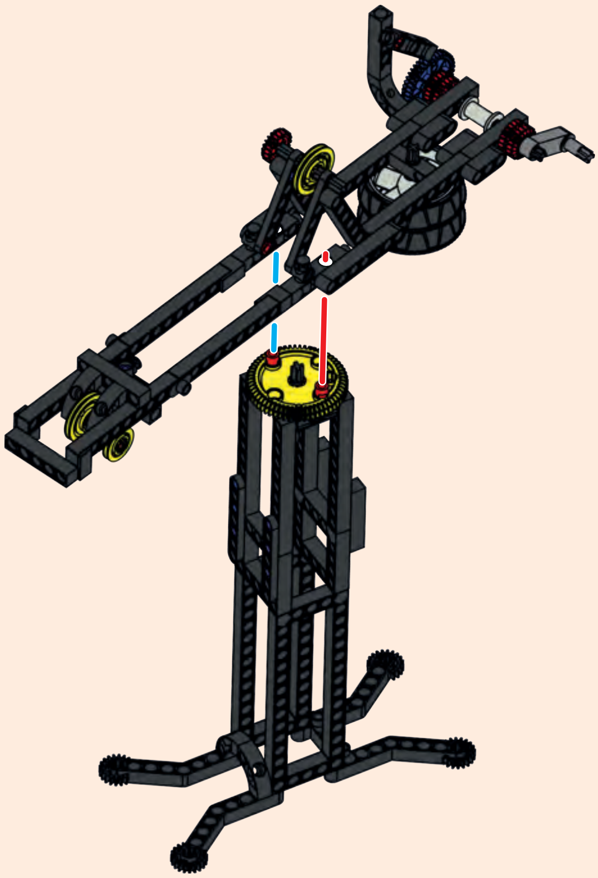

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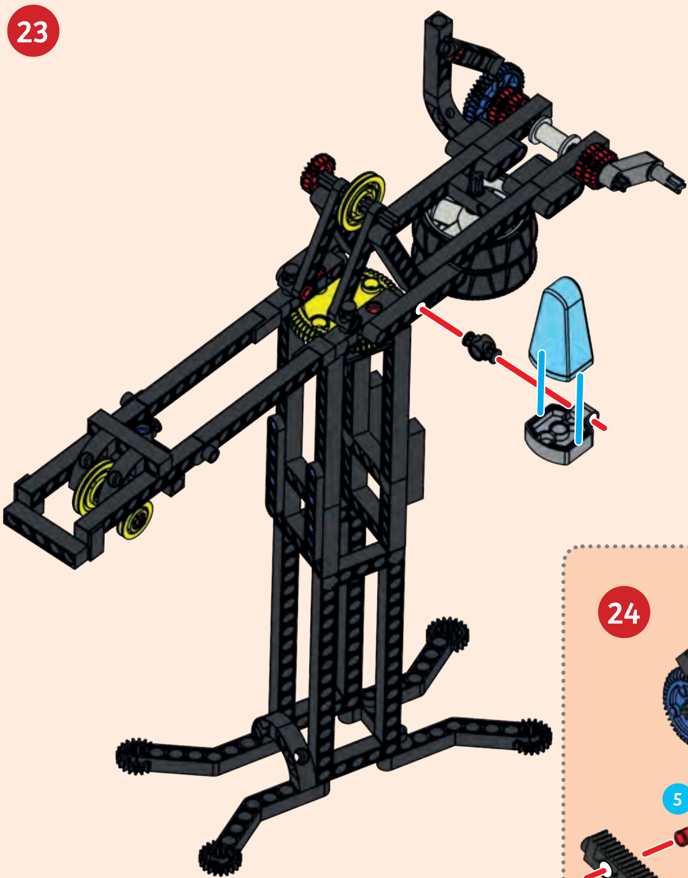

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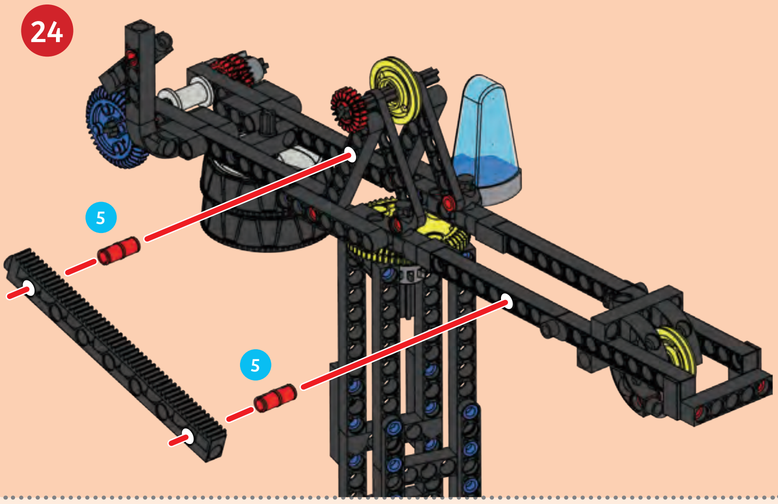

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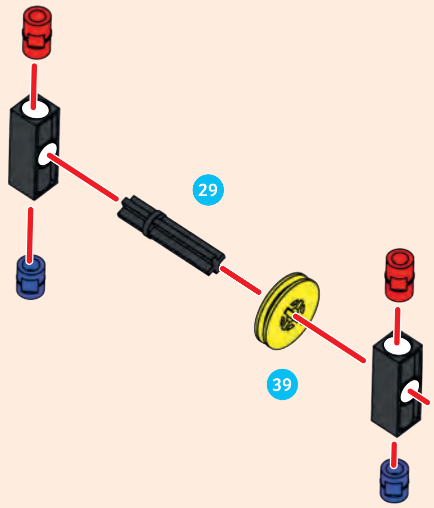

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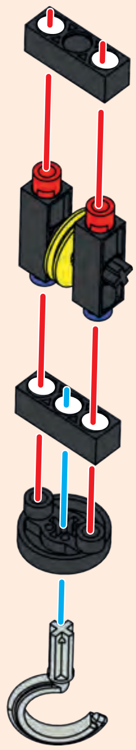

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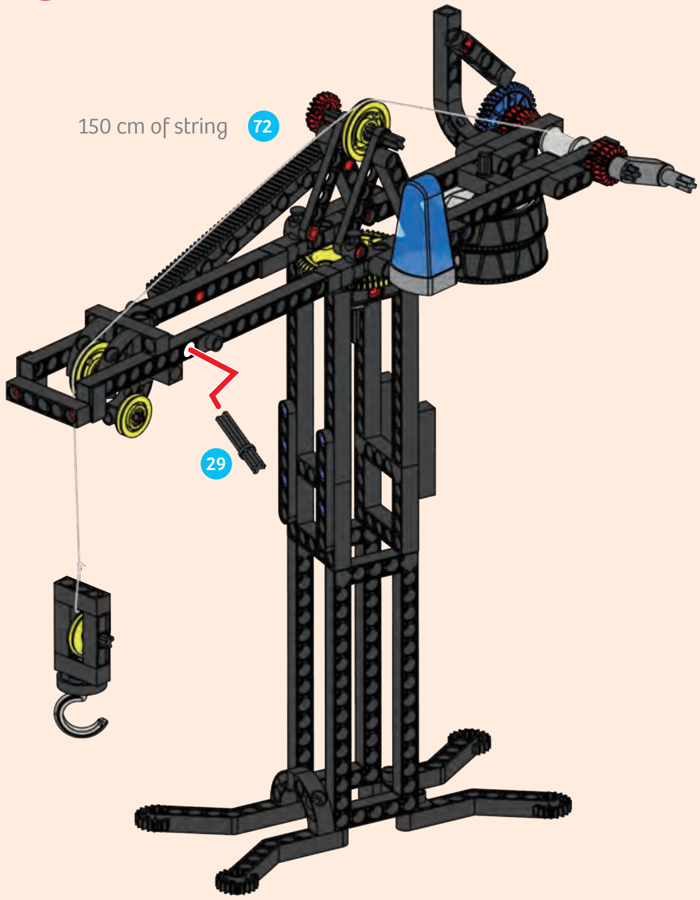

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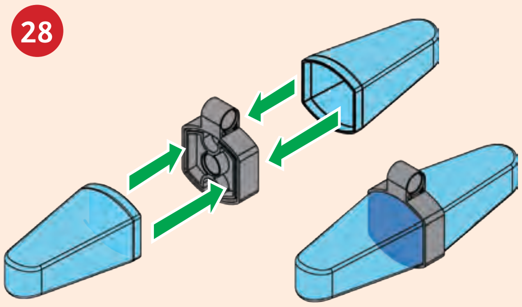

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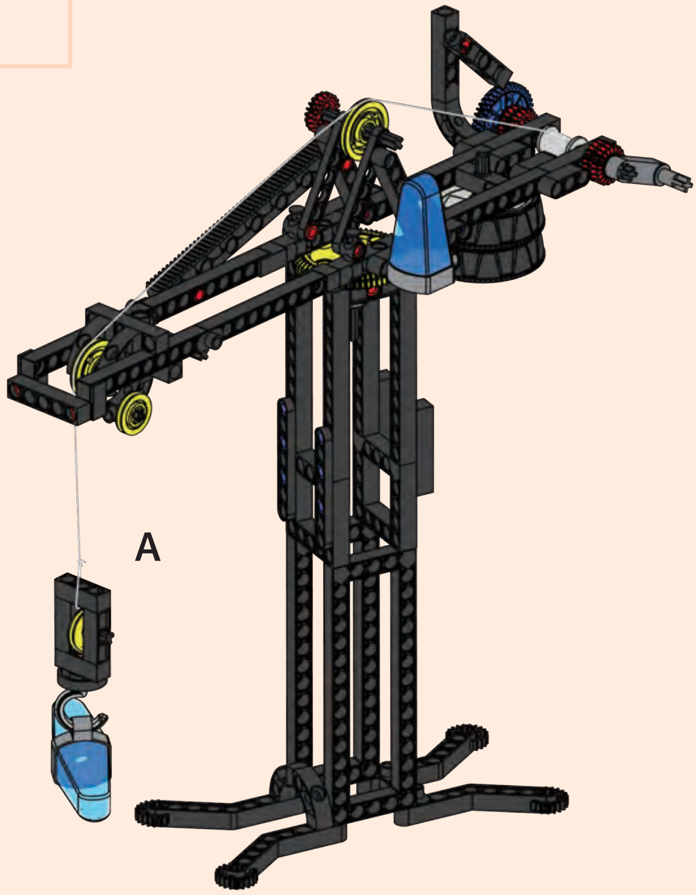
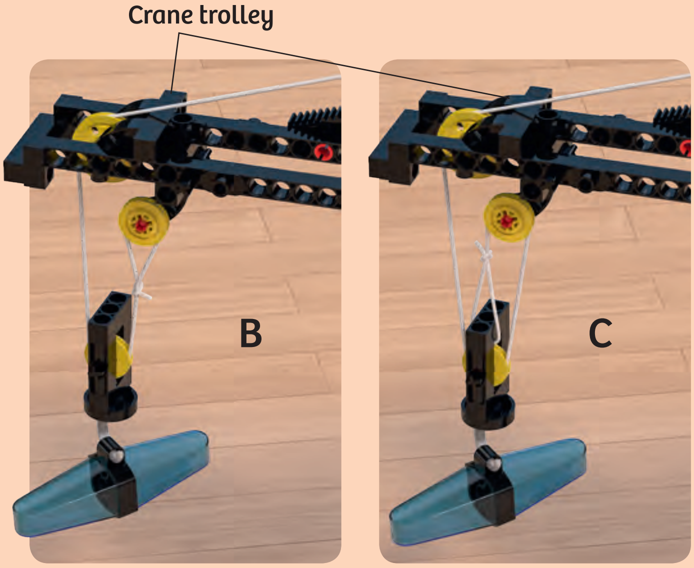


EXPERIMENT 8

Crane



YOU WILL NEED

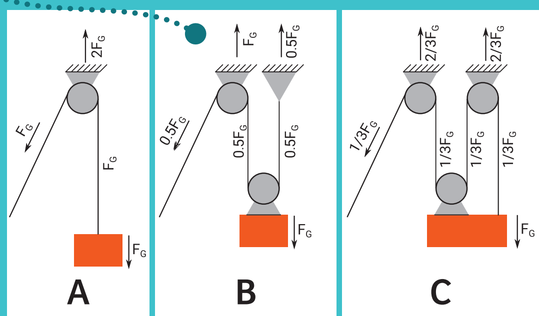
› **The assembled crane**
› *Some books to weigh down the crane*
› *Small coins or stones to fi l the pontoon*

HERE'S HOW

1. Place the books at the foot of the crane on the oor, to prevent the crane from toppling over.
2. The crane trolley is a ached to an axle. The farther forward the crane trolley is a ached, the greater the strain on the crane jib.
3. The assembled version of the crane we have here is based on block and tackle example A.
4. Position the ratchet on the gear so that the rope does not get pulled toward the crane hook.
5. Fill the pontoon with coins and stones and a ach the load to the crane hook.
6. You can now turn the crank and hoist up the load. Raise and lower the load a couple of times (releasing the gear with the ratchet).
7. Thread the rope through the pulleys as shown in example B, then try lifting and lowering the load again.
8. And fina ly, thread the rope as shown in example C. Then lift and lower the load.

KEY CONCEPT: BLOCK AND TACKLE SYSTEM

A **block and tackle** system is a technical tool that's used to lift heavy loads. It uses multiple pulleys to distribute the load. The more pulleys you have, the lower the force. However, it also means that you'll have to use more rope. In theory, this means that you can reduce the force as much as you want. However, the pulleys also add to the weight of the load and need to be hoisted up as well. The number of pulleys needed should therefore be calculated carefully, so that the necessary force can be provided with the minimum number of pulleys.



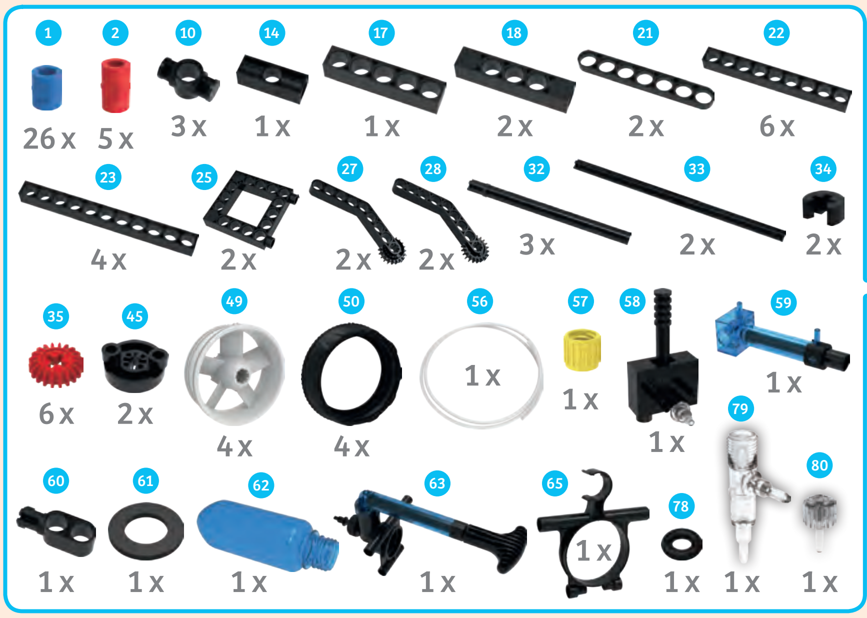
WHAT'S HAPPENING?

When you turn the crank, you are exerting force on the rope. The pulleys used in example A only in uence the direction of force — they do not in uence the amount of force. Pulling the rope simply hoists the load. With examples B and C, less force is needed because the rope is suspended from two (B) or three (C) places and these additional suspension points bear a portion of the load (see diagram on right). This explains why you have to turn the crank more. If we disregard friction, the required rope length multiplied by the force will always be the same.

WANT TO FIND OUT MORE?

You can use the crane to test the lever principle. Remove the books, a ach a load, and then test how far out you can move the crane trolley before the crane topples over. Is there any impact from the rotation direction of the jib relative to the base of the crane on the oor? Just like with a seesaw, the lever arm multiplied by the force must be equal on both sides. In other words, heavy loads must be positioned close to the mast when being hoisted.

PNEUMATIC SHOCK ABSORBER



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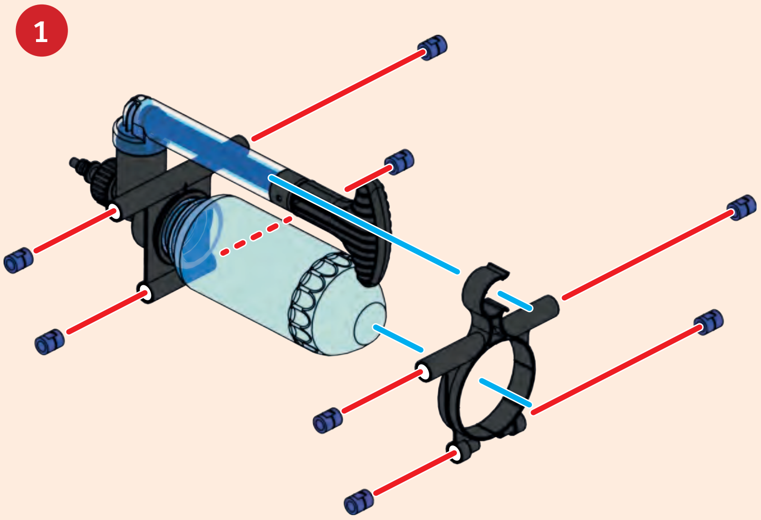

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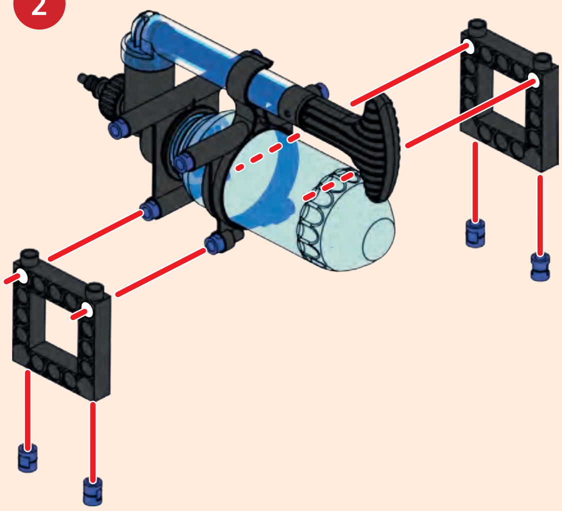

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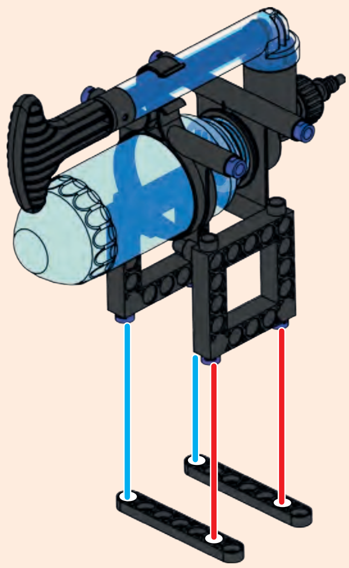

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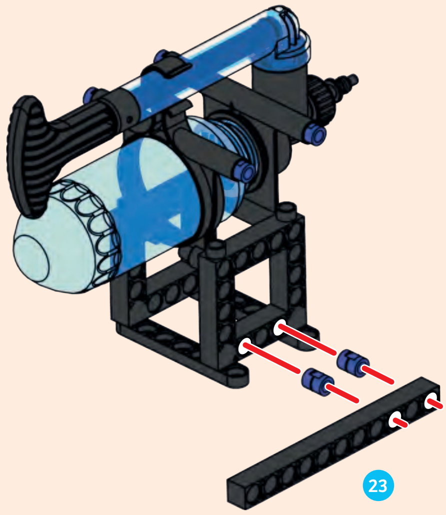

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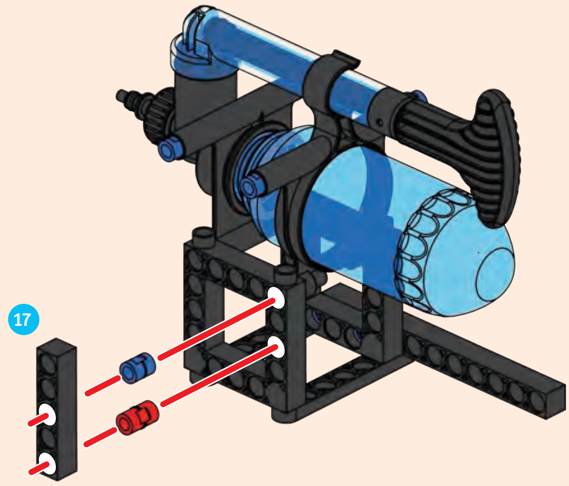

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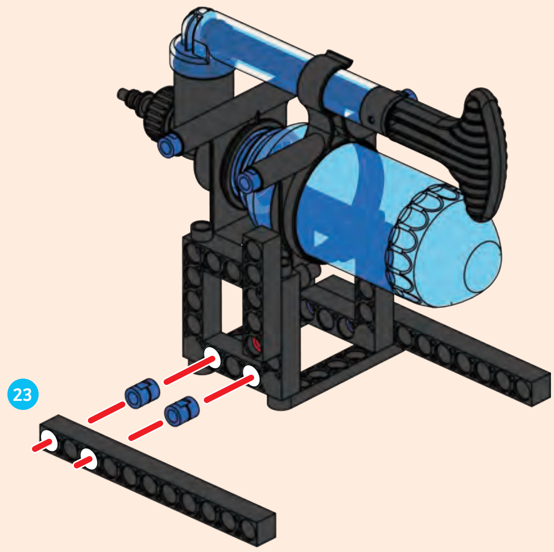

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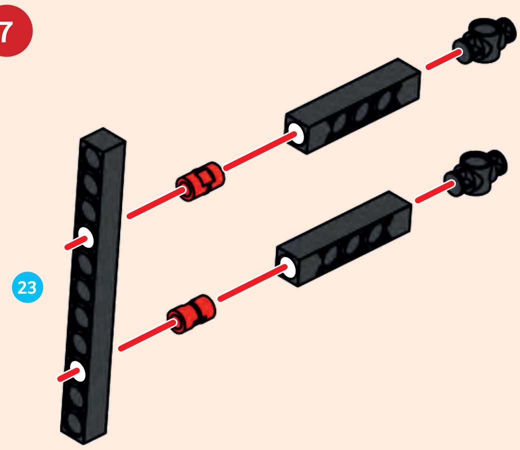

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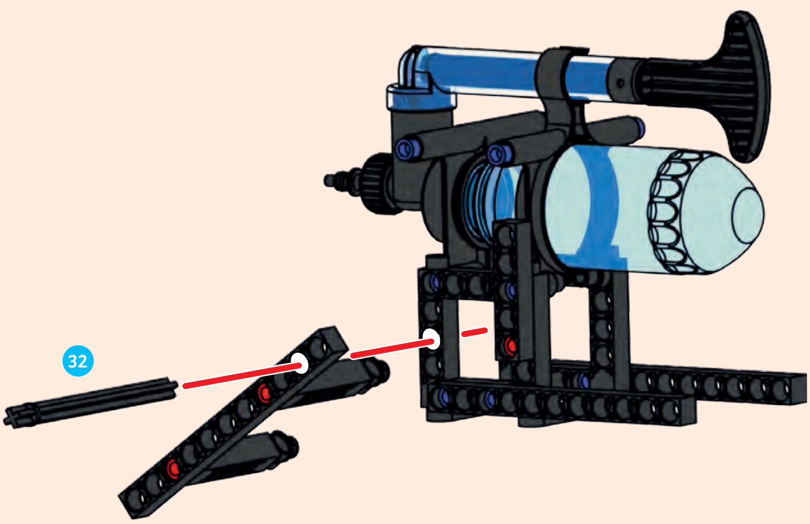

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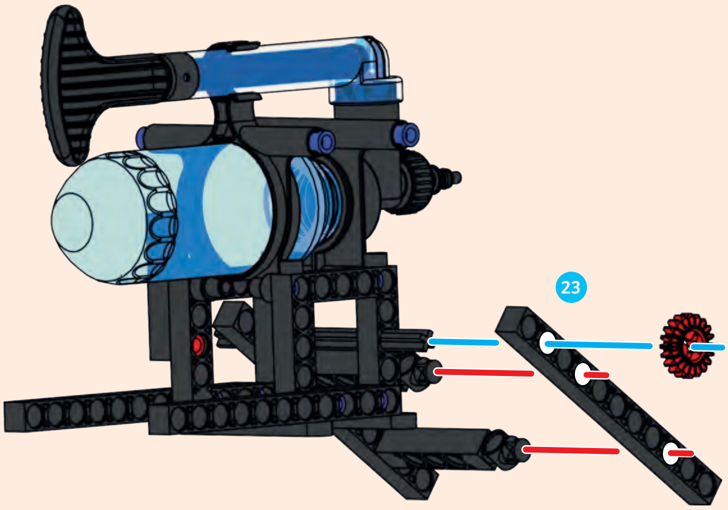

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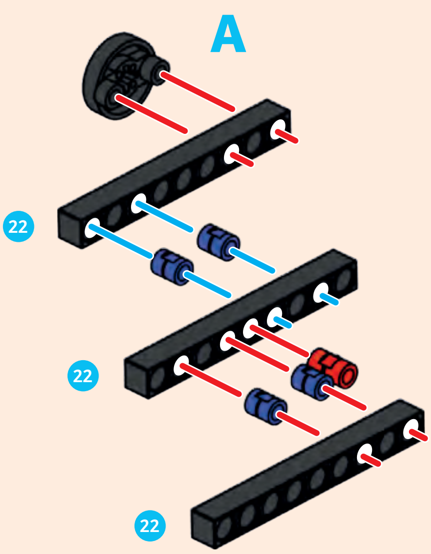

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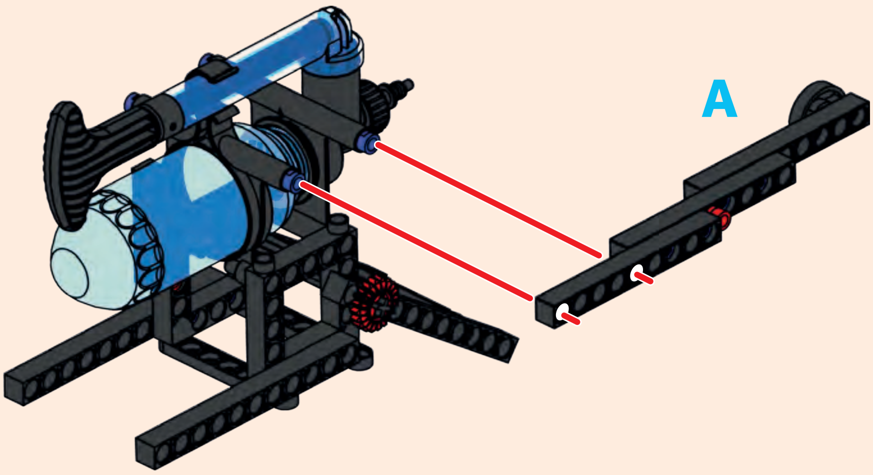

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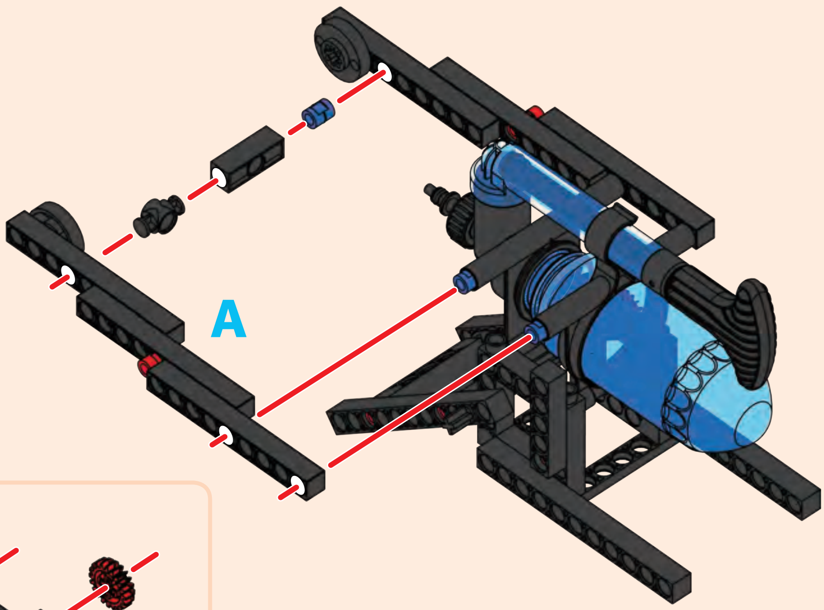

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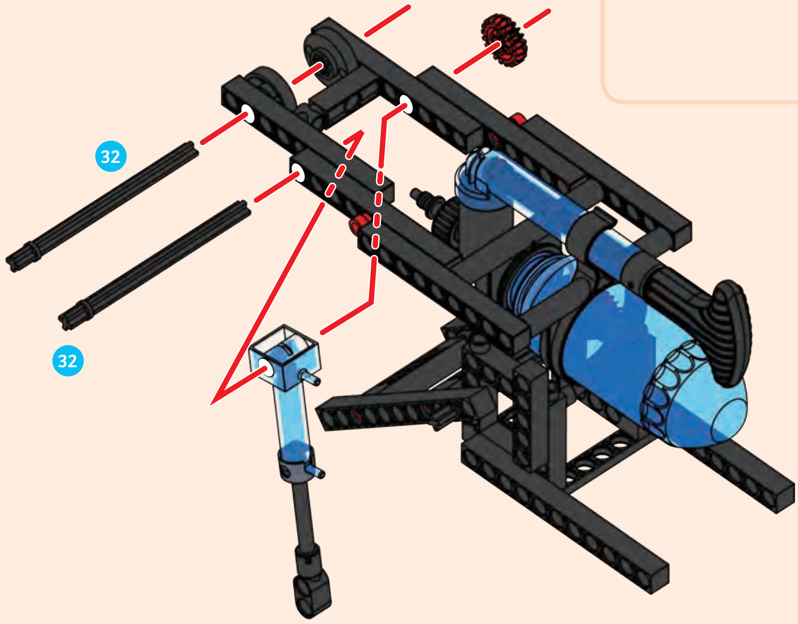

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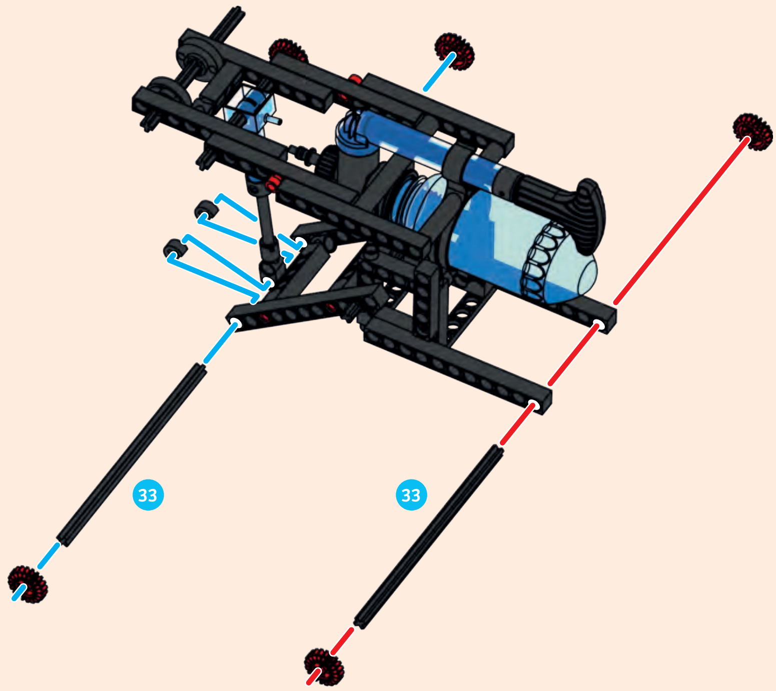

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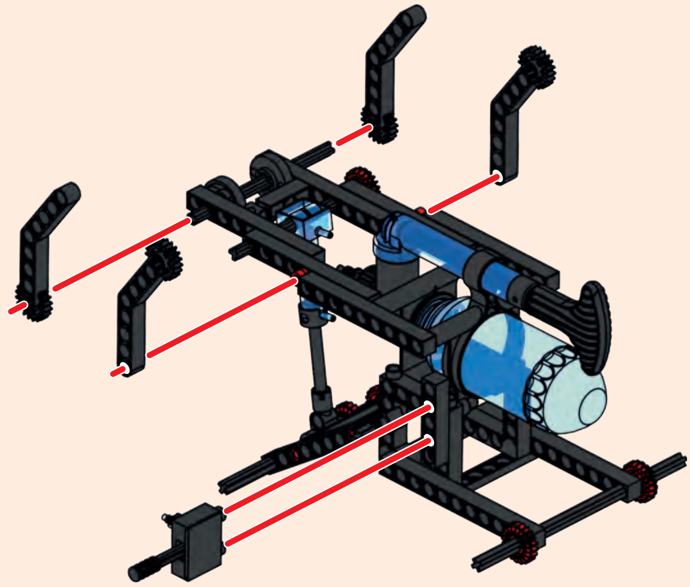

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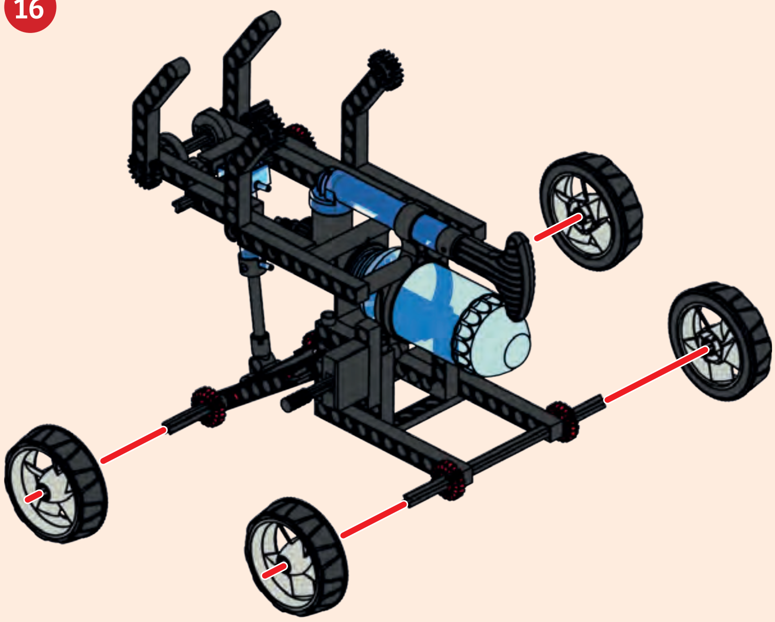

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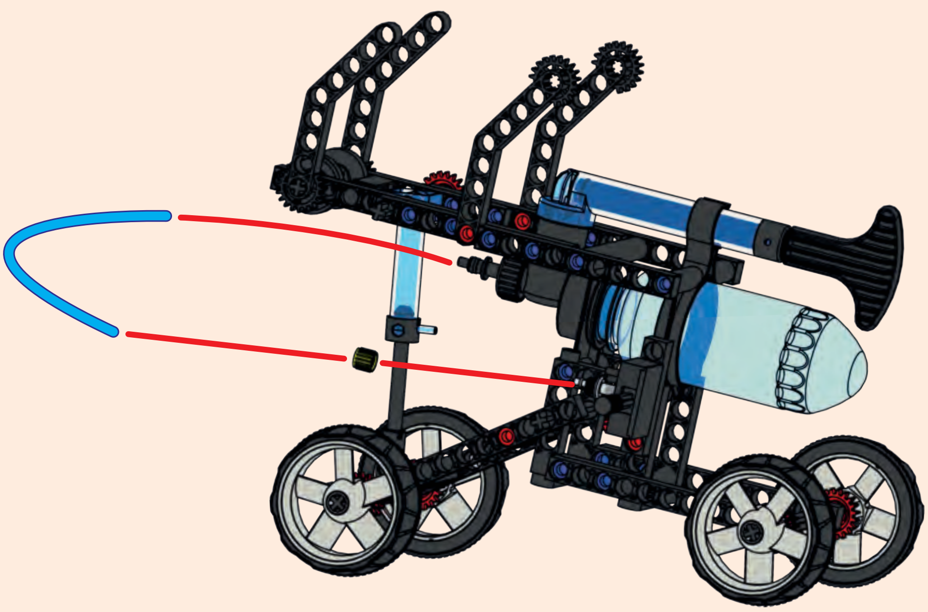

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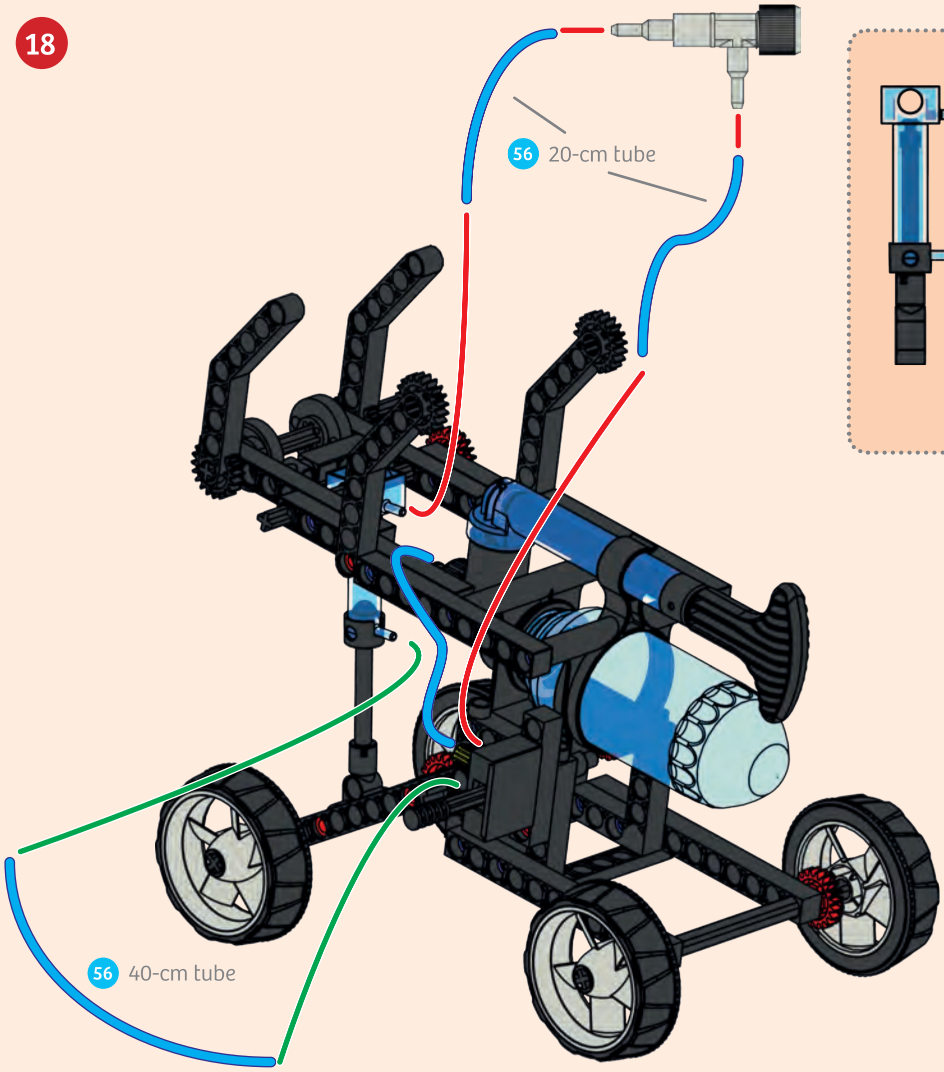
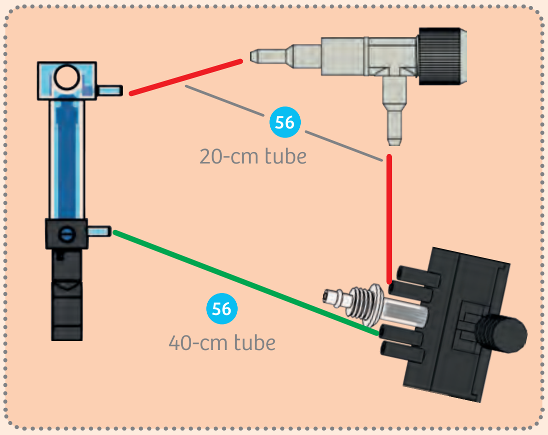
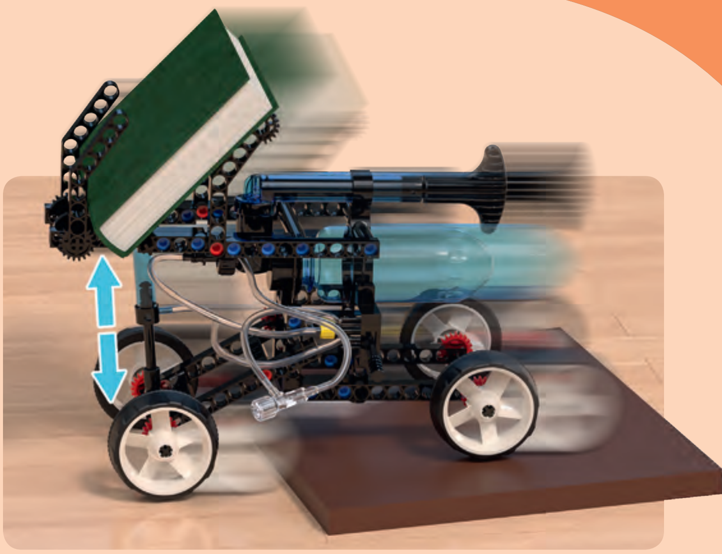




Done!

EXPERIMENT 9

Pneumatic shock absorber



YOU WILL NEED

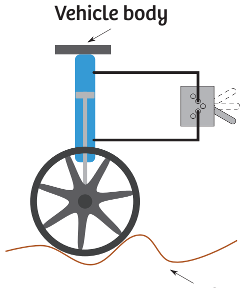
› **The assembled bus with pneumatic shock absorbers**
› *Some books to act as a load*
› *Small obstacles for the bus to drive over (pens, small sticks, etc.) or a board*

HERE'S HOW

1. Move the lever on the switch to the center position.
2. Pump air into the pressurized air tank (pump between 10 and 50 times).
3. Open the valve as much as possible.
4. Next move the lever back and forth — the vehicle body will now move up and down. Set the lever so that the vehicle body stays hoisted.
5. Then place some books on the holding bracket, so that the vehicle body is lowered a little.
6. Now give the bus a little push so that it drives over the obstacles or the edge of the board.
7. Check also what happens to the bus when the shock absorbers are fully retracted and fully extended.

WHAT'S HAPPENING ?

When driving over the obstacle, the wheel lifts, and this movement is transferred to the piston via the linkage. Because air can be compressed, the piston is able to move and thereby cushion the bus from external shock impulses. When the air is compressed, thermodynamic work is performed on the air, which results in some of the kinetic energy being converted into thermal energy. This causes the air to heat up. The movement loses energy, so that the impact can be absorbed. If it is fully retracted or fully extended, the shock absorber cannot function correctly and any shock impulses are transferred directly to the vehicle.



DID YOU KNOW?

In cars, shock absorbers consist of two components. First there is a spring, which absorbs large shock impulses, and then there is a piston in a cylinder, which is filled with oil. The piston is permeable, to allow oil to flow through it slowly. The friction caused by the piston moving through the oil then absorbs more of the shock impulses.

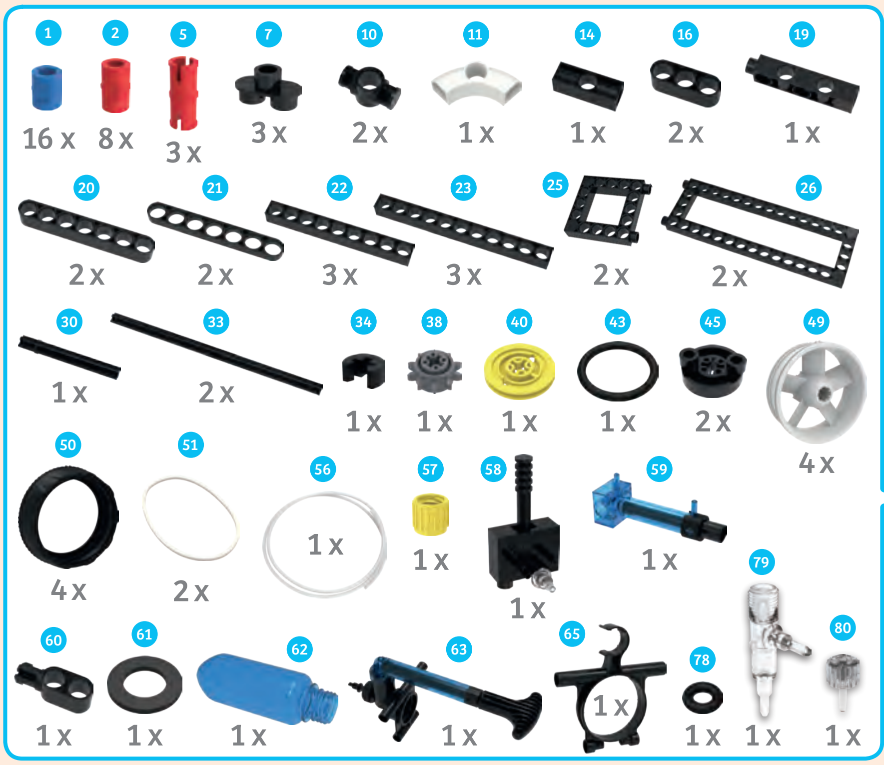
KEY CONCEPT: MOUNTAIN BIKES

A good **mountain bike** will have a suspension fork. Some models have oil-filled damping systems that absorb and dampen shock impulses. This makes for a more comfortable ride over rough terrain. Certain suspension forks even allow you to adjust the degree of damping by closing a valve. This means you can modify the bike's behavior according to the type of surface (if biking on a gravel road or forest trail with lots of tree roots, for example), so that it doesn't lose contact with the ground.

WANT TO FIND OUT MORE?

How does the shock absorber behave if you close the valve even further, or move the lever to the center position? What happens if you pump more air into the pressurized air tank? In terms of damping effect, it's important to have as much air as possible. The lower the volume of air, or the more compressed the air is as a result of being pumped, the harder the shock absorber.

CAR WITH BRAKE



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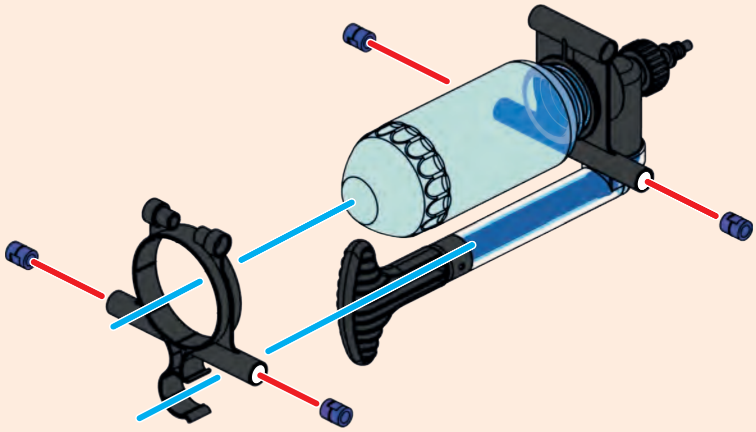

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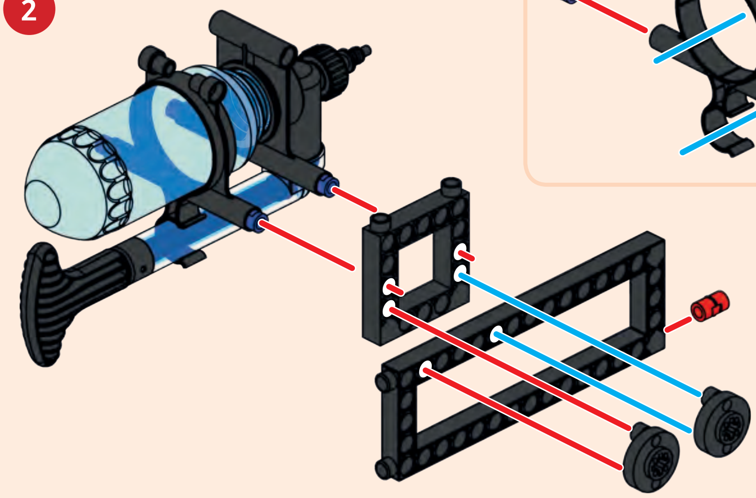

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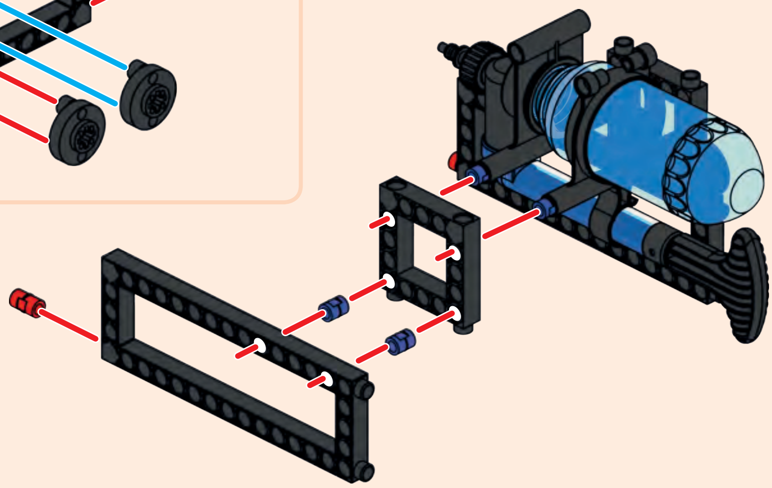

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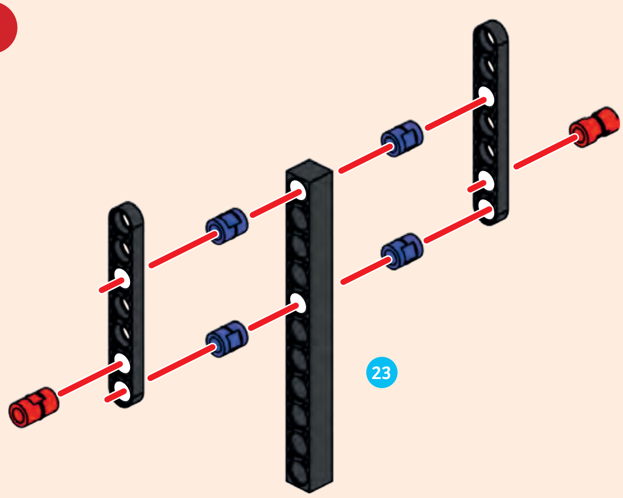

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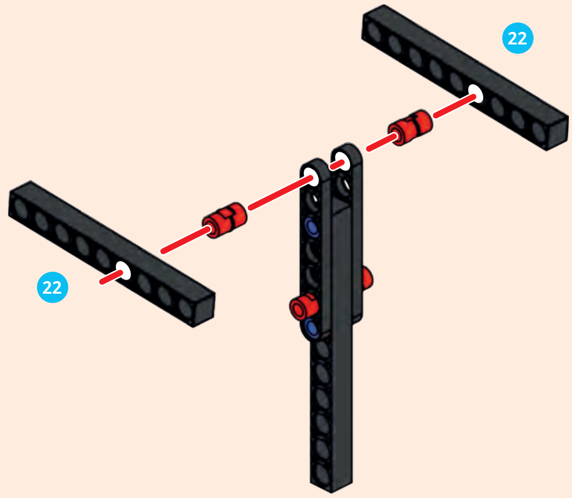

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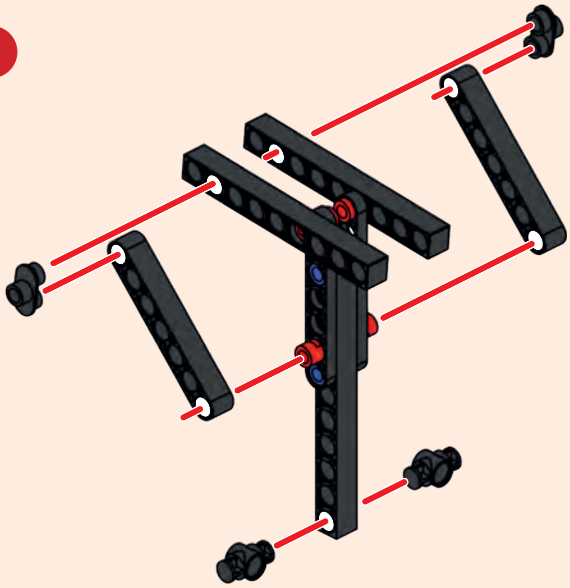

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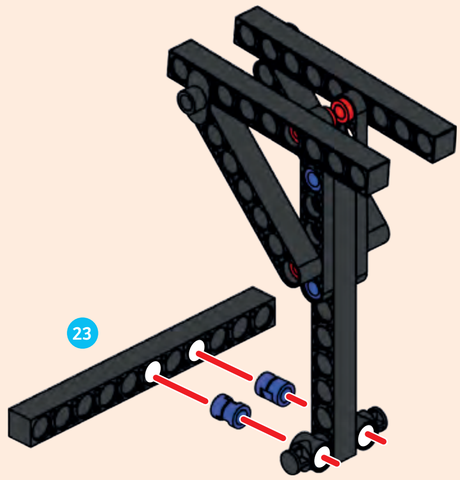

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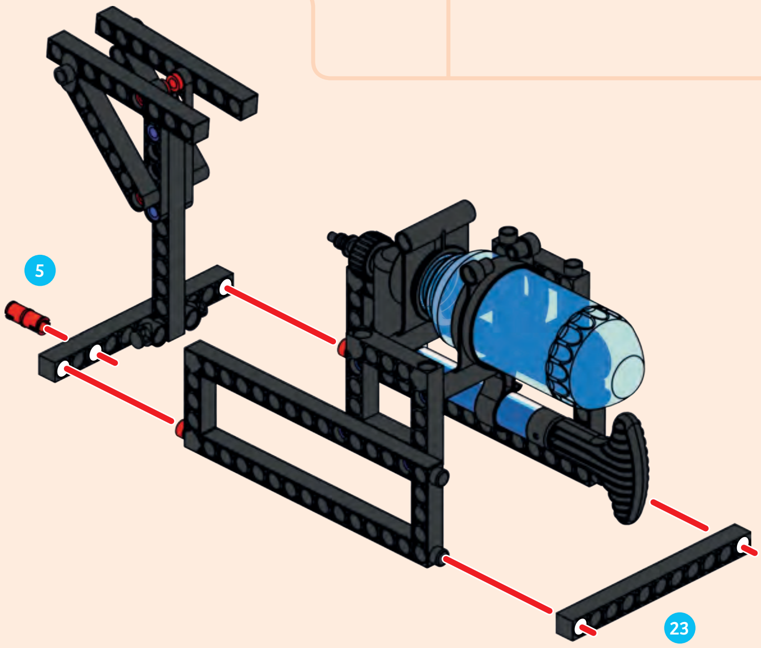

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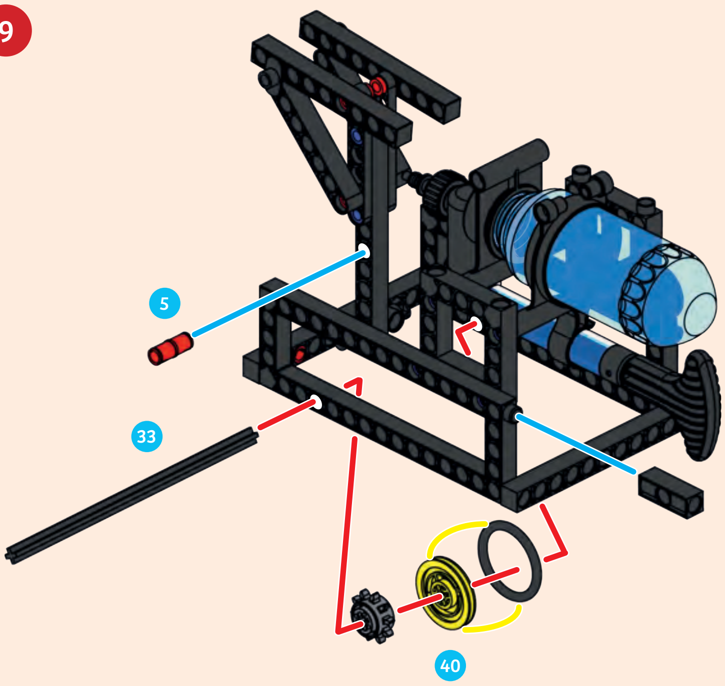

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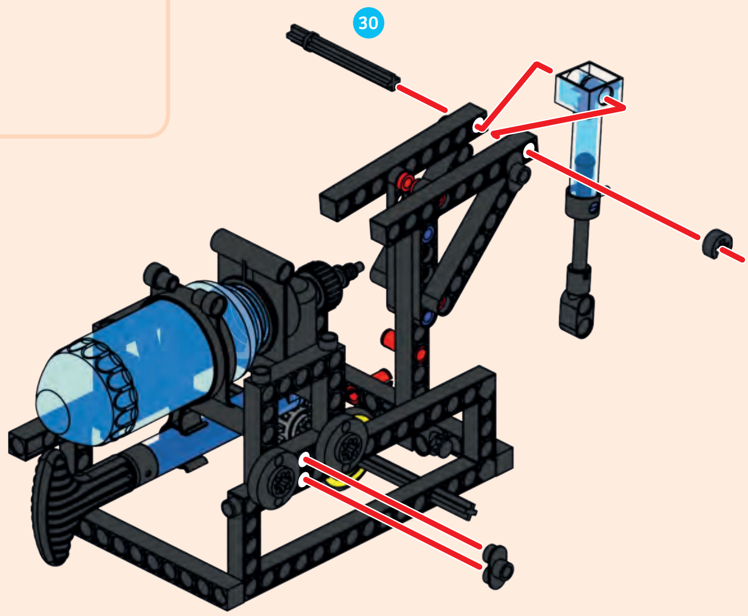

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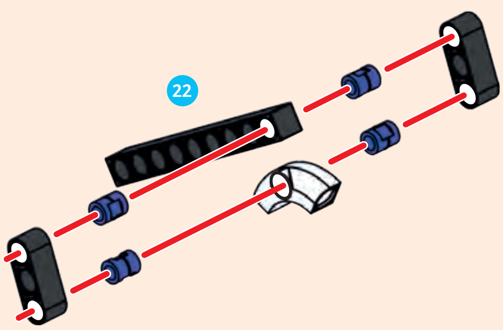

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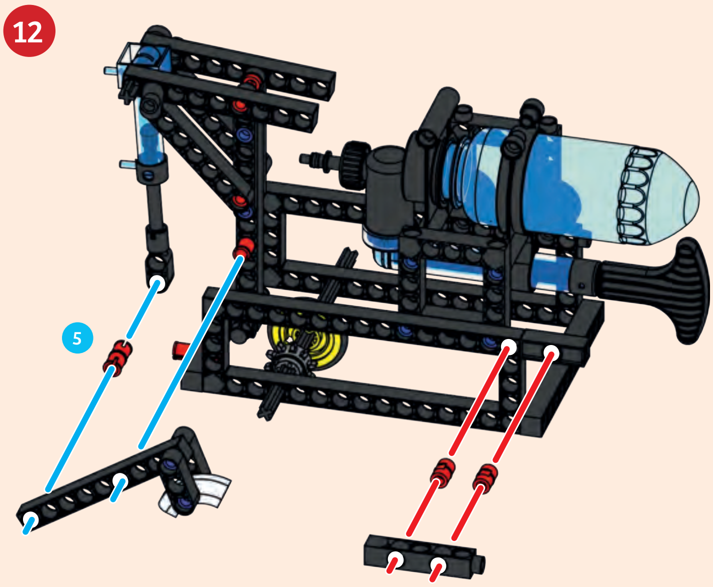

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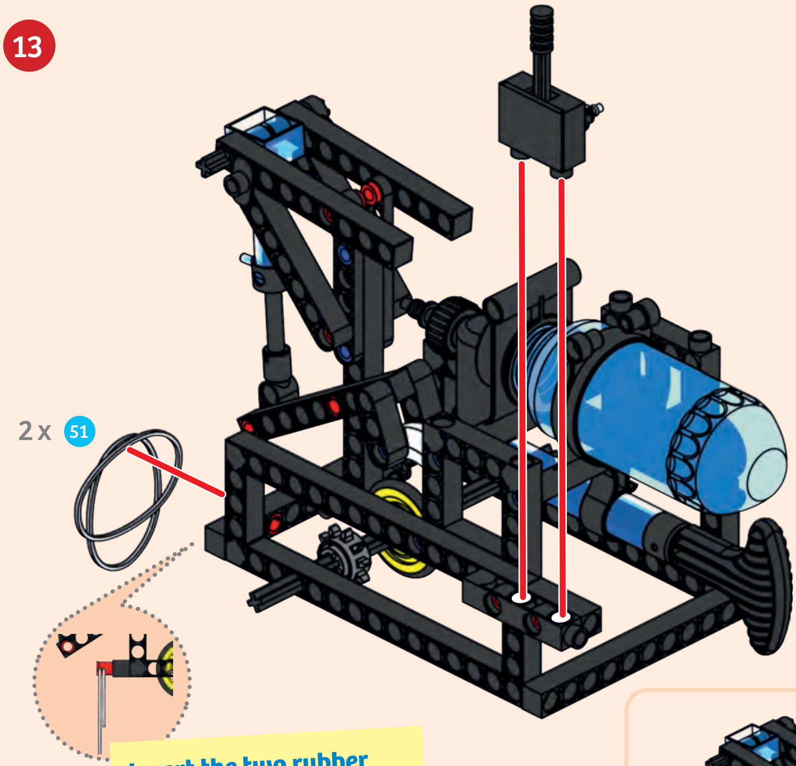

Insert the two rubber bands into the slot in the joint pin.

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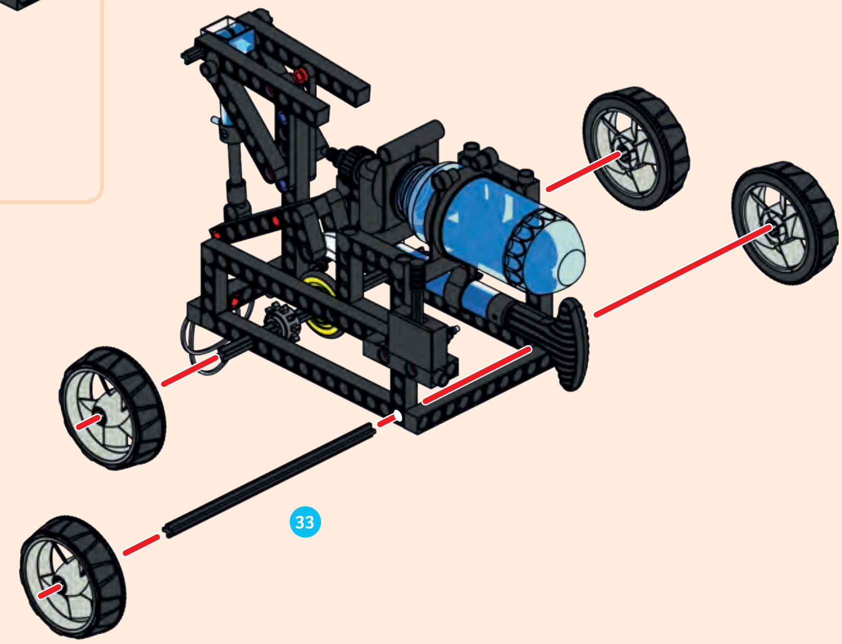

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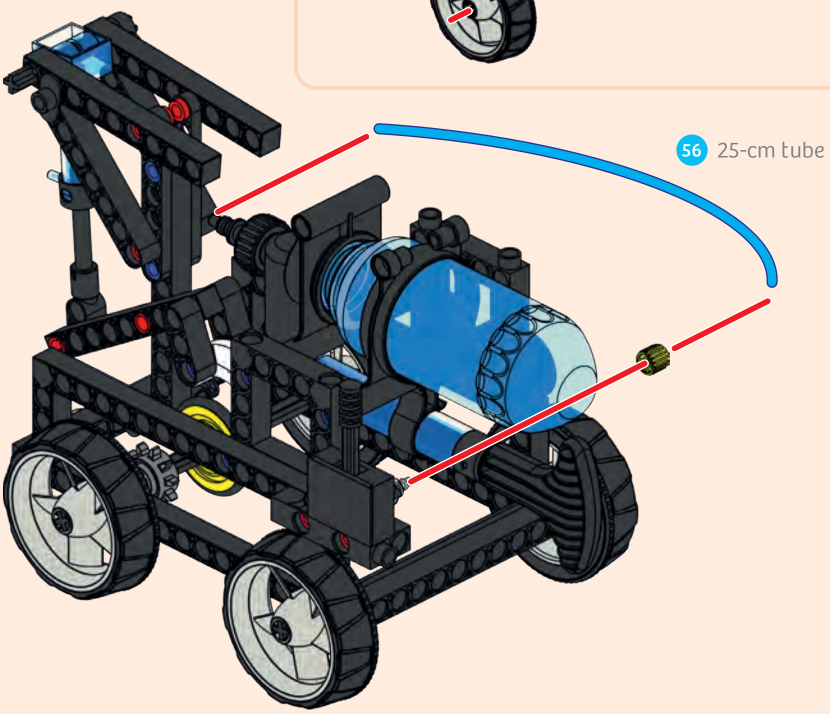

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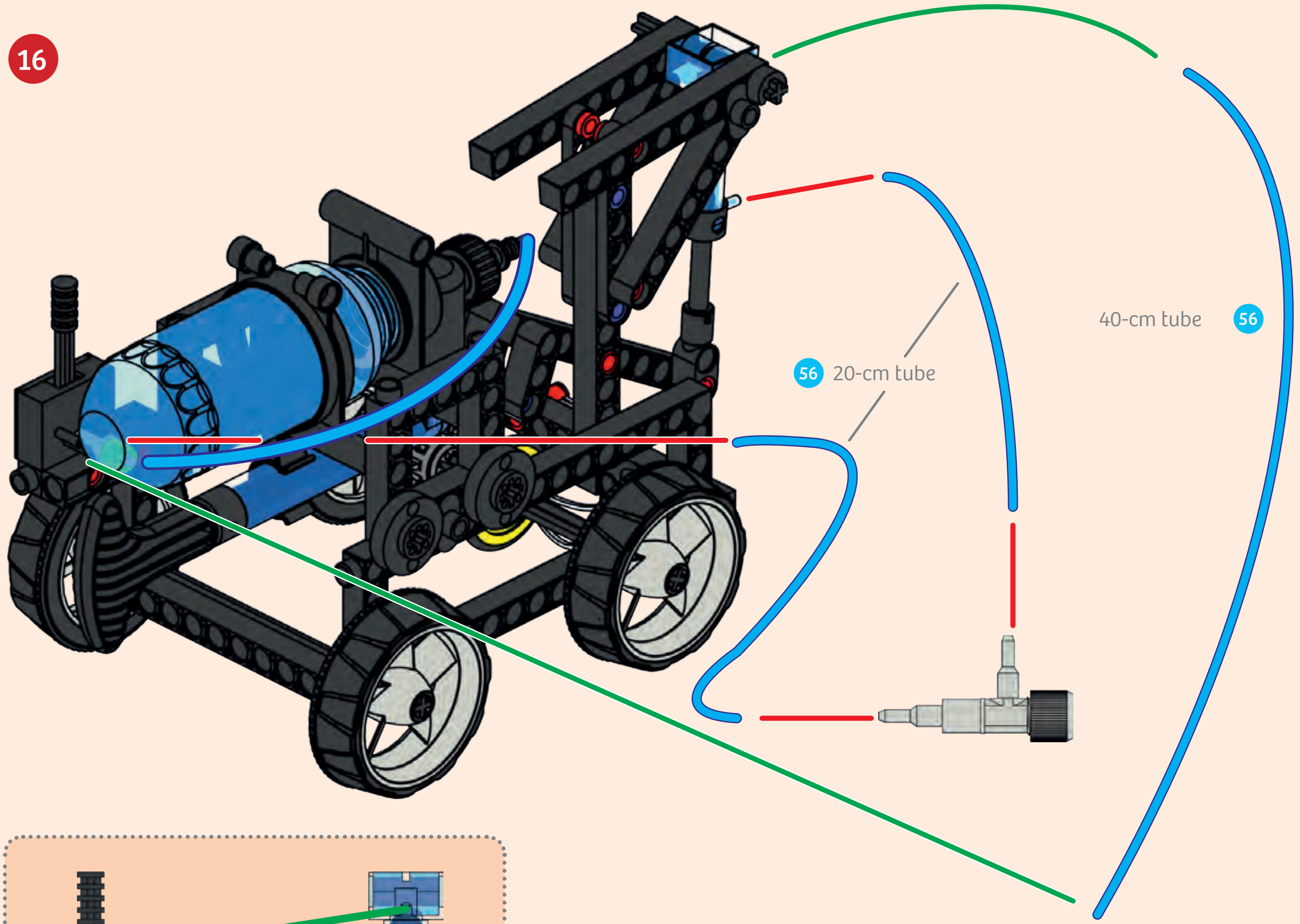
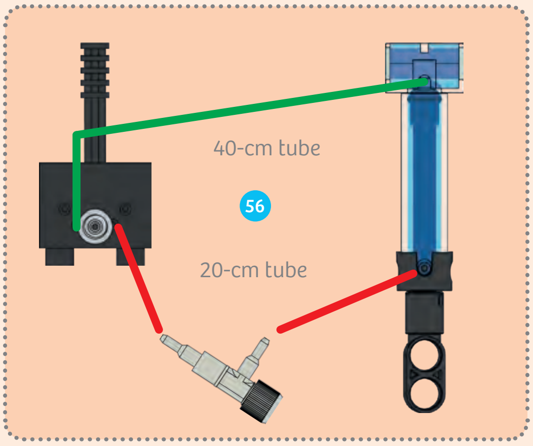
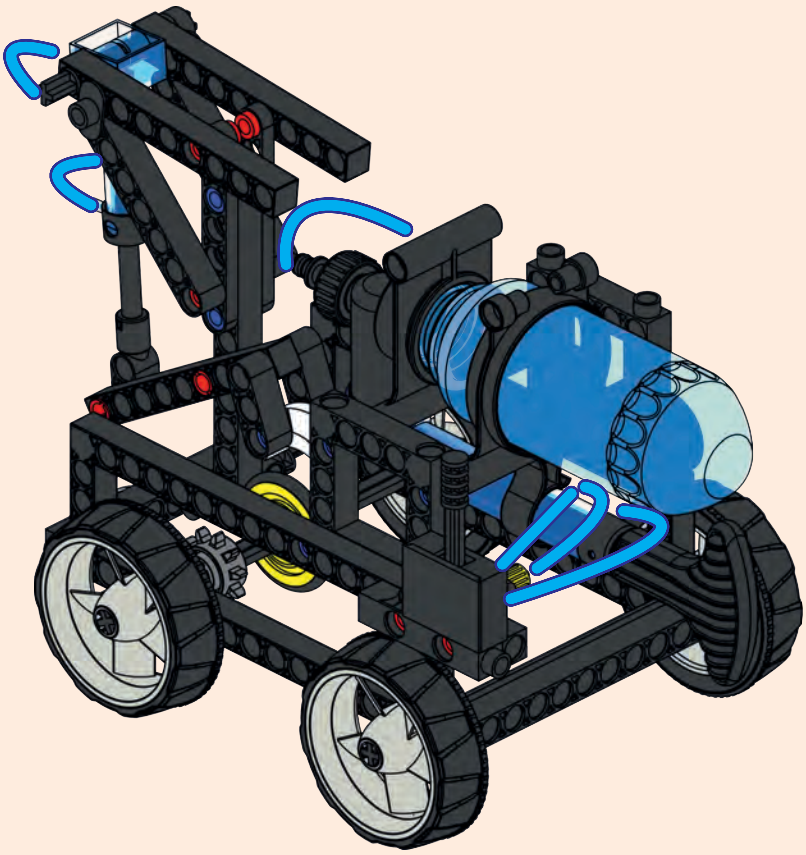


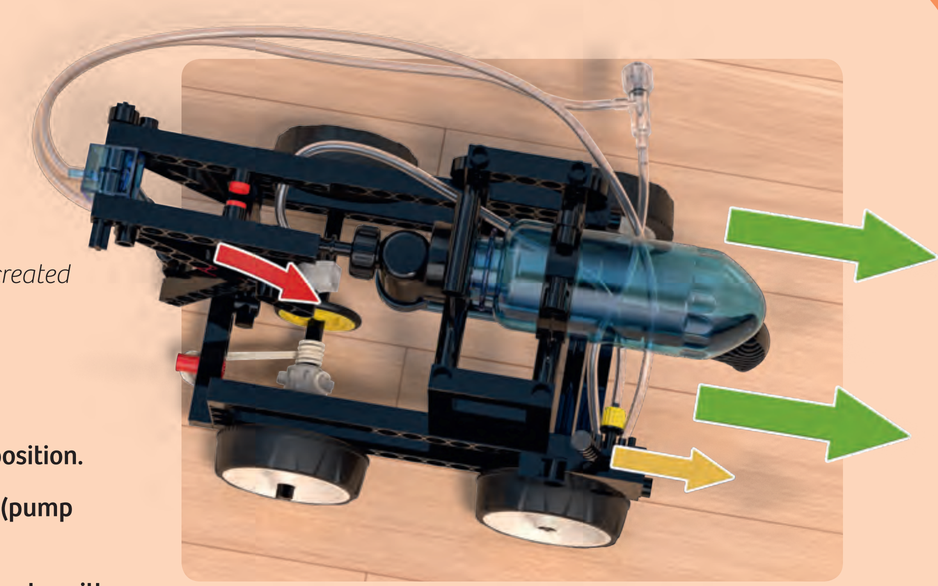




Done!

EXPERIMENT 10

Car with brake



YOU WILL NEED

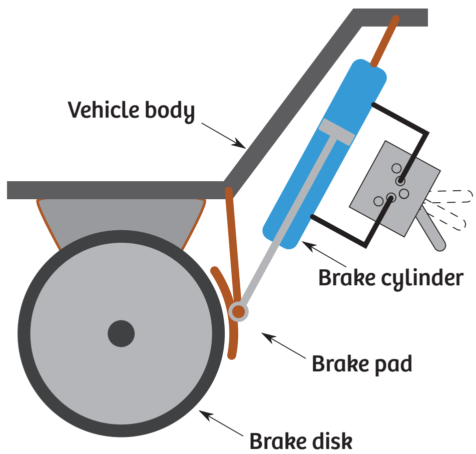
› **The assembled car**
› *Measuring tape (e.g. the measuring tape you created as part of the surveyor's wheel experiment)*

HERE'S HOW

1. Move the lever on the switch to the center position.
2. Now pump air into the pressurized air tank (pump between 30 and 50 times).
3. Next move the lever back and forth — the brake will now move up and down. You can use the valve to adjust the speed of the brakes.
4. Draw the rubber bands forward, and from below, place them around the teeth of the sprocket on the rear-wheel shaft.
5. Now drag the car backward until the rubber bands are sufficiently taut. If you're using two rubber bands, this will correspond to a distance of roughly 1 meter.
6. It's important to keep a firm grip on the back wheels so that they don't spin.
7. Line up the car so that the path ahead is clear of all obstacles.
8. Now adjust the lever so that the brake can be applied. As soon as you see the brake being applied, release the car and let it go.

WHAT'S HAPPENING?

The air in the pressurized air tank flows through the valve. It then flows through the tubes into the cylinder and pushes the piston out. The linkage transfers the movement to the brake pad. The brake pad then presses against the brake disks. Exactly how fast or slow this happens depends on the degree to which the valve is open. Friction causes the car's kinetic energy to be converted into heat, which then causes the car to come to a stop.



DID YOU KNOW?

In real-life cars, brakes function in a similar way. The only difference is that they use brake fluid — an oil-based substance — instead. Brake fluid cannot be compressed and pushes the brake pads against the brake disks. Unlike our experiment here, the brake pads are not pressed onto the circumference of the brake pad; instead, they are pressed against the sides of the wheel. Rim brakes and disk brakes on a bicycle work in the same way.

CHECK IT OUT

Converting and conserving energy

Energy cannot be created or destroyed. Energy is always converted from one form to another. This is referred to as the "conservation of energy." Energy comes in various di erent forms. Examples include kinetic energy, potential energy, elastic energy, thermal energy, chemical energy, and electric energy. Energy is needed to perform work. For example, certain work must be performed in order to lift a stone. The same applies to the potential energy that is subsequently transferred to the stone.

People sometimes talk about energy loss. Although, on a physical level, this is not actually possible, the term "energy loss" is used in everyday language to describe a situation in which a movement has ended due to friction, for example. The friction generates heat, and this heat can no longer be used. This results in a loss of usable energy. Incidentally, this usable energy is known as "exergy."

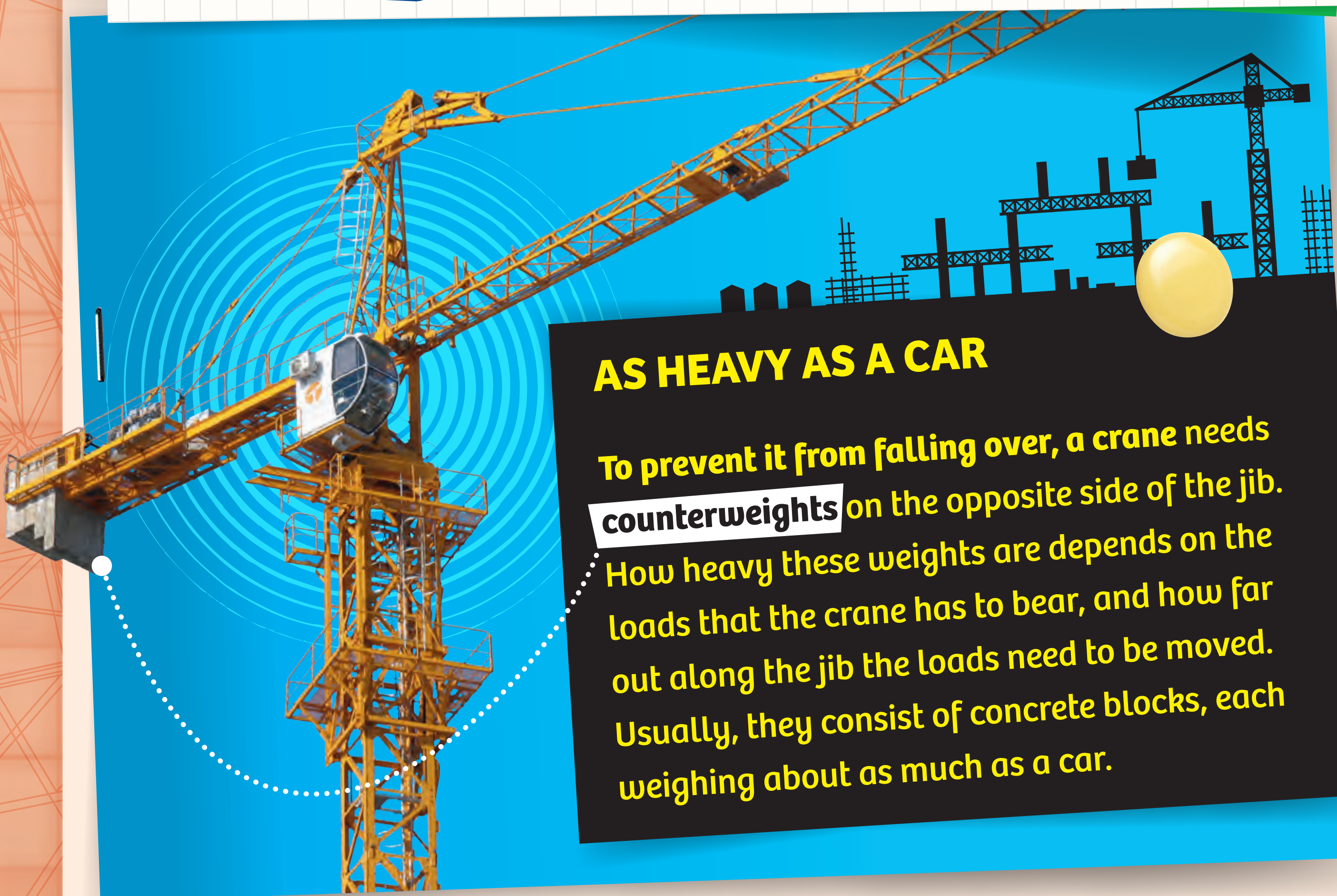
ANCIENT TEMPLES

As far back as 2,000 years ago, the Ancient Greeks were using pulley hoists to lift heavy loads. They had to move huge stones when building their temples — to erect columns, for example, or to raise wooden beams for the roof.

SPEED LIMIT?

For many people, **speed** is everything. In the animal kingdom, speed is what determines whether or not a predator will catch its quarry. And yet, even the quickest animal in the world, the **cheetah**, can only run over 100 km/h for short bursts. If it doesn't bag its prey, it'll have to wait a long time to recover.

It's much the same for race car drivers. They're very quick when they zip around the track in their speedy cars, but their fuel tanks empty just as quickly. And Formula One cars aren't even the fastest cars — **Andy Green** outpaced them all when he broke the sound barrier in a rocket-propelled car in 1997.



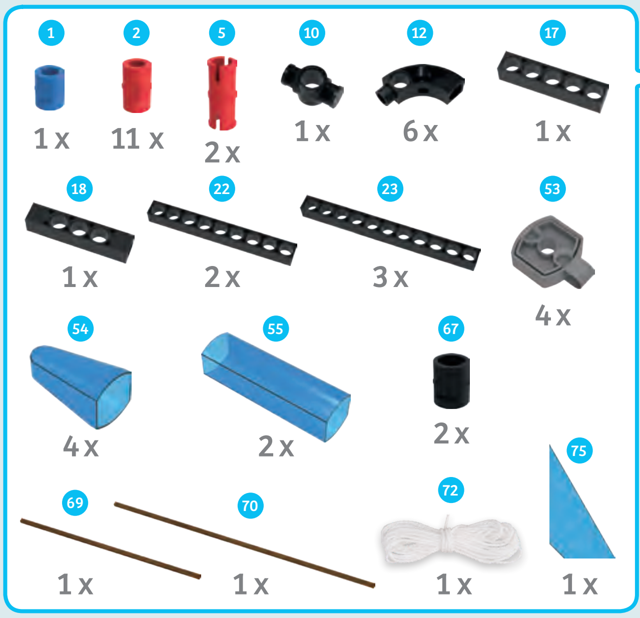
AS HEAVY AS A CAR

To prevent it from falling over, a crane needs **counterweights** on the opposite side of the jib. How heavy these weights are depends on the loads that the crane has to bear, and how far out along the jib the loads need to be moved. Usually, they consist of concrete blocks, each weighing about as much as a car.

On Land and Sea

Many thousands of years ago, the Ancient Egyptians were already using boats on the Nile to transport the heavy stones they needed to build their temples. These days, we use modern wind- or jet-propelled boats. You can build your own versions of these different boats and check out how they work. You can even send a submarine on an underwater dive.

CATAMARAN



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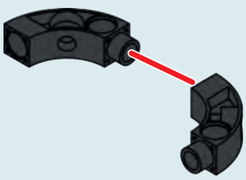

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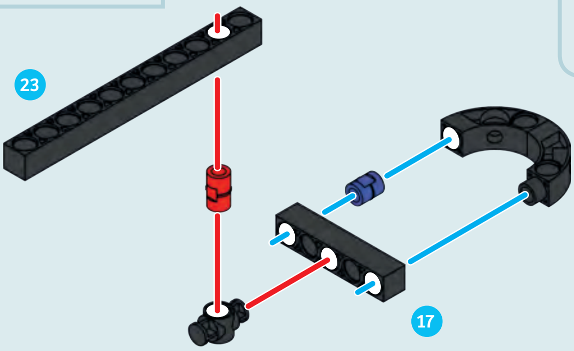

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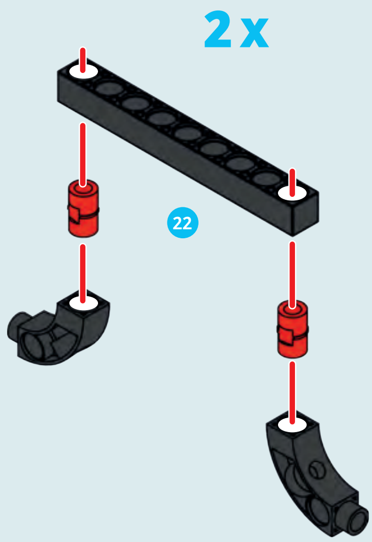

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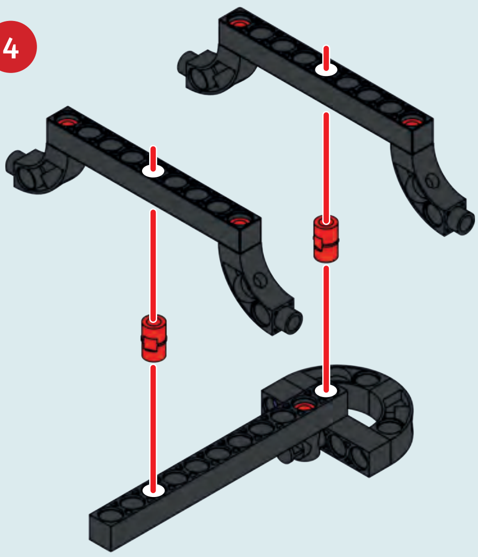

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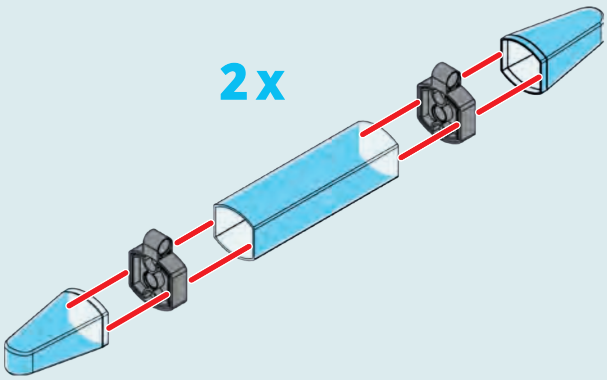

CATAMARAN

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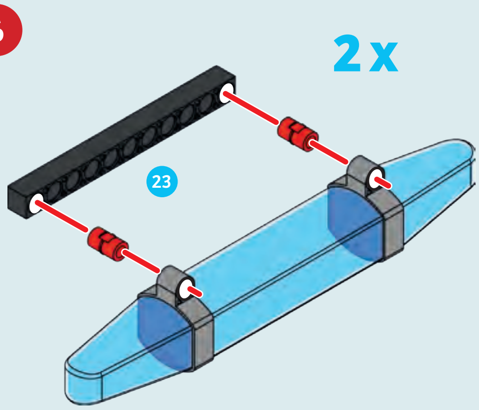

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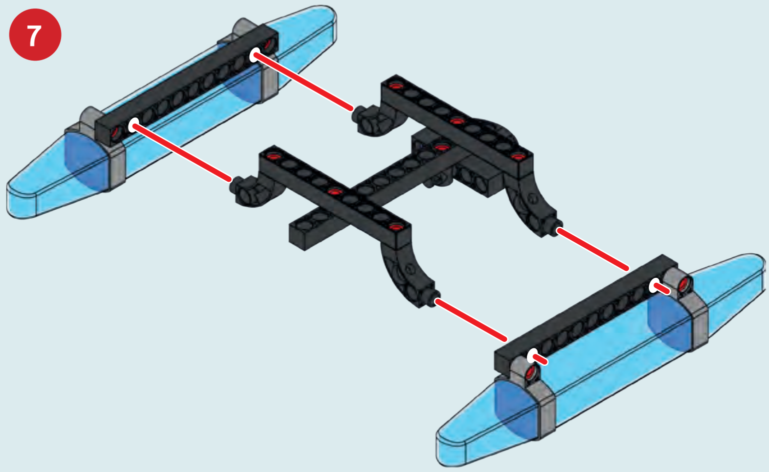

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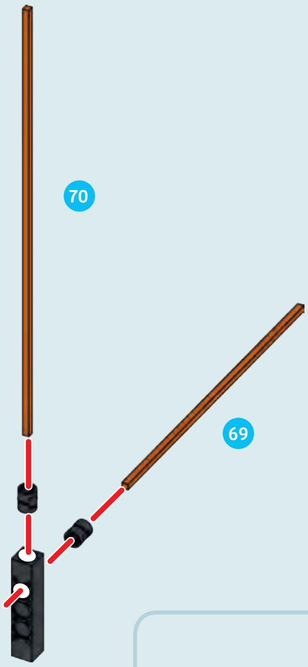

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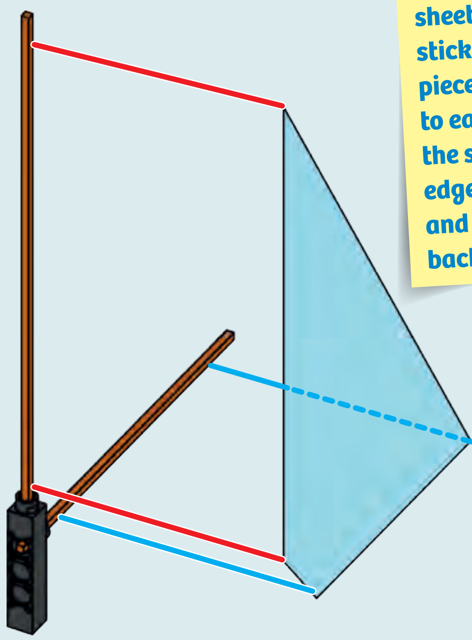

TIP!
Place the edges of the sheet onto the bamboo sticks. Then a ach two pieces of adhesive tape to each of the edges of the sheet, roll these edges around the sticks, and then stick to the back of the sheet.

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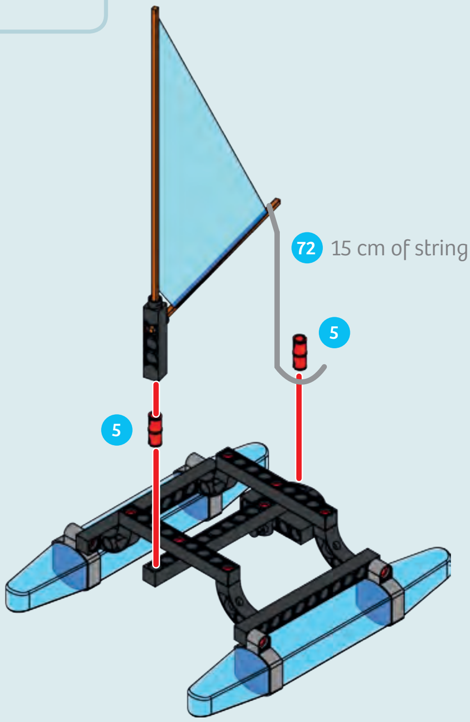
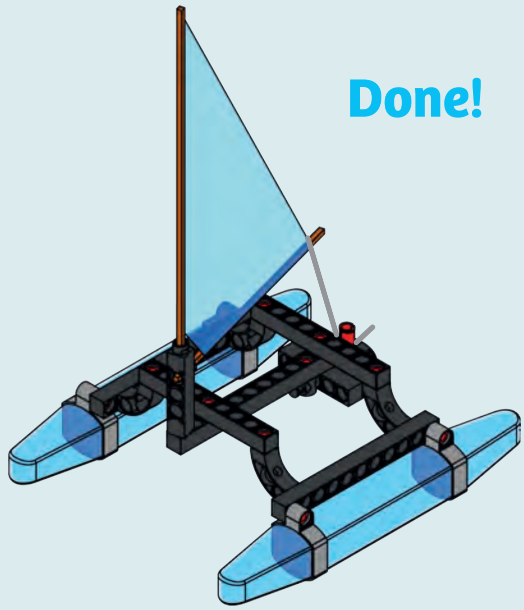
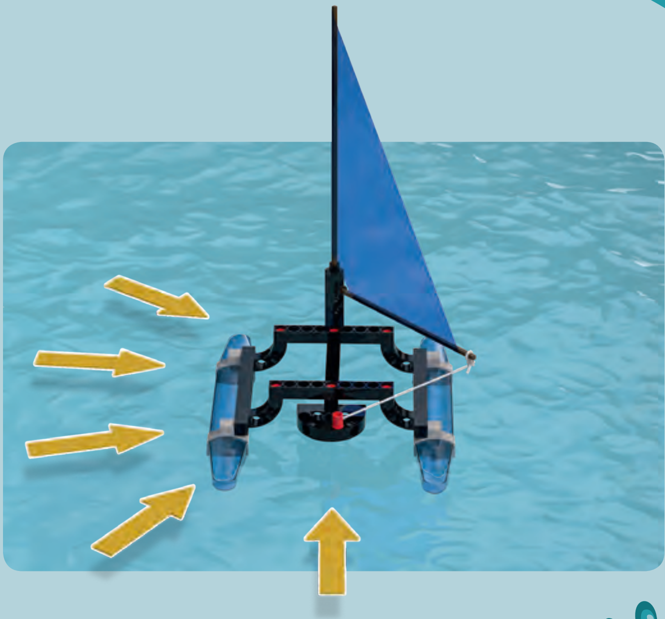




Done!

EXPERIMENT 11

Catamaran



YOU WILL NEED

› **The assembled catamaran**
› *A large water container, e.g. a fi led bathtub or a paddling pool*

HERE'S HOW

1. Place the catamaran on the surface of the water and move the sail over to one side.
2. Blow on the sail from di erent directions.
3. If you're outside, you can also use the wind for propulsion. You can find out what di ection the wind is blowing by picking some blades of grass and throwing them in the air. Which direction do they blow in?
4. Take note of the direction the catamaran is moving in.

WHAT'S HAPPENING?

When you blow at an exact right angle to the sail, air pressure rises at that spot. This is known as dynamic pressure. This creates a di erence in pressure on the other side of the sail, which is then pushed forward by the di erence. The catamaran will move in a curve in the direction that the sail is angled toward.

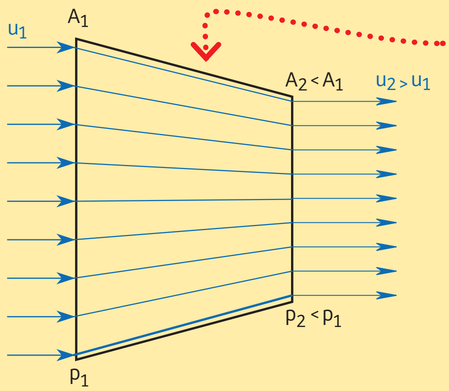
If you blow on the sail diagonally from the front, the air will ow along the outer side (the side facing the water more) and the inner side (the side facing the boat more) of the sail. In order for the air to ow along the outer side, it must move faster because it has farther to travel. This results in a drop in pressure (Bernoulli's principle). The pressure di erence applies a force to the sail and causes the catamaran to move outward.

WANT TO FIND OUT MORE?

A ach the sail so that it's exactly perpendicular to the hulls of the catamaran. Then blow on the sail from behind. Compare the speed of the catamaran now to its speed when the sail was slanted. You'll notice that the catamaran is now slower. This is because the surface of the sail now presents a greater ow resistance than when it was slanted.

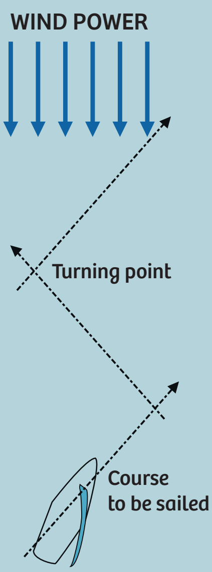
KEY CONCEPT: BERNOULLI'S EFFECT

Discovered by and named after Daniel **Bernoulli**, the e ect describes a situation where the pressure in a ow decreases as its speed increases. Conversely, it increases as the ow slows down.

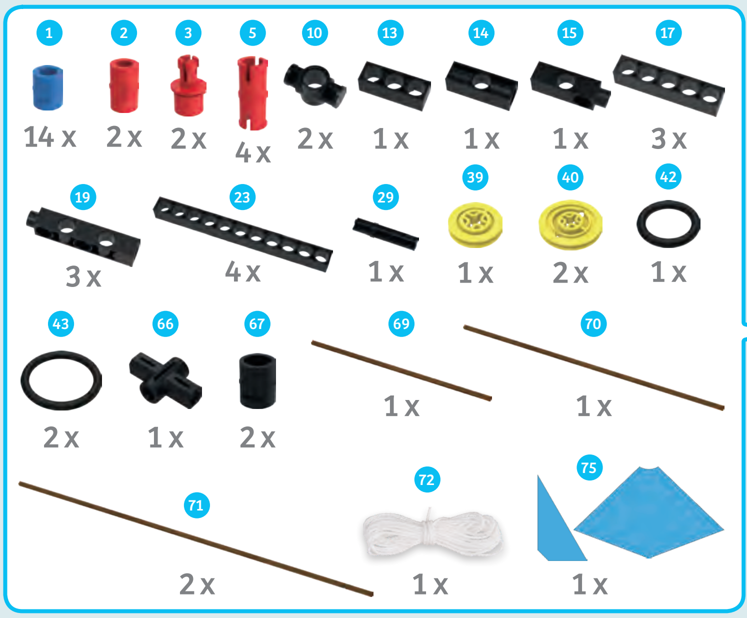


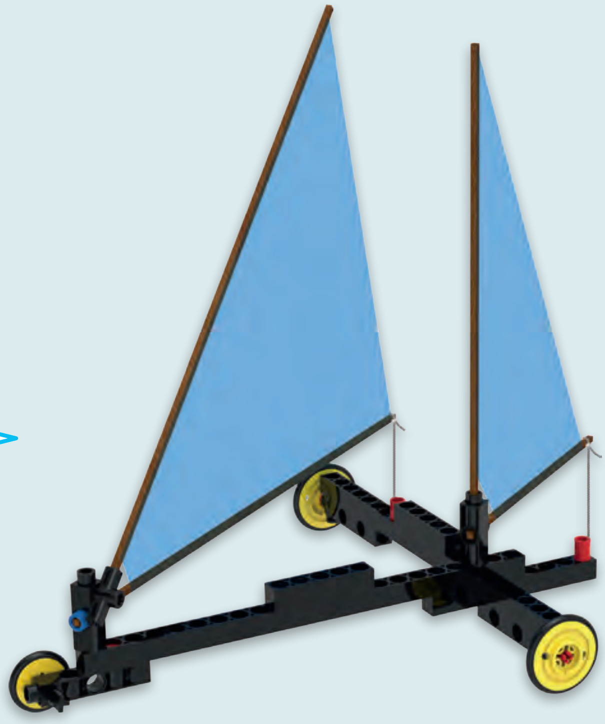
DID YOU KNOW?

Skillful sailors can even sail their boats against the wind. To do so, they position the boat and the sails at an oblique angle to the wind and apply the Bernoulli e ect. When the boat is moved out of the wind, its direction is altered slightly, so that the wind is hitting the sail from the optimal angle once again. This kind of sailing is called "tacking."



LAND YACHT





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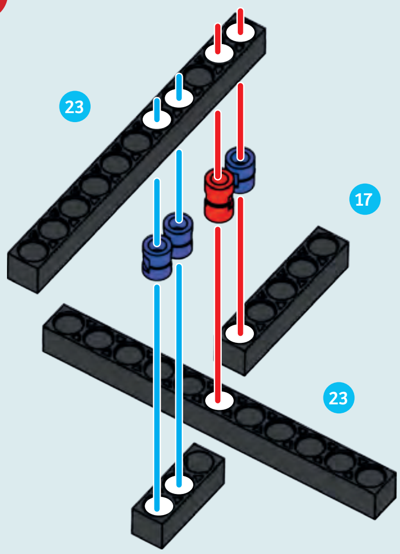

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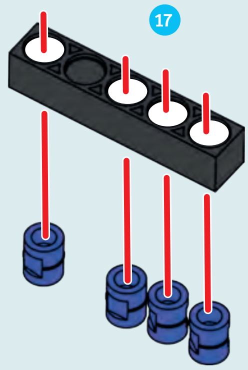

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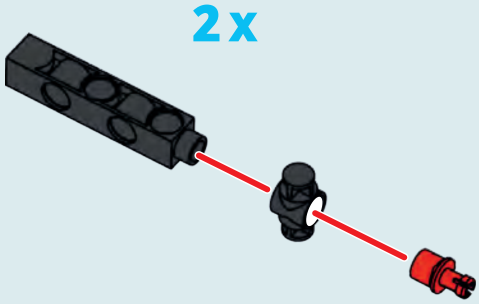

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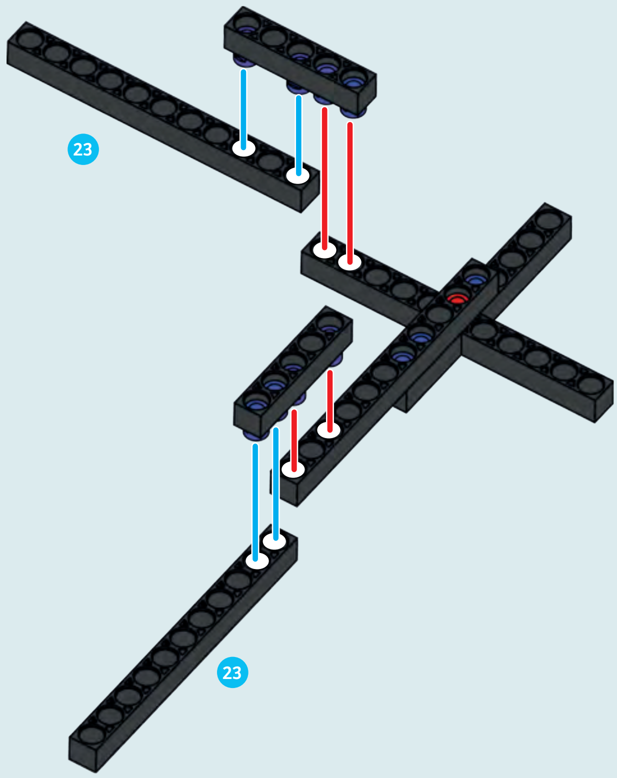

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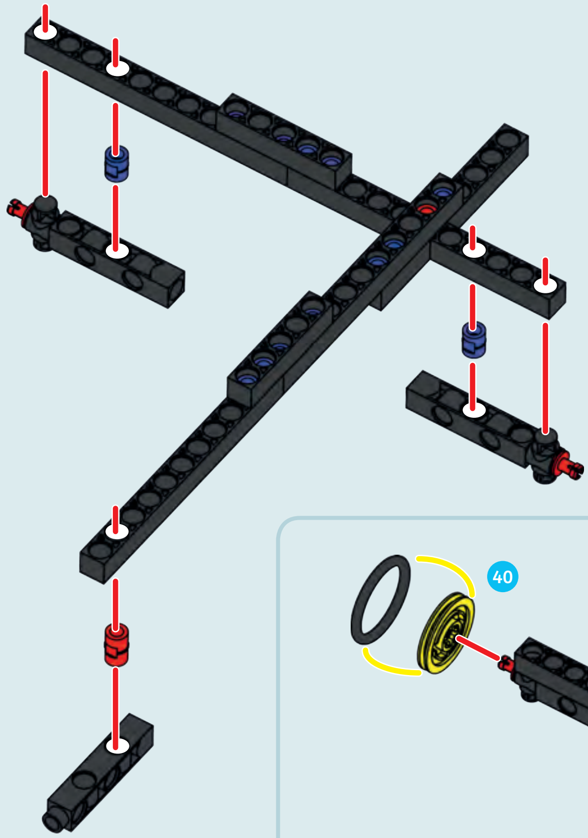

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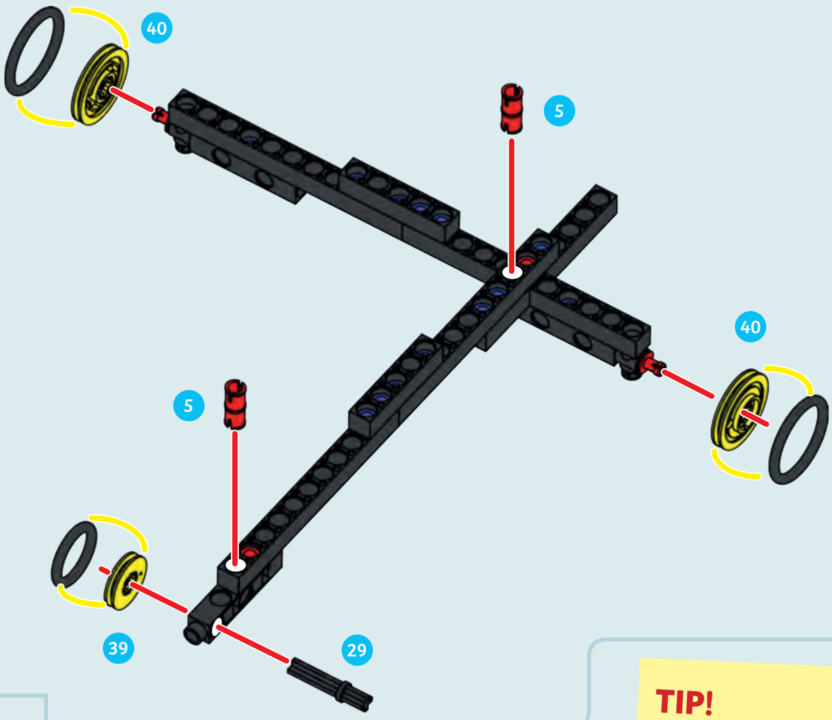

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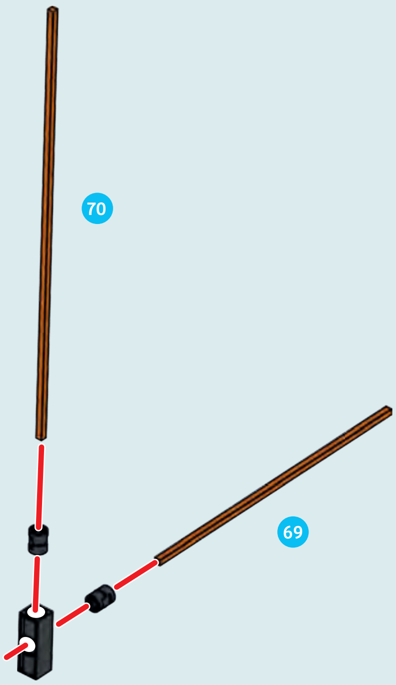

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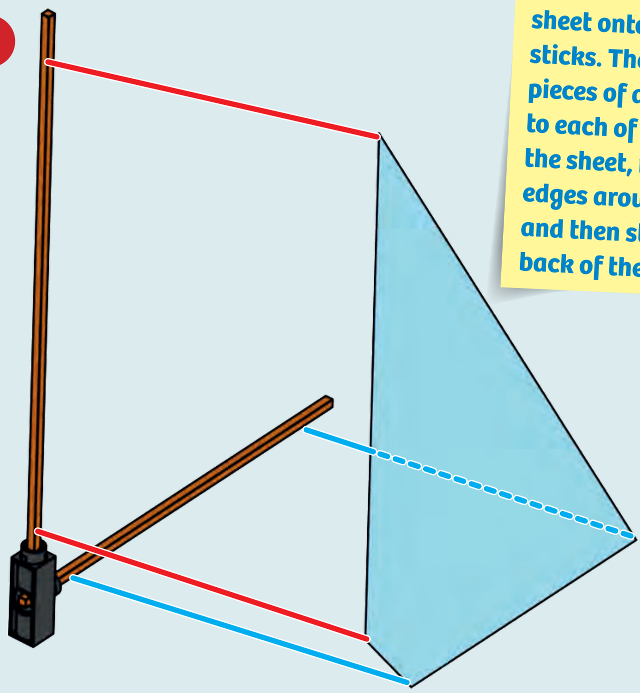

TIP!
Place the edges of the sheet onto the bamboo sticks. Then a ach two pieces of adhesive tape to each of the edges of the sheet, roll these edges around the sticks, and then stick to the back of the sheet.

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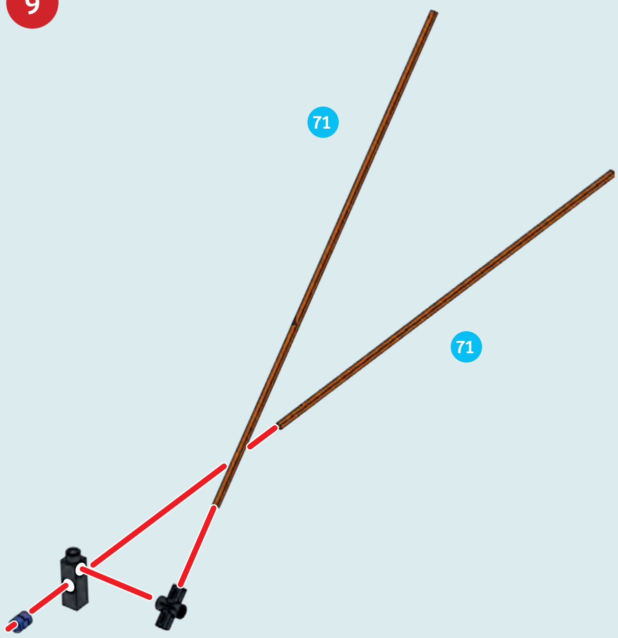

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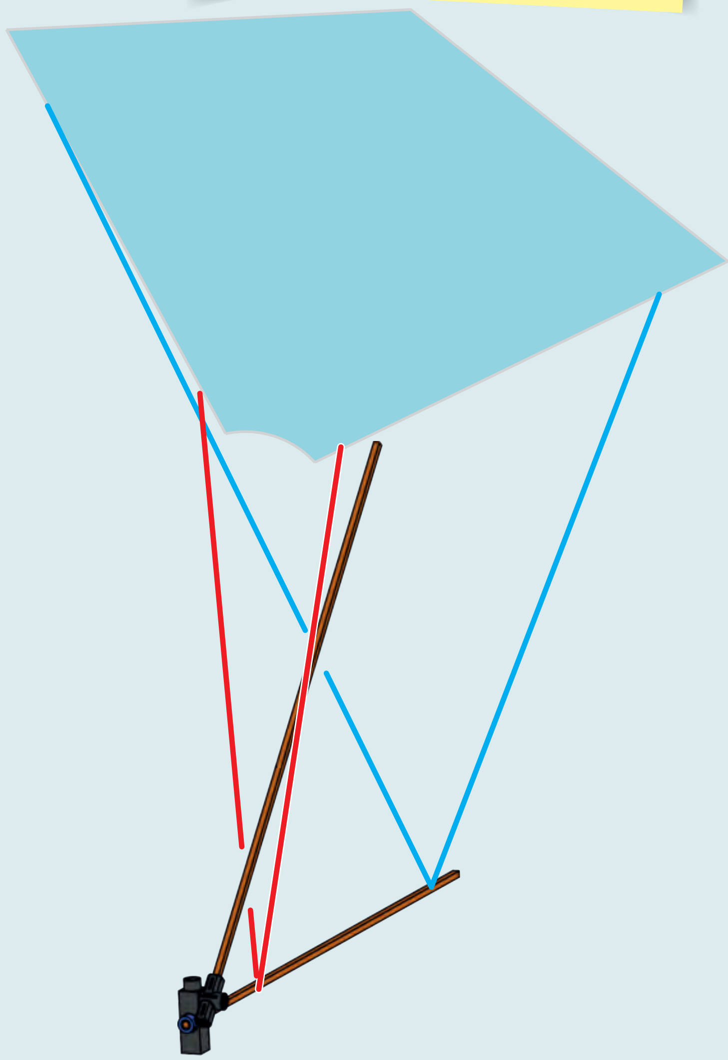
TIP!
Place the large sheet over the upper bamboo stick and a ach it to the lower stick using adhesive tape, so that the tape is sticking to both the sheet and the bamboo stick.



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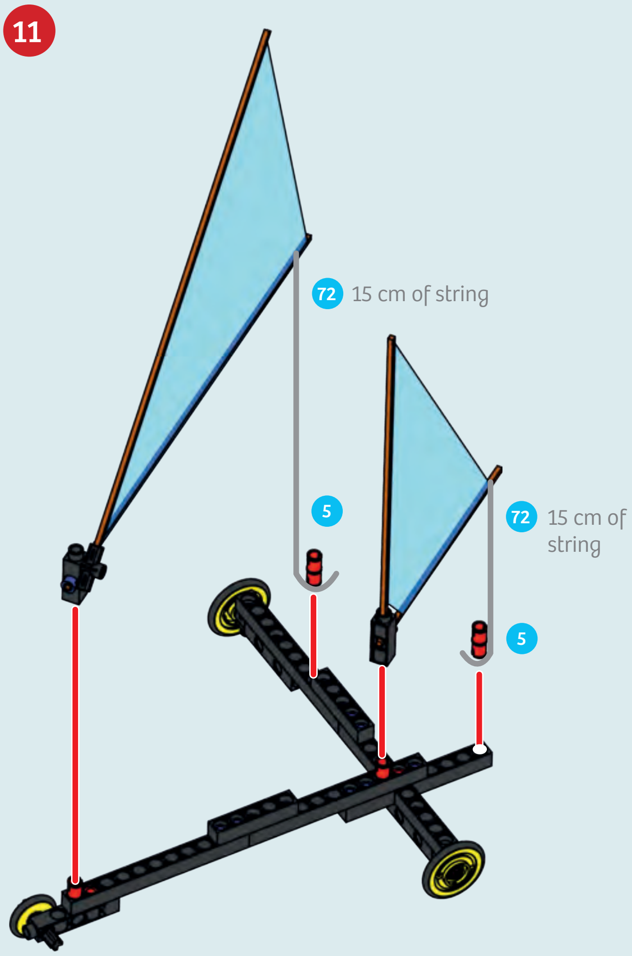
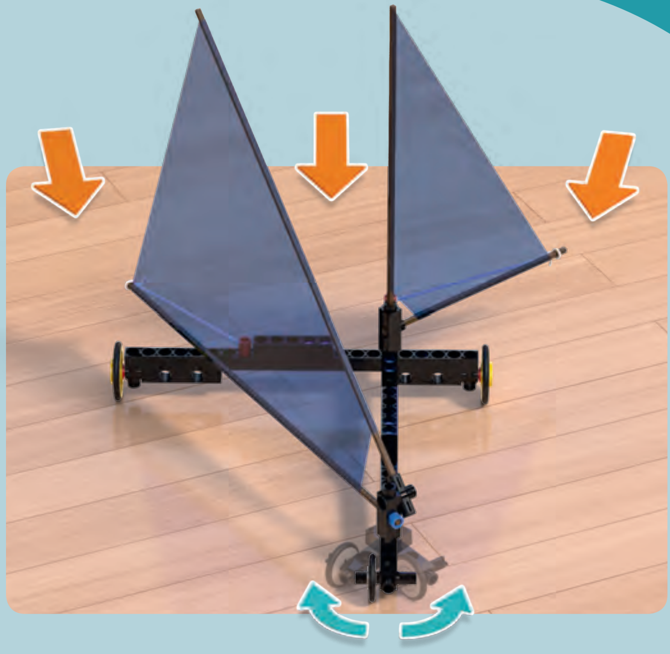


Done!

EXPERIMENT 12

Land yacht



YOU WILL NEED

- **The assembled land yacht**
- *The smoothest ooring possible, such as tiles, laminate, parquet, etc.*
- *Measuring tape (e.g. the measuring tape you created as part of the surveyor's wheel experiment)*

HERE'S HOW

1. Point the front wheel straight ahead and set the sails out fully, with the large sail to the right and the smaller one to the left.
2. Now you can blow on the sails from behind. How far does the land yacht travel?
3. Now turn the front wheel a li le to the left and measure how far the land yacht travels again.
4. How far does the yacht go when the front wheel is turned a li le to the right?

WHAT'S HAPPENING ?

When you blow on the sail, you exert a force on the sail. This force can be calculated by multiplying the pressure di erence by the surface area. This is what enables the land yacht to take o . When the front wheel is pointing straight, the yacht will travel straight ahead — even when the sails are at an angle. This is due to the position of the wheel. However, when the wheel is slanted at an angle, the land yacht also goes in this direction. As the sails are di erent sizes, the yacht travels be er to the left than it does to the right.

WANT TO FIND OUT MORE?

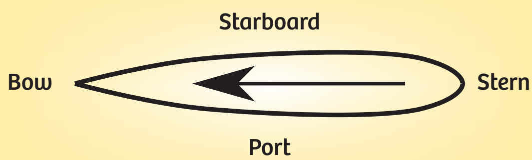
Try out your land yacht on a windy day outdoors using a smooth surface.

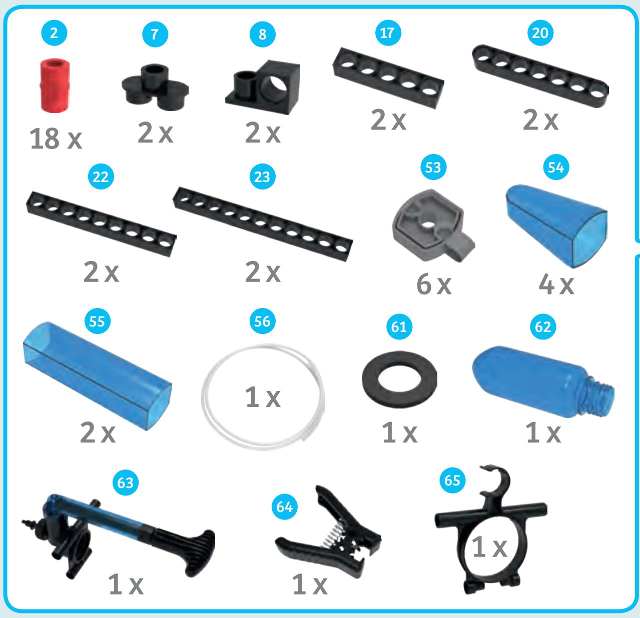
DID YOU KNOW?

The function carried out by the front wheel here is carried out by the rudder on a boat. However, the di erence is that the rudder is a ached to the stern of a boat. Because of this, steering has a noticeably stronger e ect than if the rudder were a ached to the bow. The same applies to road vehicles. Forklifts, for example, have steerable wheels at the back and front, as this makes them much more maneuverable.

KEY CONCEPT: BOW AND STERN

The terms **bow** and **stern** are seafaring terms. The bow is the front part of a boat while the stern is the back part of the boat. Two other terms come up in the nautical context: **port** and **starboard.** When looking from the stern to the bow, starboard is on the right and port is on the left. If you only used "left" and "right" when on a boat, you would quickly get confused, because they change depending on which direction you're facing. With port and starboard, everyone is always clear about direction, regardless of which way they're facing.

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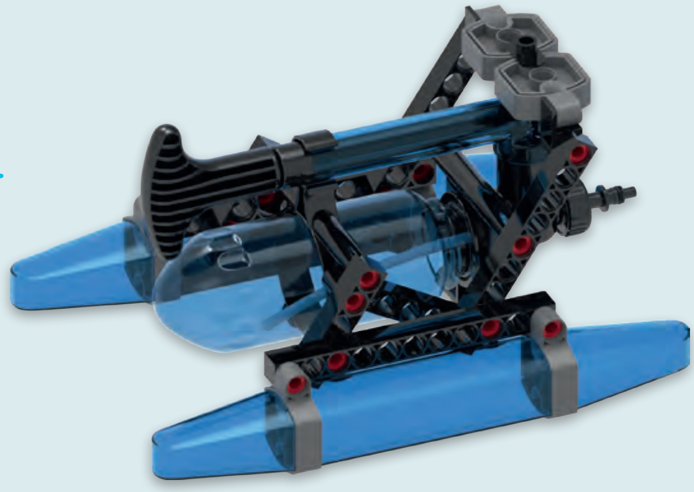

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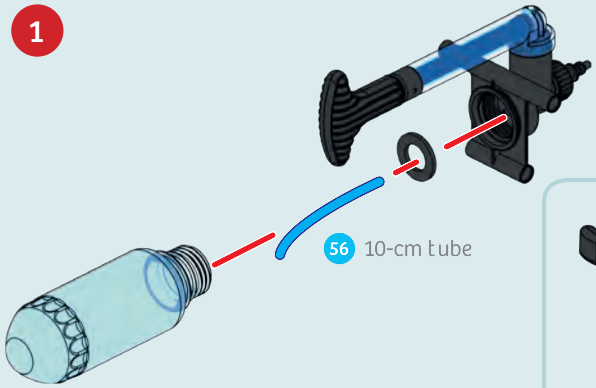
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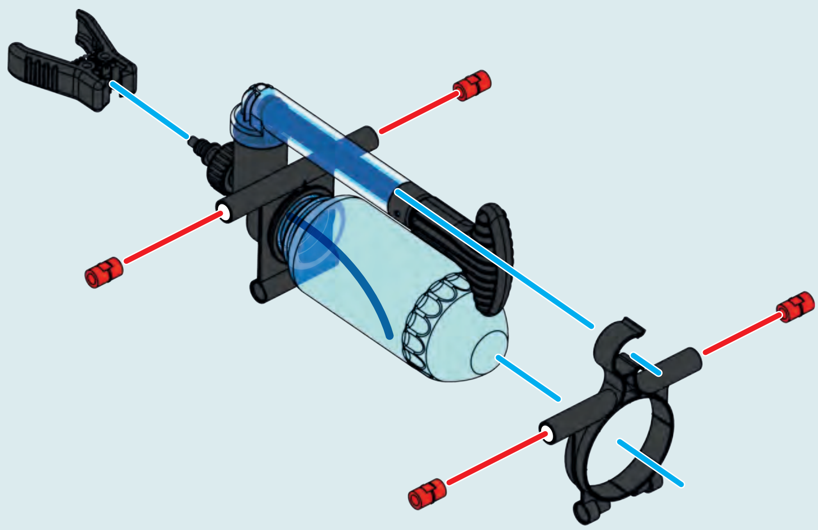

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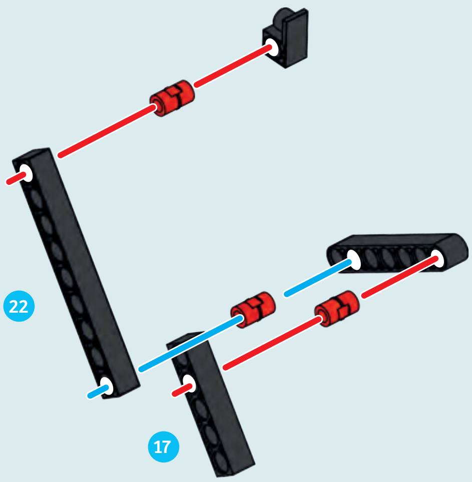
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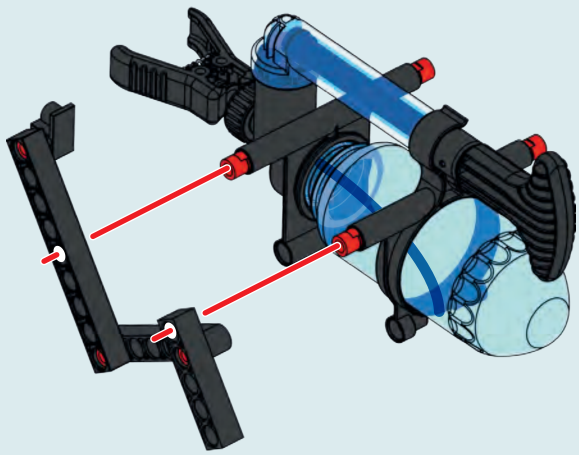

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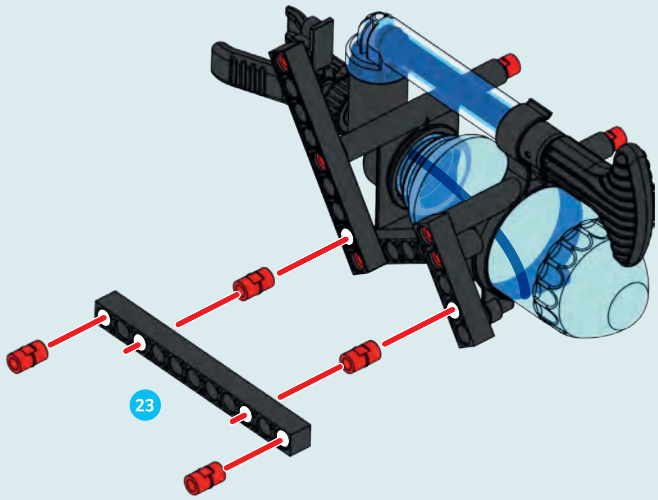

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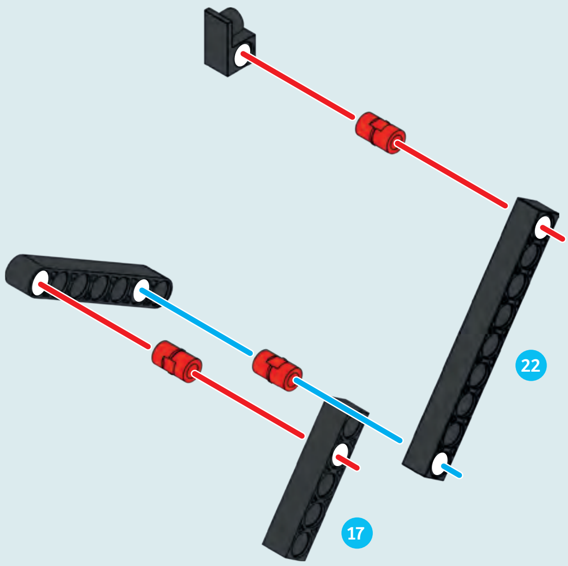

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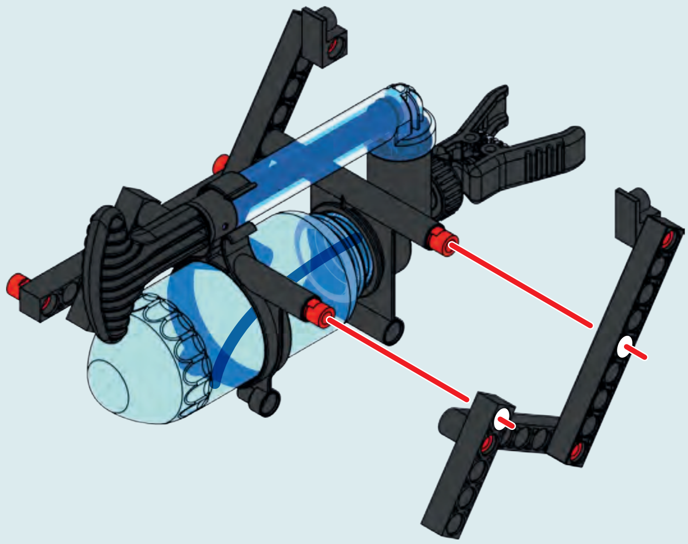

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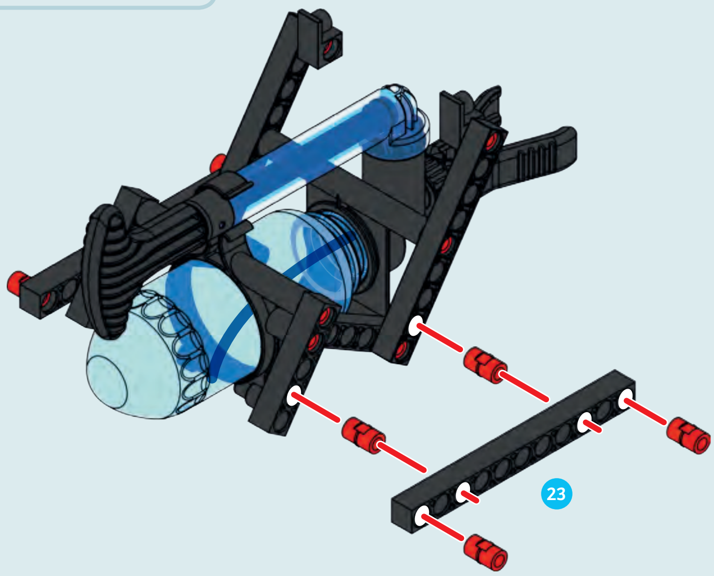

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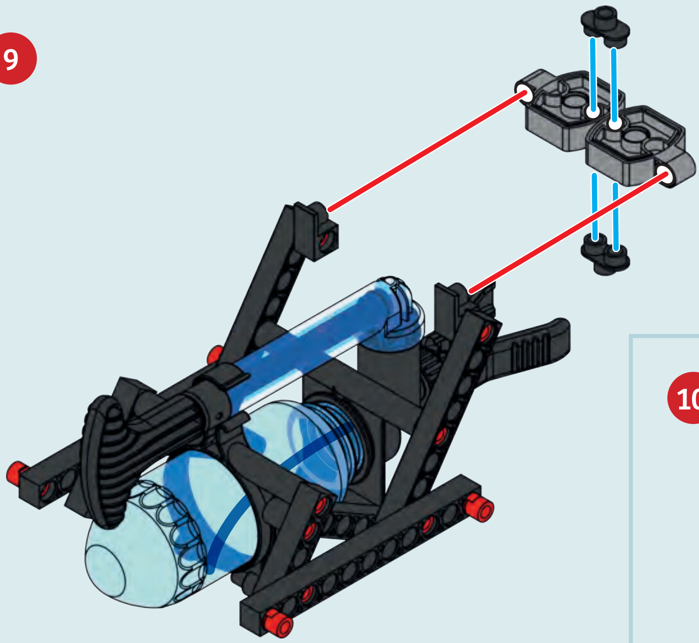

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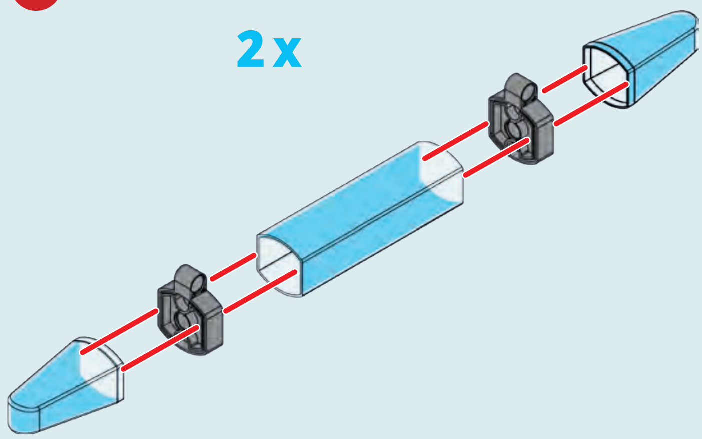

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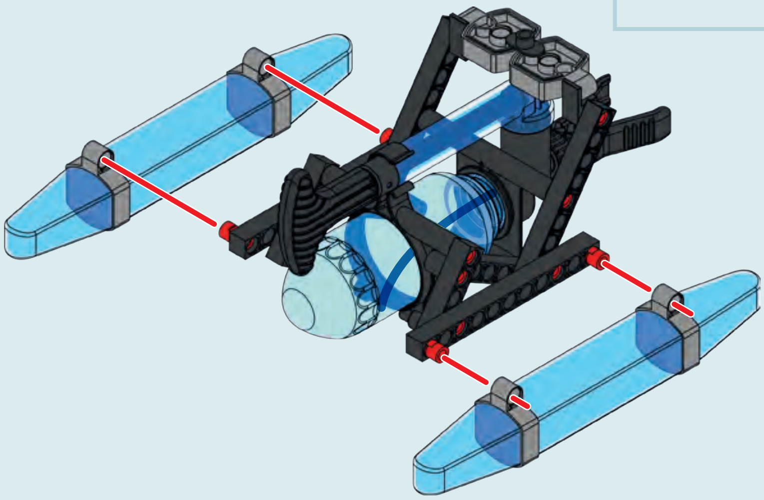

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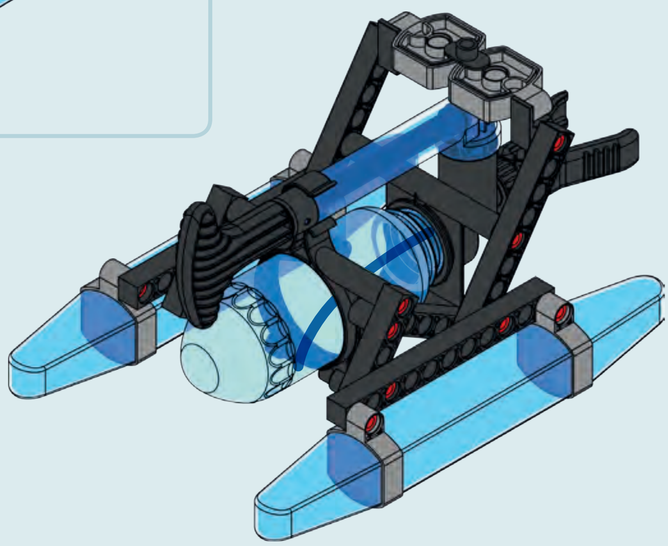
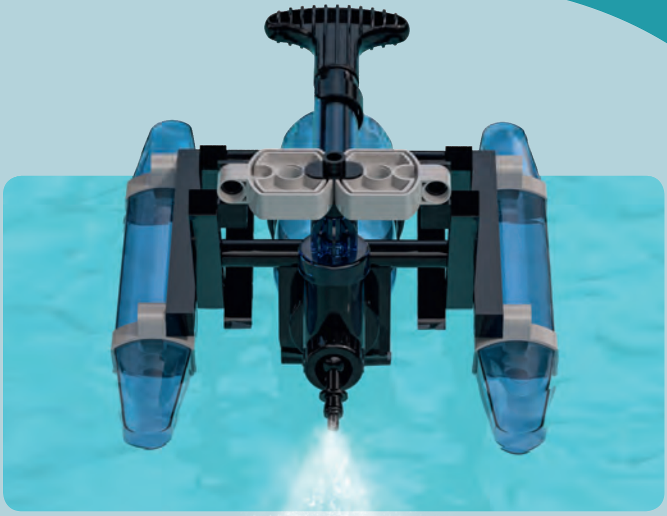


EXPERIMENT 13



Jet boat

YOU WILL NEED

› **The assembled jet boat**
› *A large water container, e.g. a fi led bathtub or a paddling pool, etc.*

HERE'S HOW

1. Place the jet boat on the water and make sure the clamp is securely a ached to the nozzle of the pressurized air tank.
2. Now pump air into the pressurized air tank (pump between 30 and 50 times).
3. Now when you remove the clamp, the air will ow out and propel the boat forward.
4. Try this a few times.
5. Unscrew the pressurized air tank, half-fi l it with water and rea ach the tank to the boat.
6. Now seal the nozzle with the clamp and pump again (pump between 30 and 50 times).
7. When the clamp is removed, a combination of air and water ows out. Is the boat any faster now than it was before?
8. Adjust the nozzle and check out what happens.

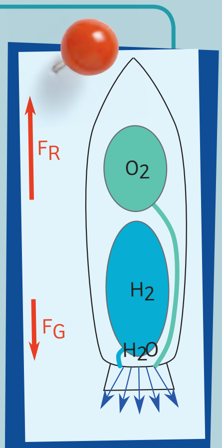
KEY CONCEPT: MOMENTUM

Like mass and energy, **momentum** is a physical quantity that doesn't change. To find the momen um of an object, you multiply its mass by its velocity. If an object's momentum changes over time, it means a force is being exerted. Now you can understand why the boat

accelerates more quickly when it has water in its tank. The density of the water is around 850 times higher than that of air.

DID YOU KNOW?

The same principle is used in jet engines and rockets. In this case, a combustible material, like kerosene or hydrogen, is burned and the exhaust gases are accelerated as a result of passing through a nozzle. Once the ratio of internal to external pressure is a li le higher than two, the air in the narrowest parts of the nozzle reaches the speed of sound.



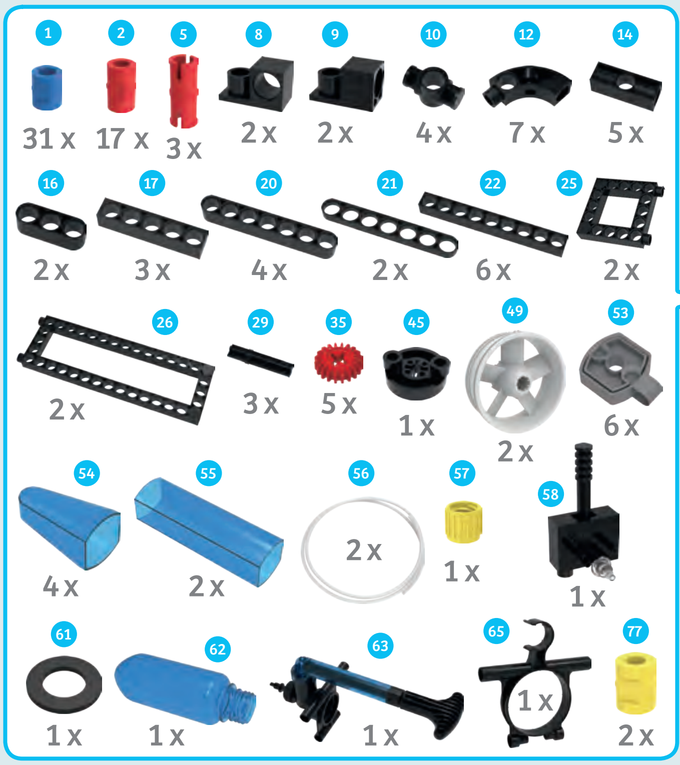
WHAT'S HAPPENING?

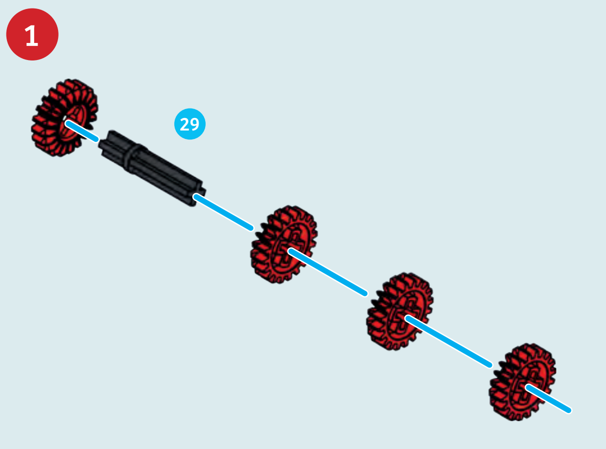
The air accelerates as it ows out of the nozzle. The force that occurs in the process also a ects the boat. This is known as the law of action and reaction. In this case, it doesn't actually ma er whether or not the air hits the water. When a combination of air and water ows out of the nozzle, as opposed to just water alone, the force becomes noticeably stronger. This accelerates the boat much more quickly. As the nozzle is movable, you can use it to steer the boat.

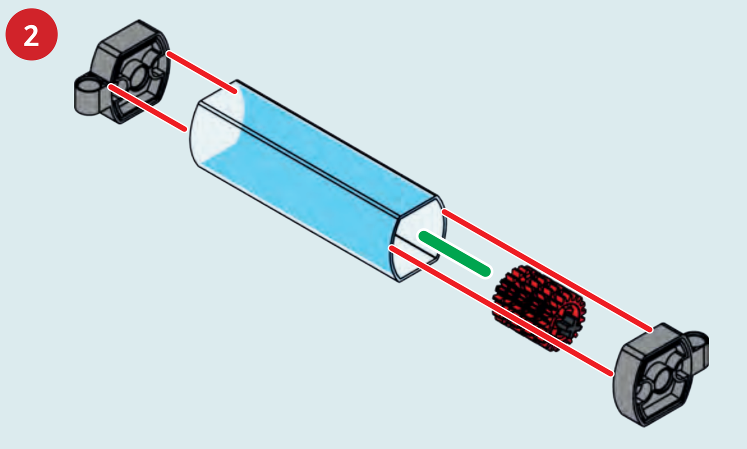
WANT TO FIND OUT MORE?

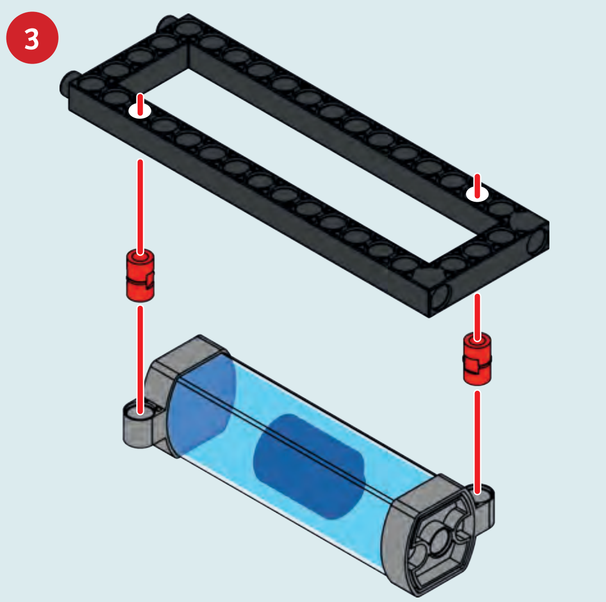
If you build a small rocket using the pressurized air tank and a small frame, you can test whether the momentum of the air-water combination is enough to allow the rocket to take off in a ertical position. This is best done outside in an open green space. Once again, half-fi l the pressurized air tank with water and pump air into it. If you now hold the rocket upright, so that water can escape downward from the nozzle, there's a good chance that the rocket might take o .

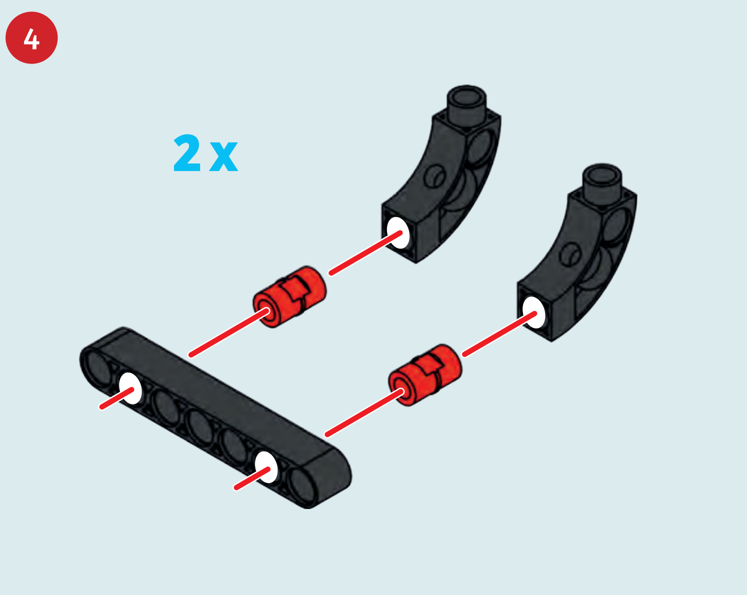
SUBMARINE AND PUMPING STATION











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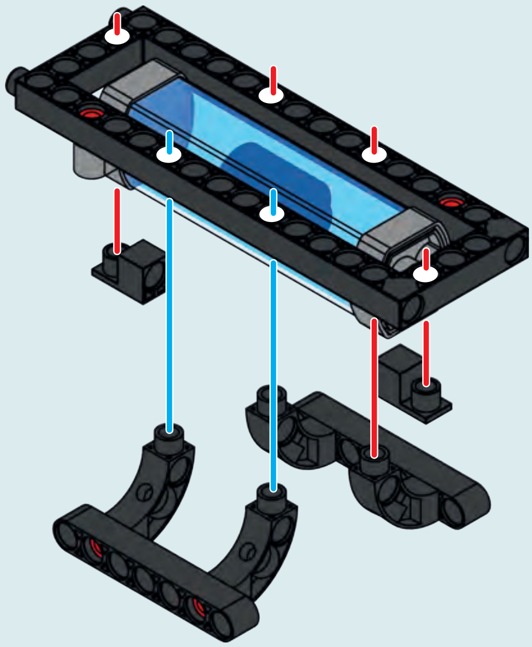

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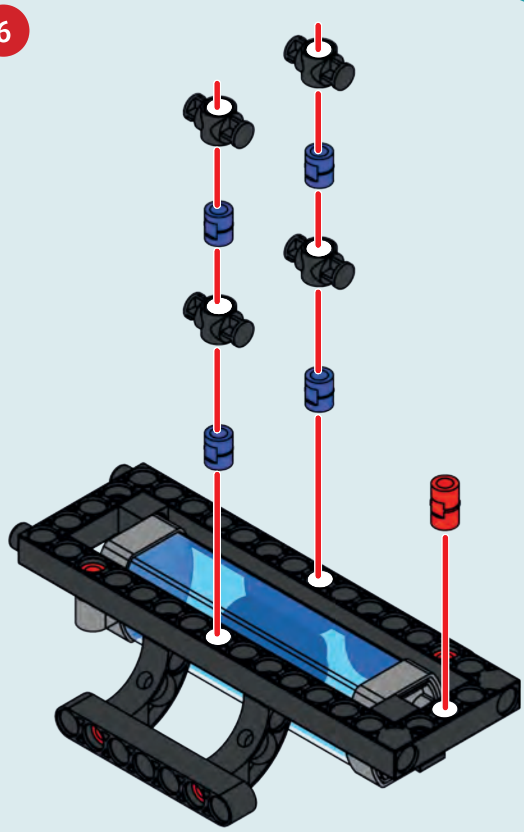

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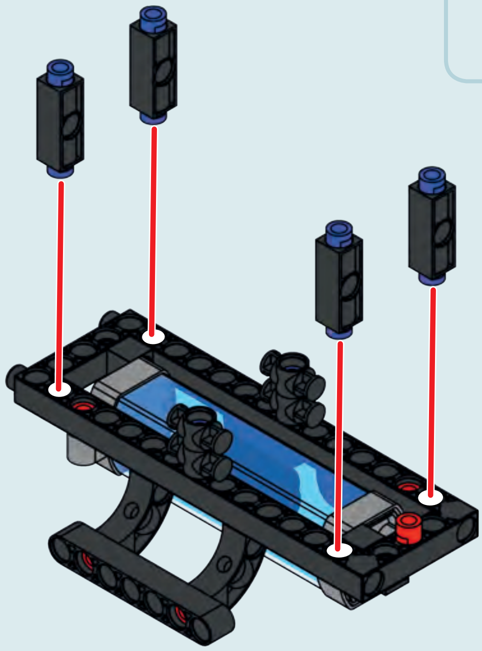

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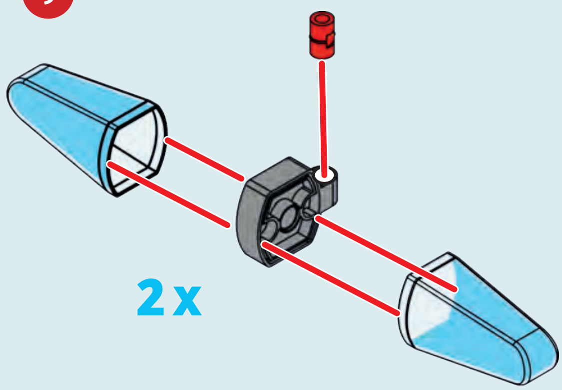

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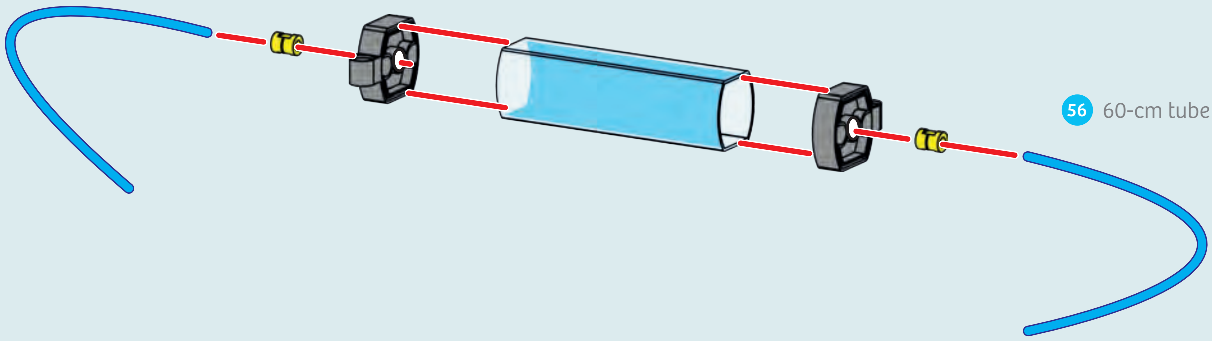

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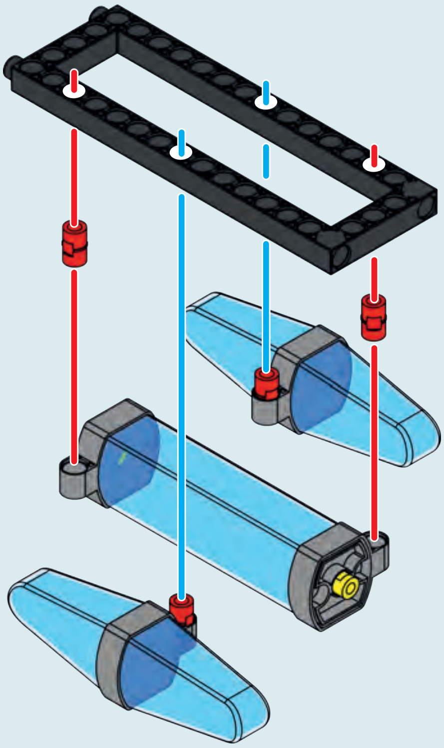

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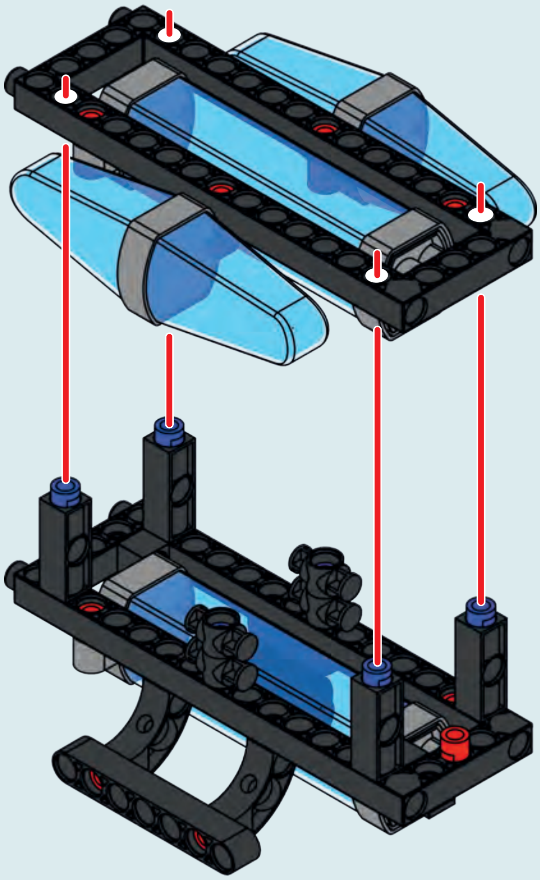

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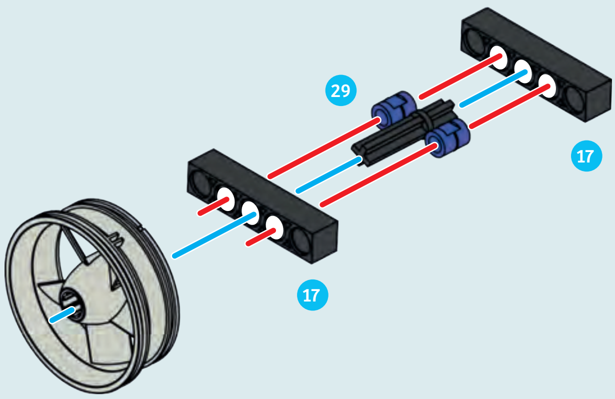

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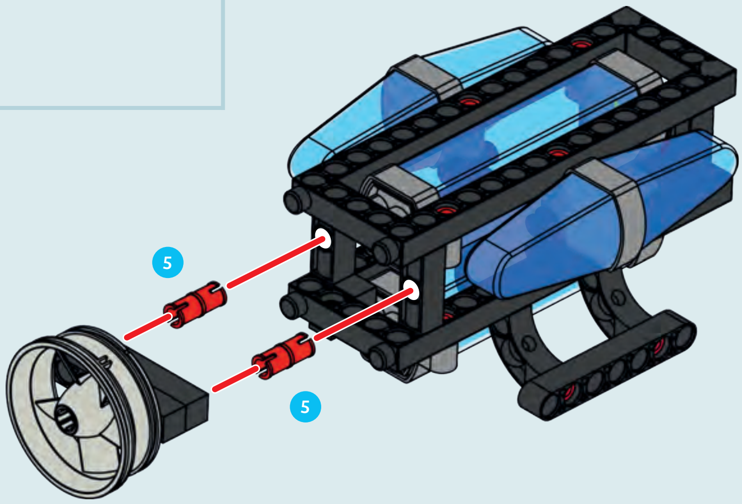

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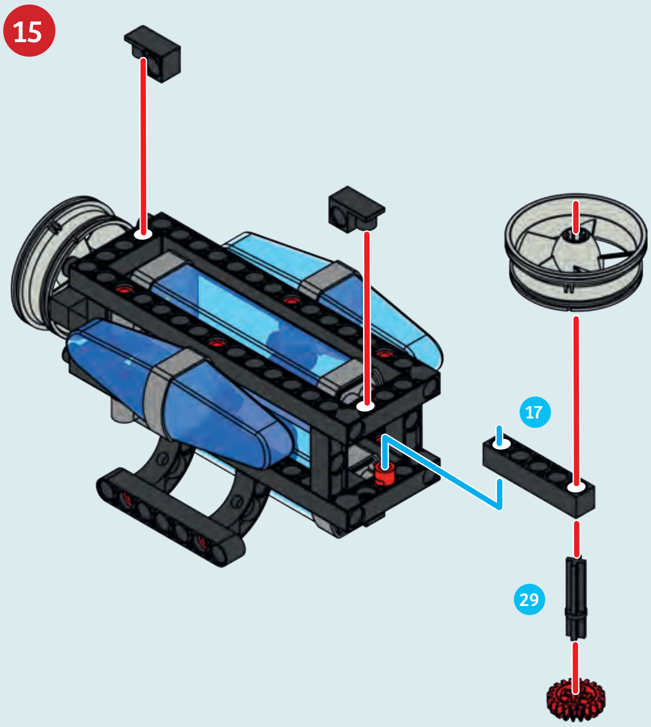

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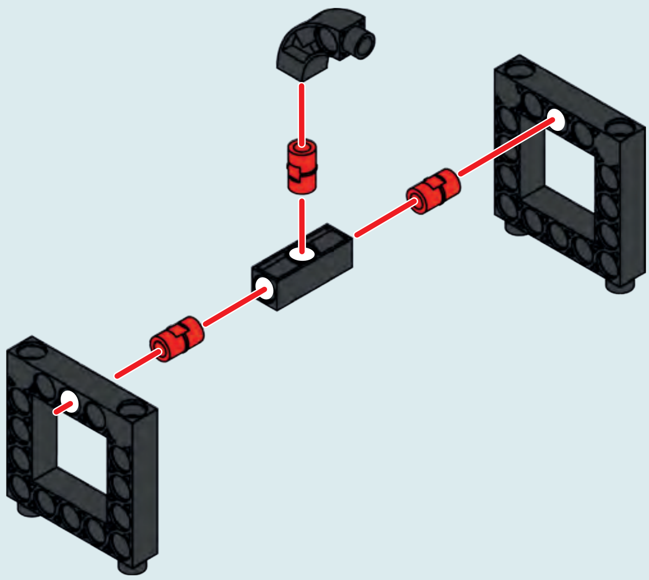

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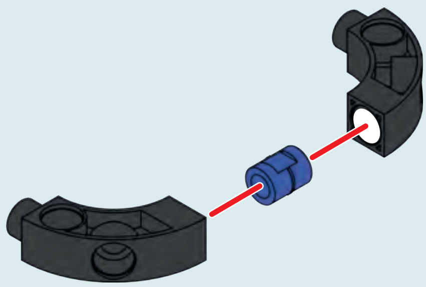

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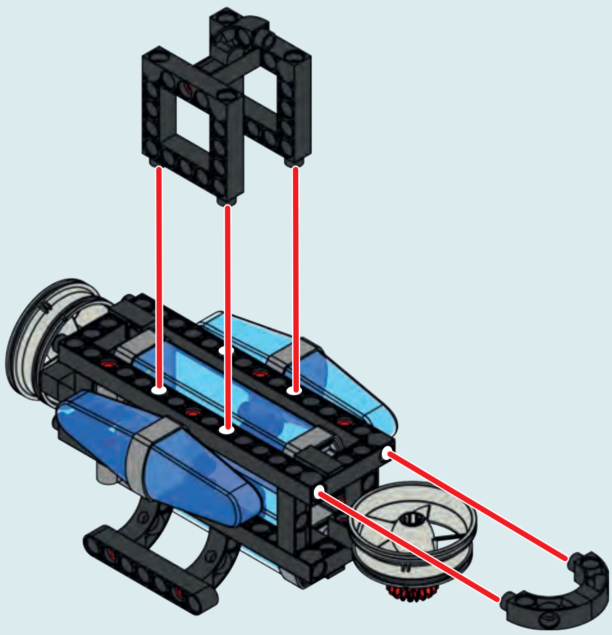

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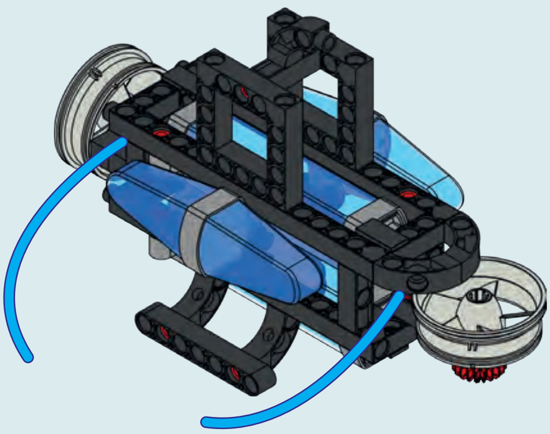

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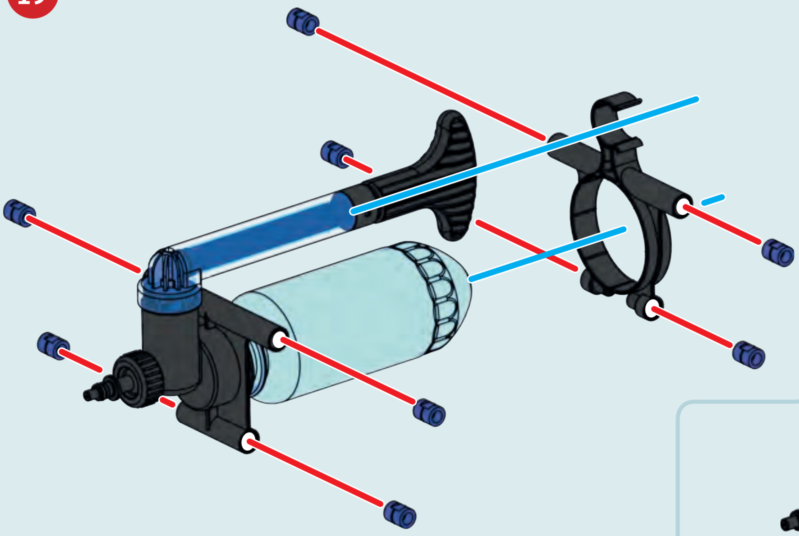

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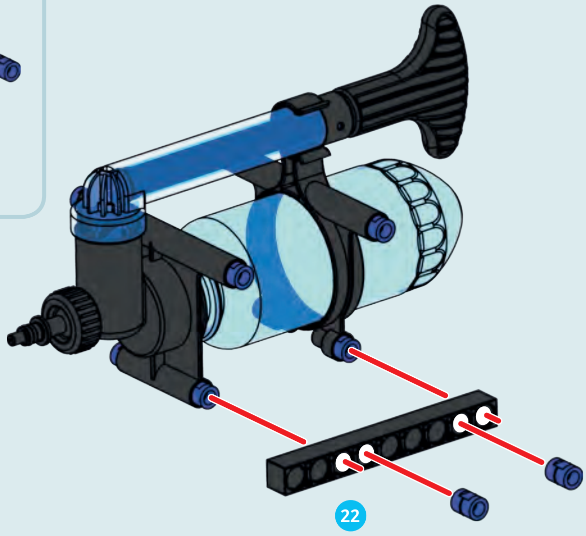

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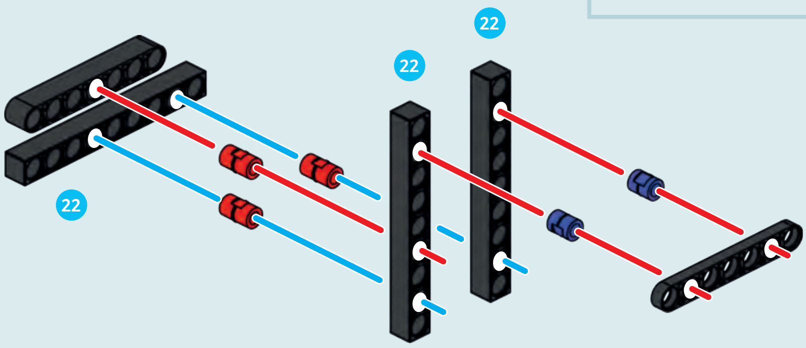

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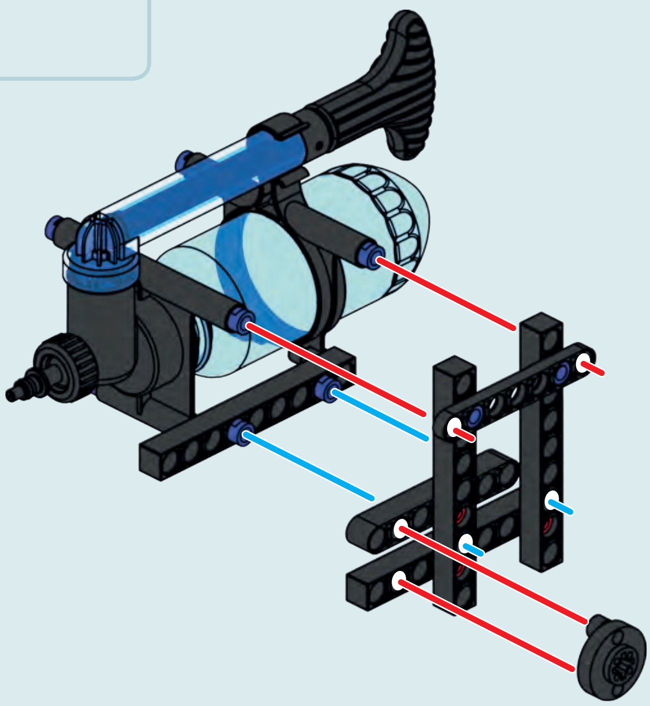

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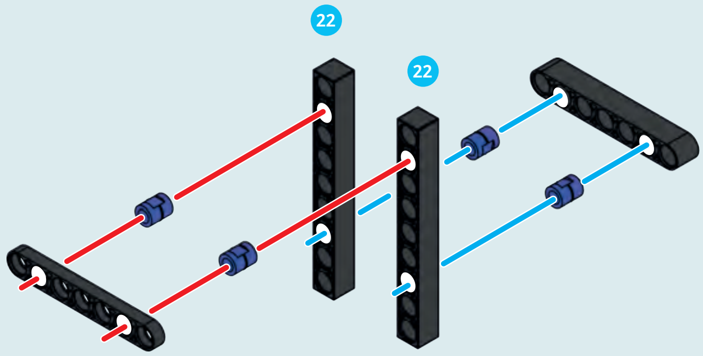

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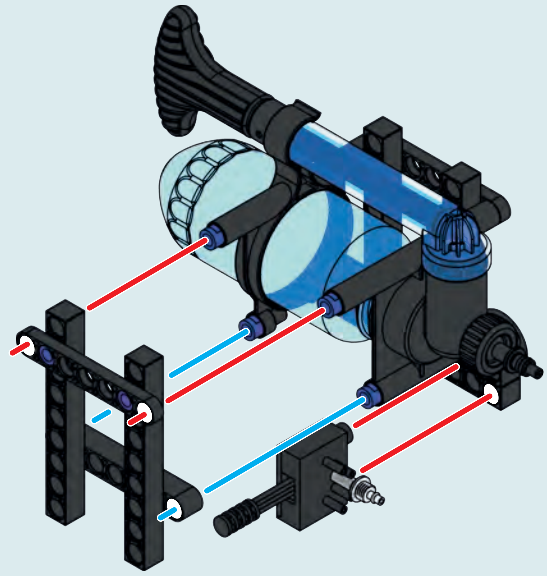

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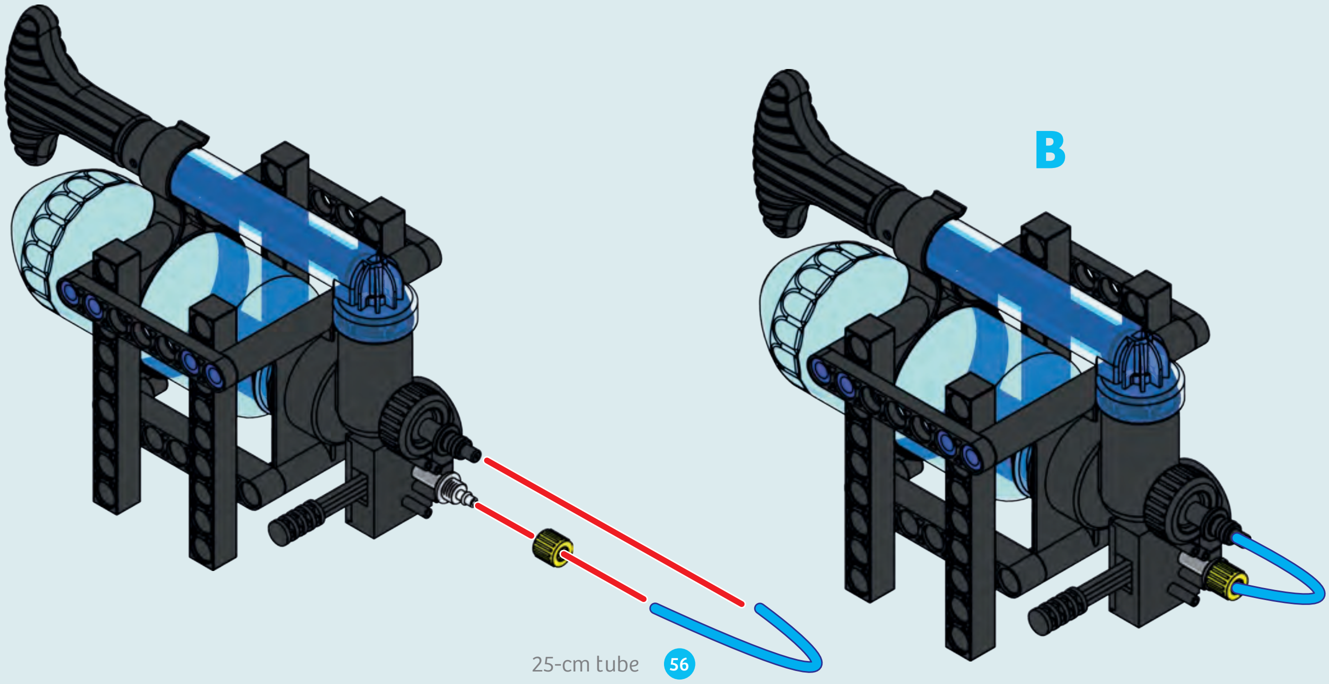

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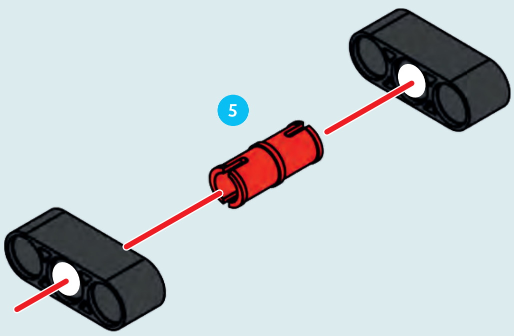

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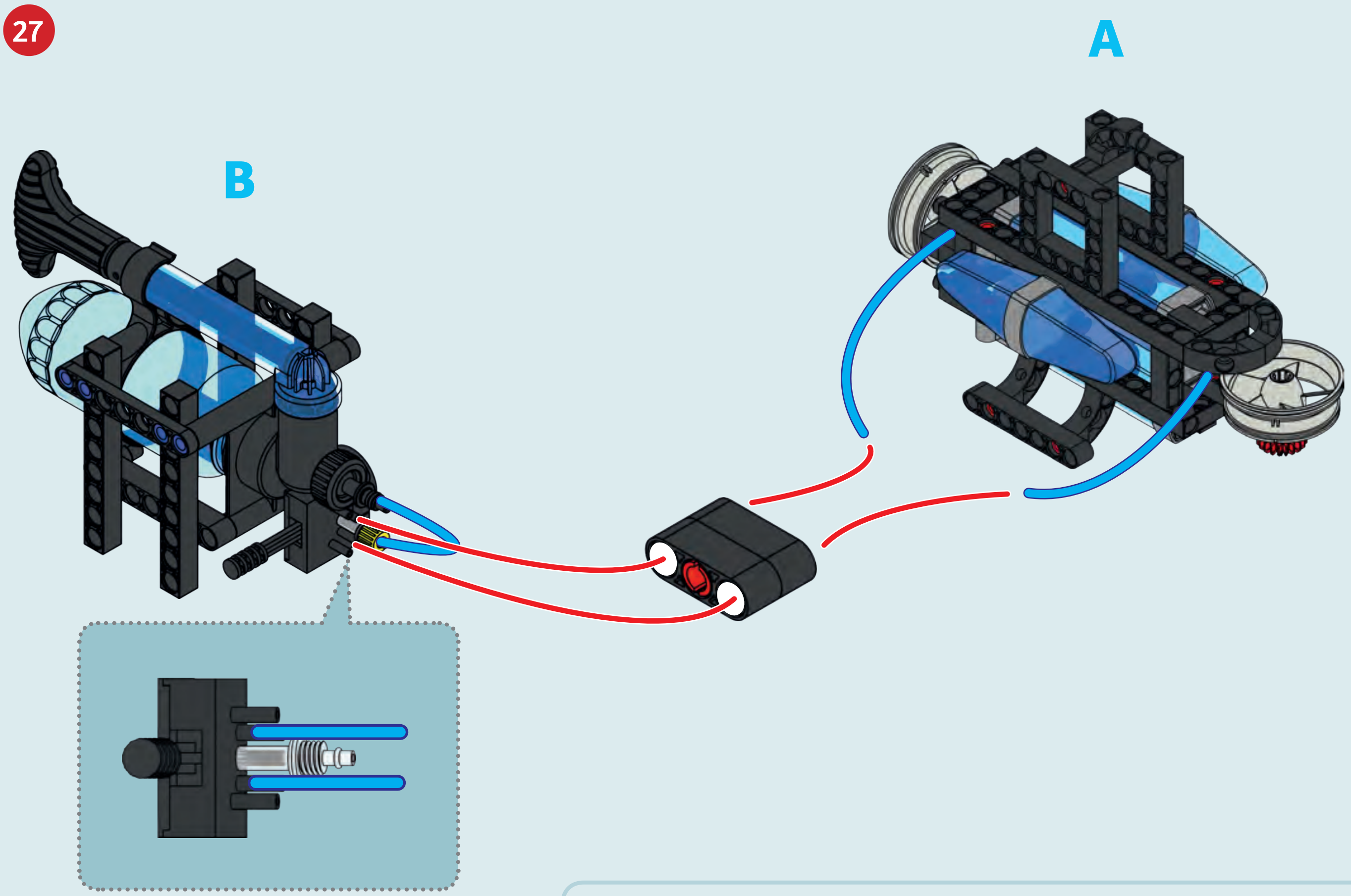
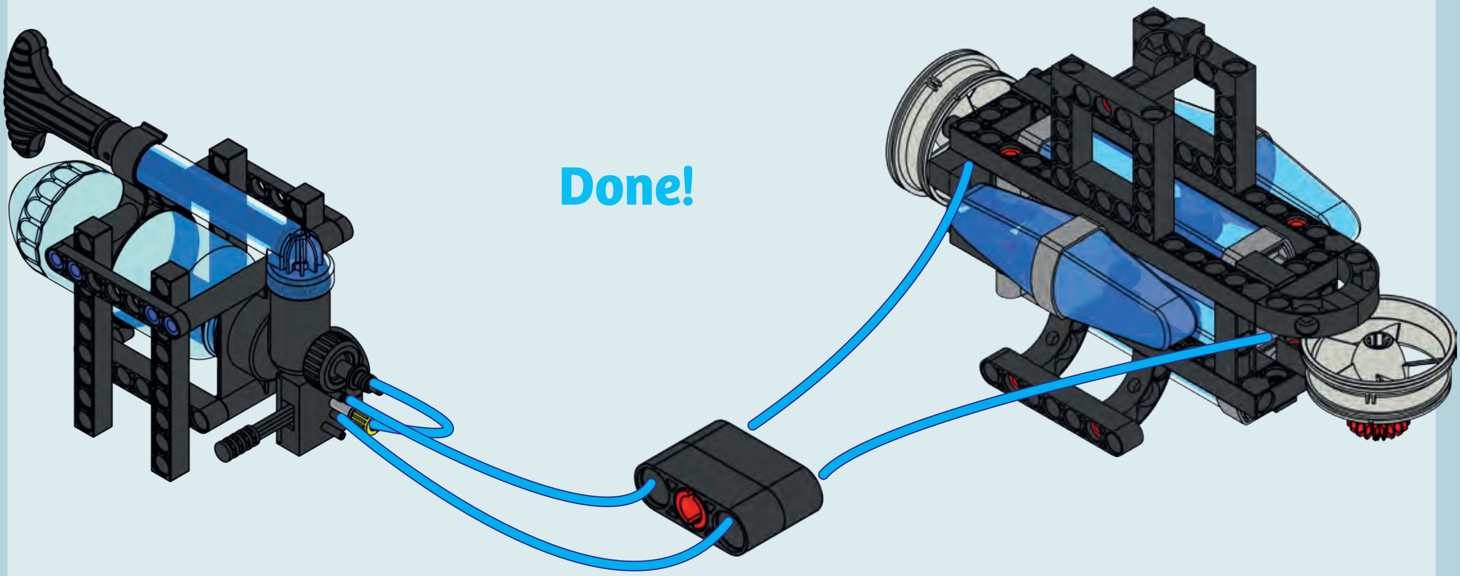
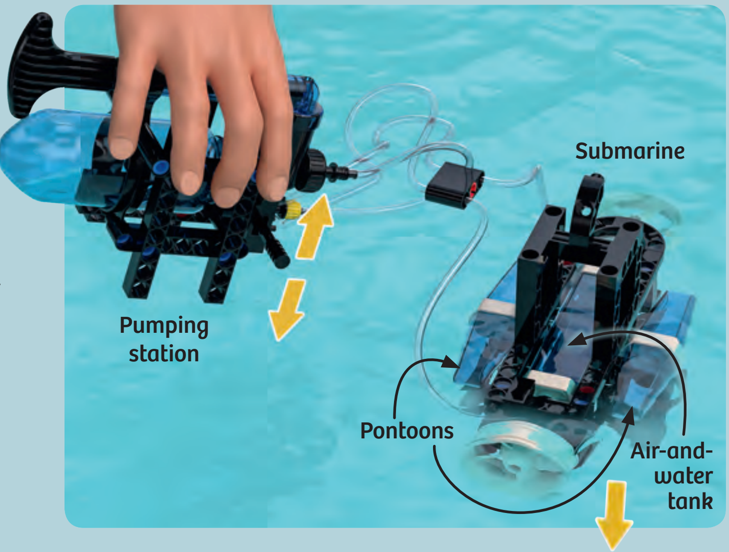




EXPERIMENT 14

Submarine and pumping station



YOU WILL NEED

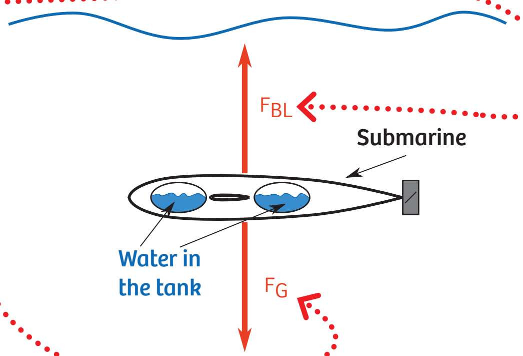
› **The assembled submarine and pumping station**
› *A water container, e.g. a large bucket or a plastic tub, etc.*
› *125 grams of washers, or 22 quarters (coins), for ballast*

HERE'S HOW

1. For the submarine to submerge, you have to prepare it as described below.
   a. Add the ballast (e.g. washers or coins), weighing about 125 g, to the two ballast tanks, to the left and right of the red gear, so that the submarine stays horizontal. At around 125 g of ballast, the pontoons should still be just about visible above the water.
   b. Now, using the pumping station, half-fill the tank with water and reattach it to the submarine.
   c. Move the switch to the center position and pump between 20 and 25 times.
   d. To submerge the submarine, hold the pumping station with the tube connections pointing downward and move the switch; it doesn't matter what direction you move it in.
2. To allow the submarine to surface again, move the switch to the center position and pump between 25 and 30 times. As you're doing this, the pumping station must be positioned so that the tube connection is pointing upwards. Then you can move the switch.
3. To resubmerge the vessel, water must be pumped into the submarine's tank again. This means that you must move the switch to the center position, half-fill the tank with water again if necessary, hold the pump station pointing downwards, and then move the switch.

WHAT'S HAPPENING?

If a submarine is of equal weight to the right and the left, gravitational and buoyant forces will balance each other out. If water enters the submarine's tank at this point, then the **gravitational force** will increase and exceed the **buoyant force.** This causes the submarine to sink. When the submarine is surfacing, air is reintroduced into the tank, which displaces the water — the submarine becomes lighter and can ascend.

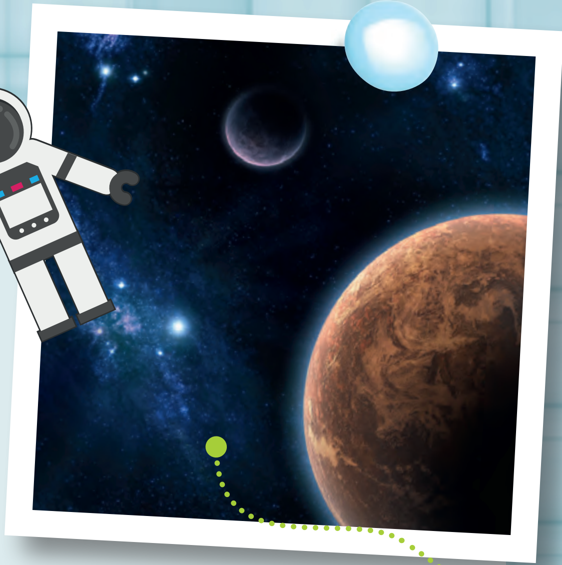


DID YOU KNOW?

Modern submarines are high-tech vessels. This is why they are able to stay under water for weeks at a time. Air and water are treated and recycled, so that the sailors can live there on a daily basis. Submarines are driven by high-powered electric engines. During submersion, these engines are powered by a nuclear reactor or batteries. When a submarine is traveling near the surface, diesel generators are generally used.

CHECK IT OUT

The reaction principle …



… it isn't necessary for a vehicle (such as a jet boat, or a rocket, etc.) to direct its jet stream against something solid. The ma er leaving the vehicle through the nozzle is sufficient by i elf. The vehicle e ectively pushes off the jet stream itself. This is why jet engines can also be used in **space,** where there's almost no ma er at all.

LIKE A FISH IN THE SEA

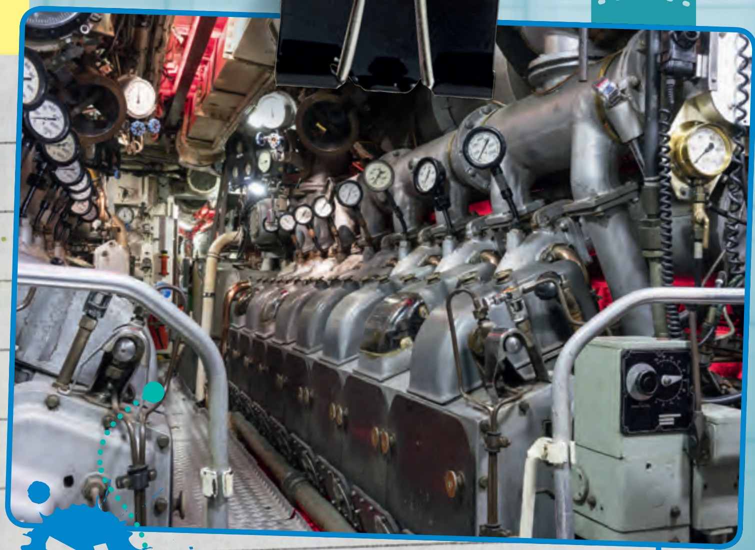
It's important for a **boat** to have a streamlined **hull,** so it can move easily through the water. This ensures that no eddies are formed when the current ows along the hull. Eddies cause ow resistance, which means the boat's engine has to expend more energy.

Do you know the di erence between **pneumatics** and **hydraulics**?

Essentially, they both describe the same thing; namely transport of a uid (a word for both liquids and gases) from one place to another through a conduit in order to carry out a particular task. Both terms originate from the language of the Ancient Greeks. Pneumatics is concerned with air **(pneumo)** while hydraulics is concerned with uids such as water **(hydro)** and **oil.**

Lookout

How do sailors in submarines see what's happening above the surface of water without ascending? Submarines have a **periscope** for exactly this reason. This is made out of a pipe and two mirrors, which are a ached to the inside of the pipe at an angle. The lower mirror is located in the submarine while the other one is above the surface of the water. If you look into the lower mirror, you'll see a re ection of what's above the water, i.e. what's shown in the upper mirror. If lenses are added, it can even act as a telescope.



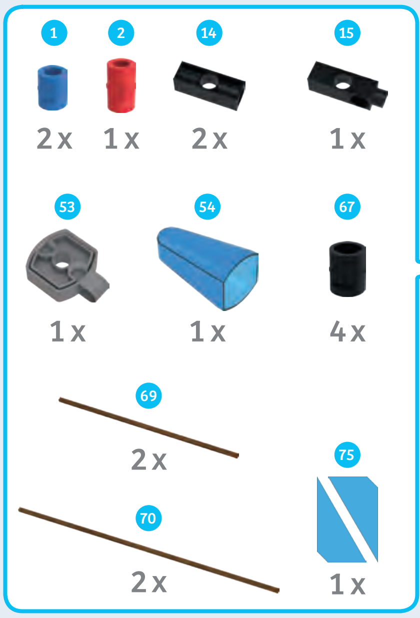
FULL SPEED AHEAD

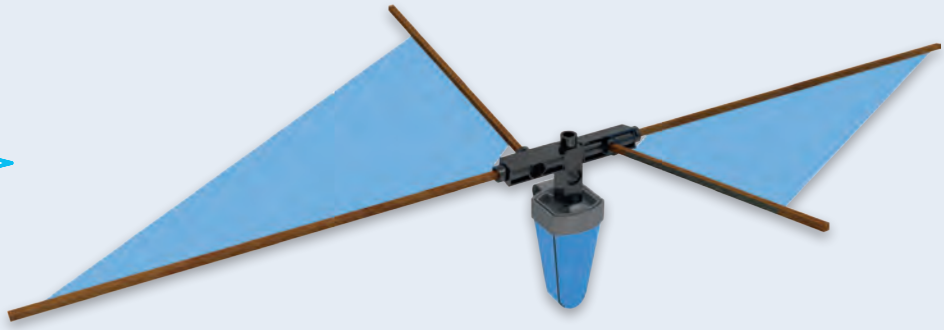
Submarines are powered by electric engines. The energy needed to power these engines comes either from diesel generators, nuclear reactors, or ba eries. When the submarine is on a dive, it doesn't have any spare air for burning diesel, so ba eries or nuclear reactors are used. Above water, this isn't a problem, so **diesel generators** can be used.

Up in the Air

Since ancient times, humans have been fascinated by flying. Some clever people — such as Leonardo da Vinci, for example — studied the flight of birds and designed flying machines. But it was Otto Lilienthal who, in 1891, first managed t o fly longer distances — several hundred meters in this case. Since then, progress has been made at a terrific pace. These experiments let you try out for yourself the many things that need to be kept in mind when flying.

SYCAMORE MAPLE SEEDS





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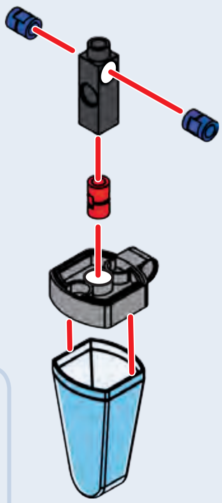

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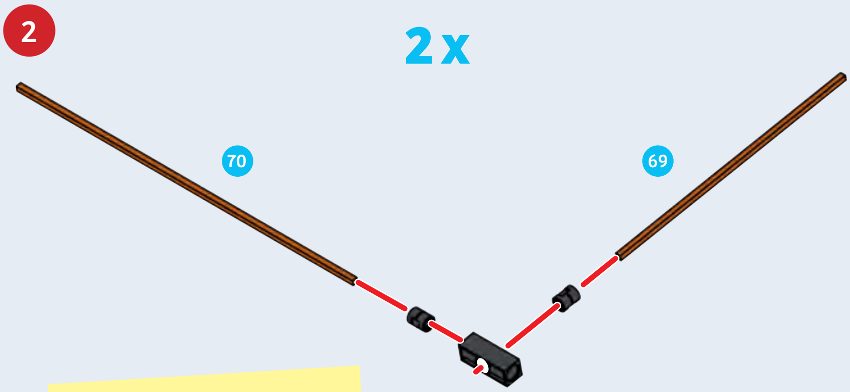

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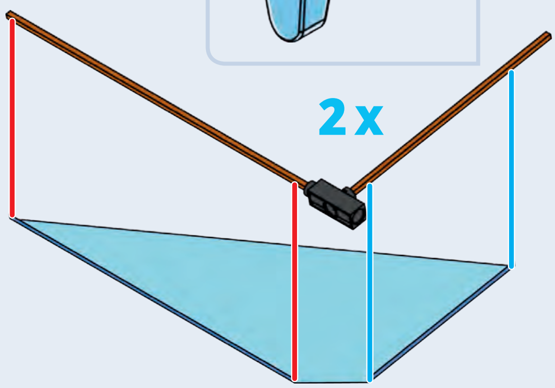
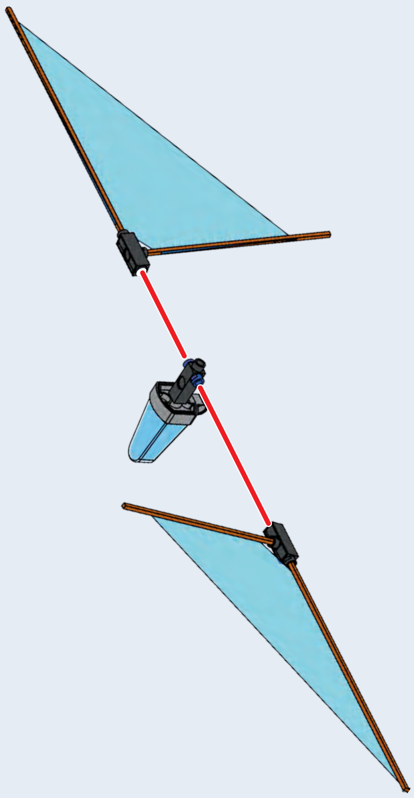


TIP!

Place the edges of the sheet onto the bamboo sticks. Then a ach two pieces of adhesive tape to each of the edges of the sheet, roll these edges around the sticks, and then stick to the back of the sheet.

4



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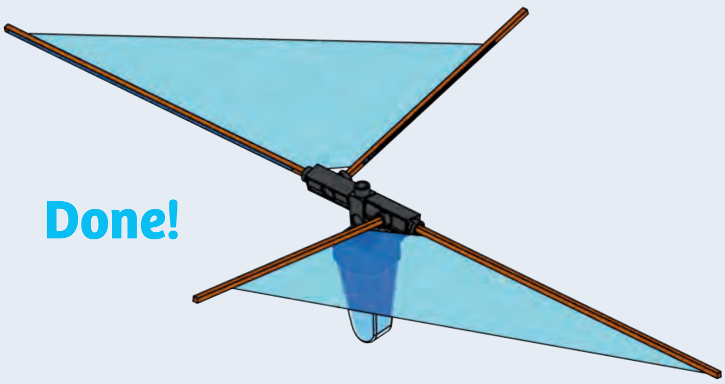
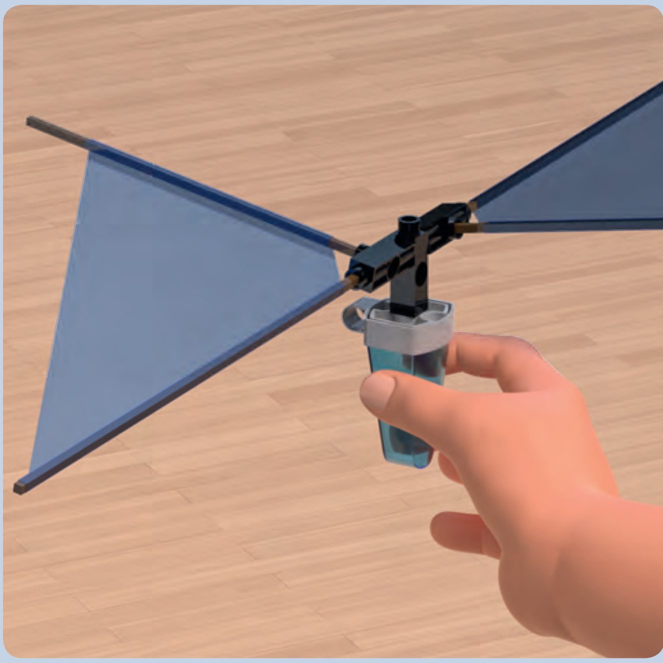


EXPERIMENT 15

Sycamore maple seeds



YOU WILL NEED

- **The assembled sycamore maple seed glider**
- *A chair*

HERE'S HOW

1. Rotate the wings so that they are both slanted upwards in the same way.
2. Now stand on a chair and hold the glider around the center.
3. Stretch out your arm and let the glider fall.
4. Now set the wings horizontally and let the glider fall again.

WHAT'S HAPPENING?

When you let the glider fall, the force of gravity pulls it to the ground. At the same time, the air ows along the diagonally positioned wings and exerts a force on the glider. This causes the glider to rotate. When the wings are in a horizontal position, the seed will just fall, swaying its way to the oor. This is because the air can no longer ow along a slope, meaning that the force required for rotation is absent.

DID YOU KNOW?

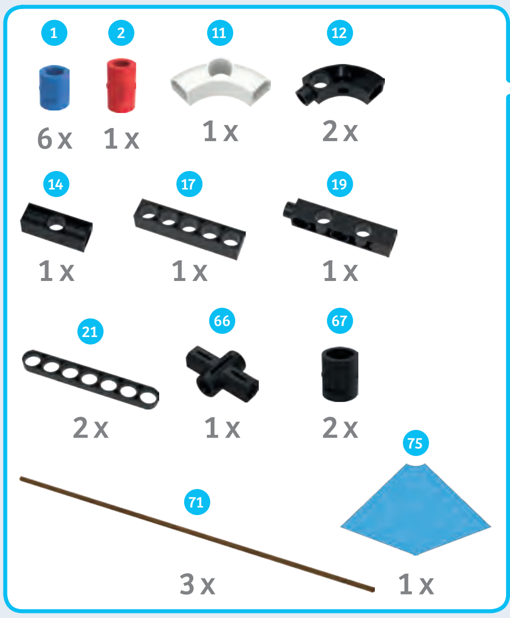
The same principle is at work when you drive a screw into wood, for example. The di erence here is that the force that drives the rotation is applied via the screwdriver, and the slanting threads then cause the screw to bore through the wood.

When a helicopter's main engine malfunctions, the rotor will begin to turn as it falls. This slows down the fall.

KEY CONCEPT: AUTOROTATION

When a sycamore maple seed falls and begins to rotate, this is called autorotation. "Auto" means "by itself." In the natural world, this property is extremely useful. Rotation reduces the speed at which the seed falls. This buys it some time to be carried away by the wind and allows the maple tree to distribute its seed across a much wider area.

HANG GLIDER



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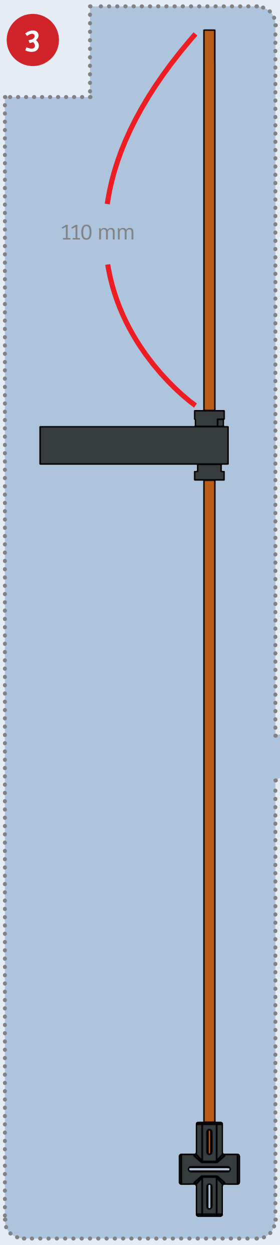

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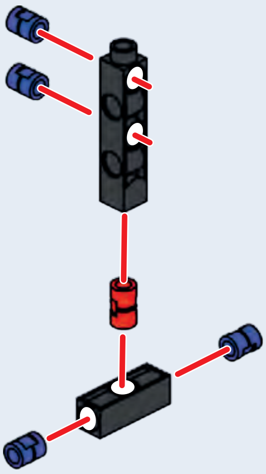

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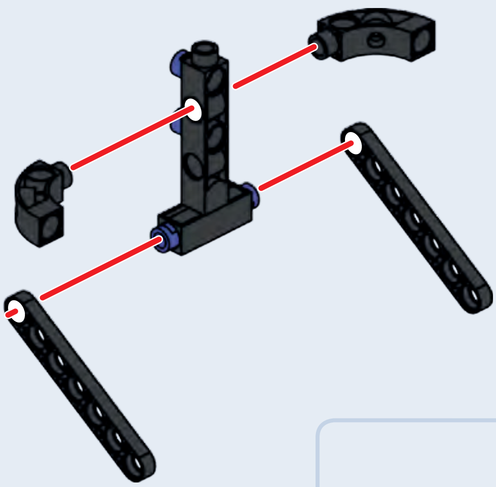

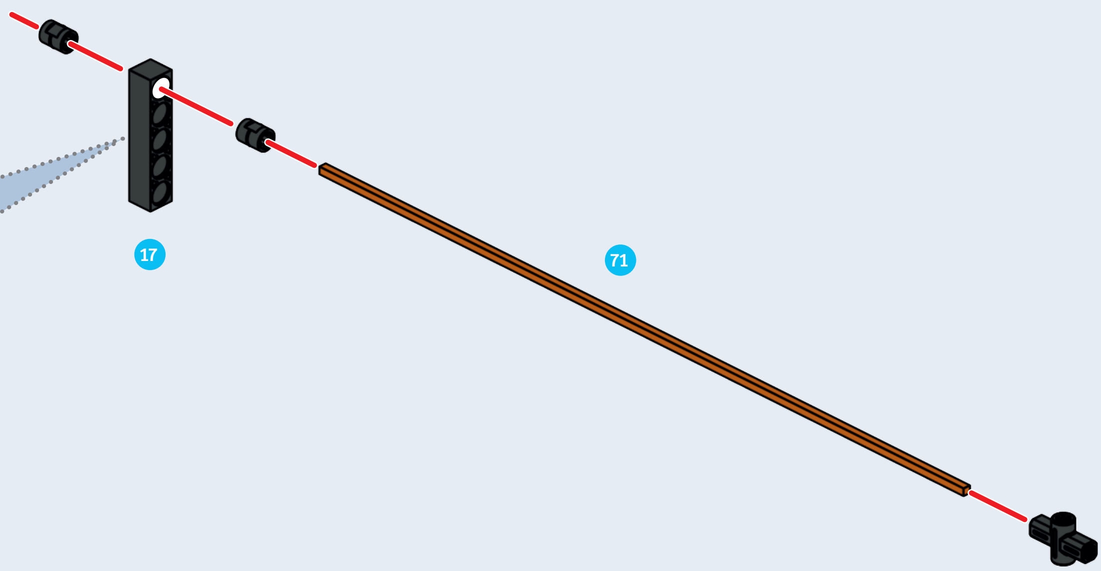

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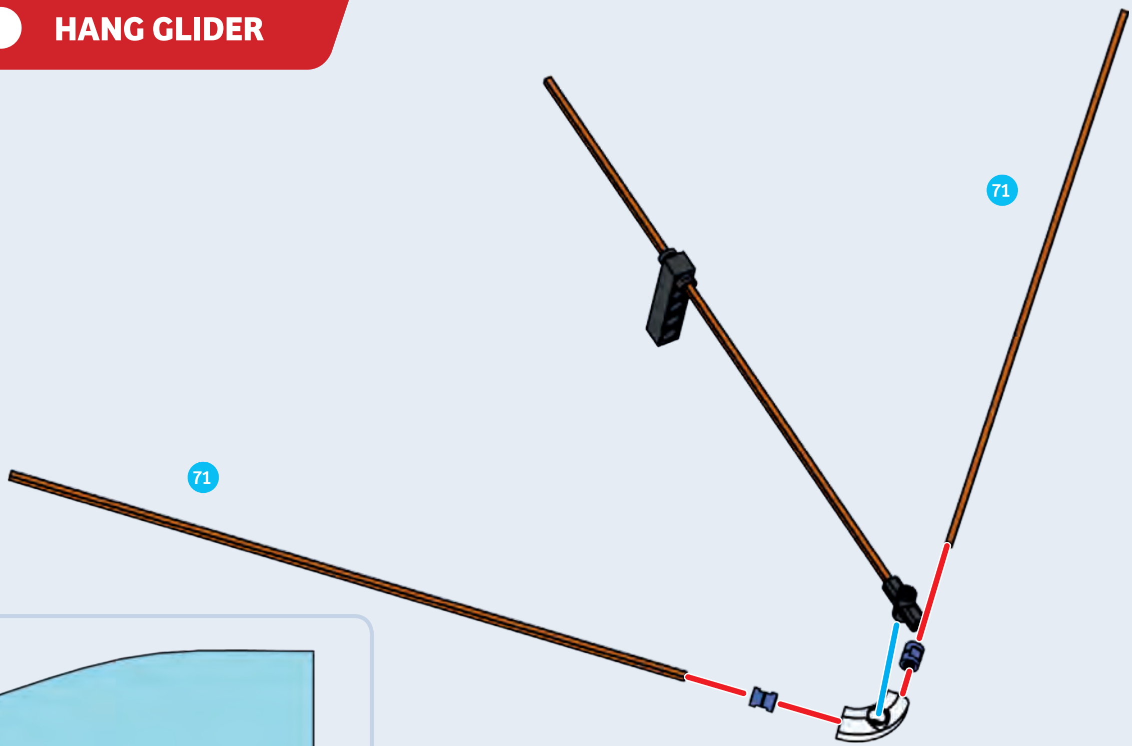

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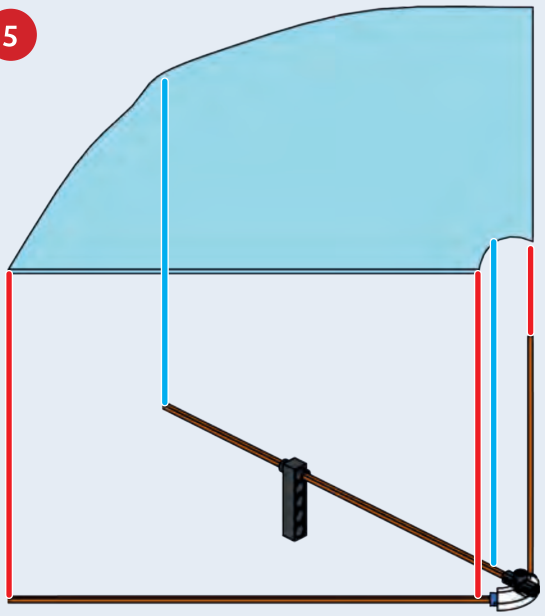
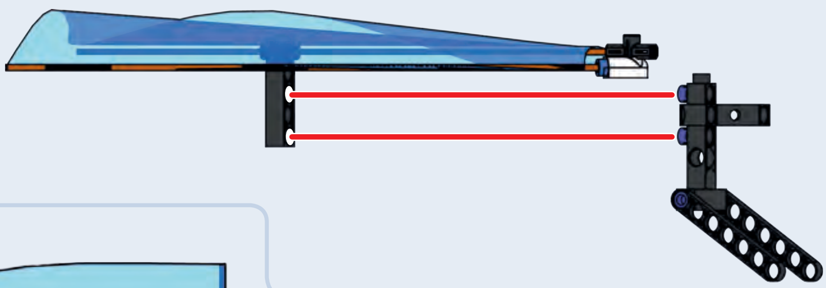
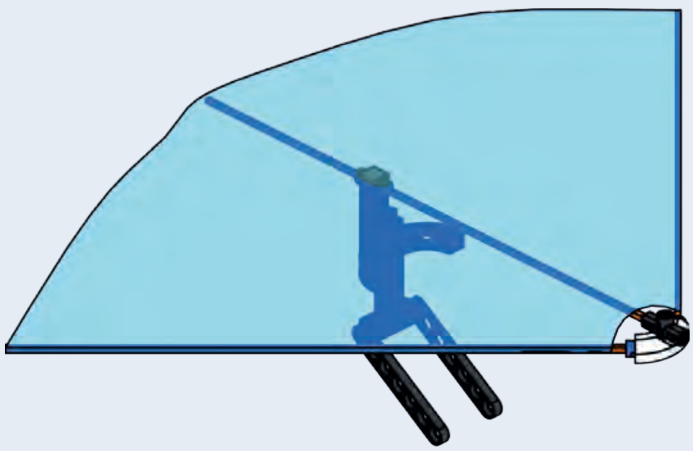


TIP!
Place the edges of the sheet on the outer bamboo sticks. Then a ach two pieces of adhesive tape to each of the edges of the sheet, roll these edges around the sticks, and then stick to the back of the sheet. Using another two strips of tape, a ach the middle stick to the underside of the sheet.

6





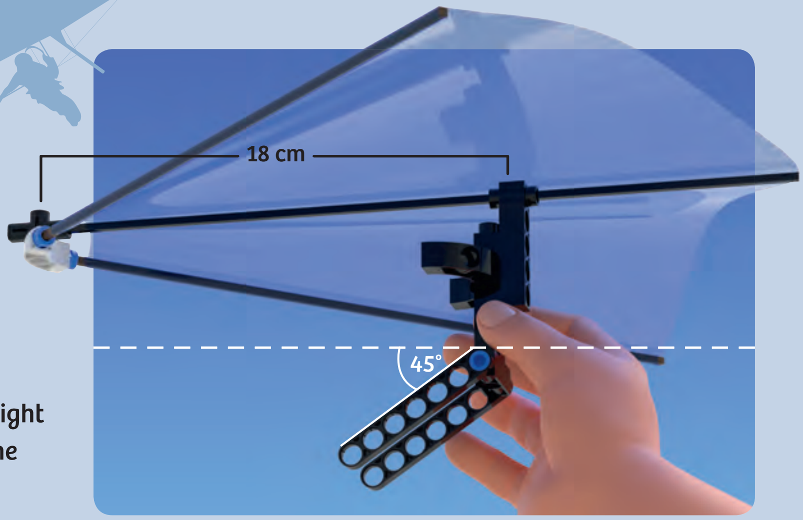
Done!

EXPERIMENT 16

Hang glider

YOU WILL NEED

› **The assembled hang glider**
› *A chair*



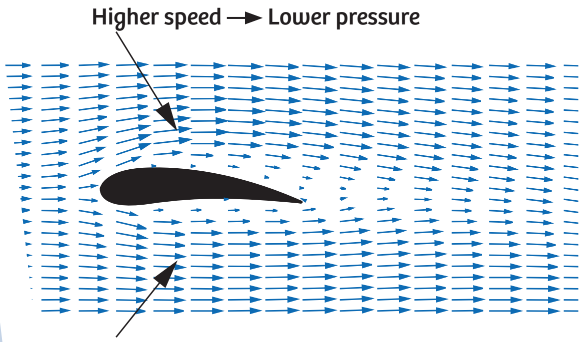
HERE'S HOW

1. In order to balance the glider correctly, the trim weight must be placed about 18 cm behind the nose and the base must lowered at an angle of 45°.
2. Stand on a chair and launch the hang glider forward.

DID YOU KNOW?

Real-life gliders work in exactly the same way. They need a "push-start," either from an aircraft with an engine, or from a cable winch that's used to accelerate the glider and launch it into the air. When a winch is used, the engine that's propelling it stays on the ground. If the glider is going fast enough, the cable is released and the loose end falls back to the ground on a little parachute.

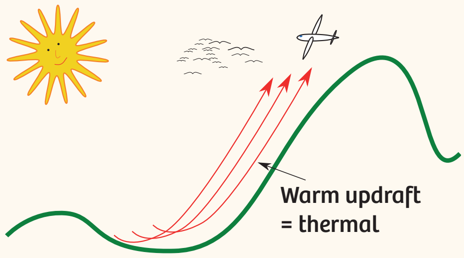
WHAT'S HAPPENING?



When you release the hang glider, the air flows along the underside and over the top of the wings. As the air has further to travel along the top than it does along the underside, it must flow faster over the top. This lowers the air pressure, exerting a force upwards — this lift force acts against the force of gravity. If gravity didn't exist, the glider would continue to fly until its entire movement was completely stopped by air friction.

KEY CONCEPT: THERMALS

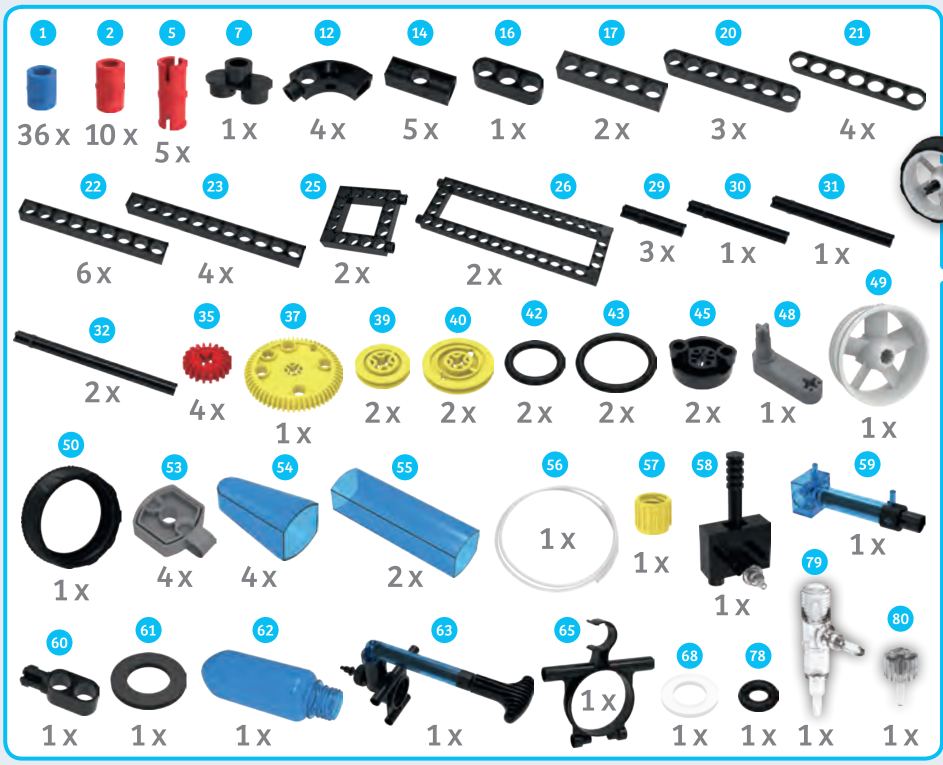
When the weather is right for gliding, pilots can use warm updrafts of air, or **thermals**, to fly for hours. As the sun warms the Earth's surface, the warm air rises and provides the glider with more energy for flying.

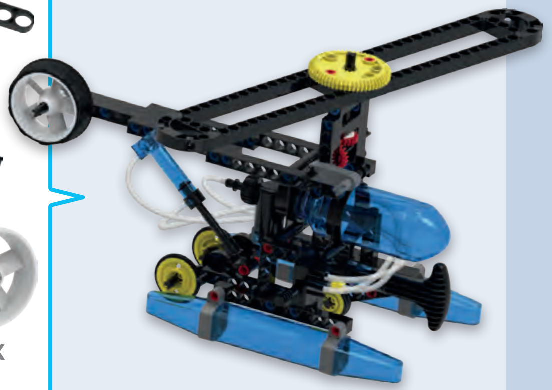


WANT TO FIND OUT MORE?

What happens when you turn the trim weight to the left or to the right? Does the glider fly in a curve? Try it out!

HELICOPTER





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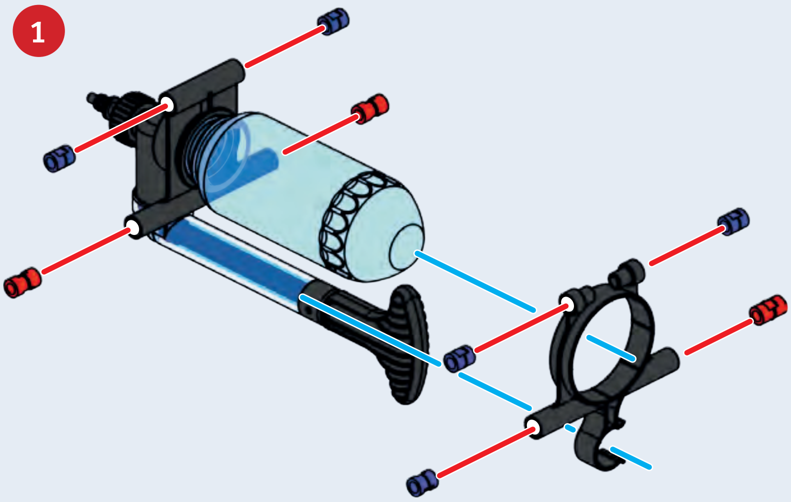

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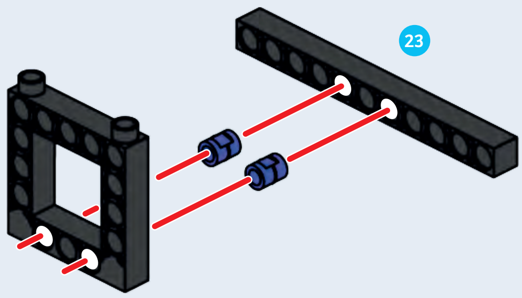

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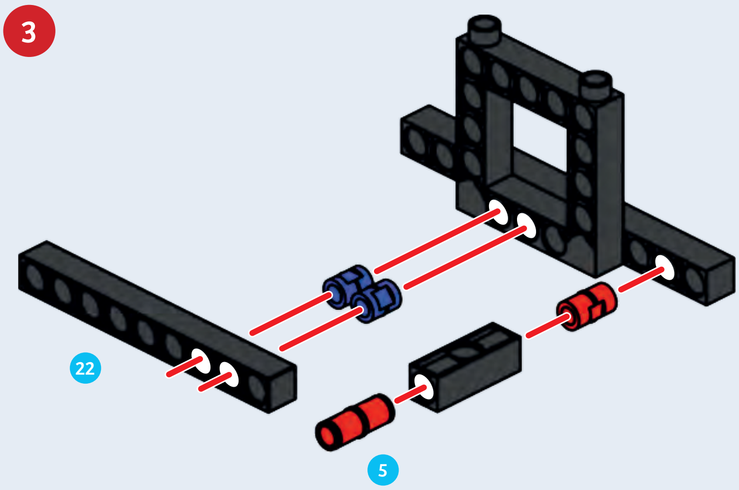

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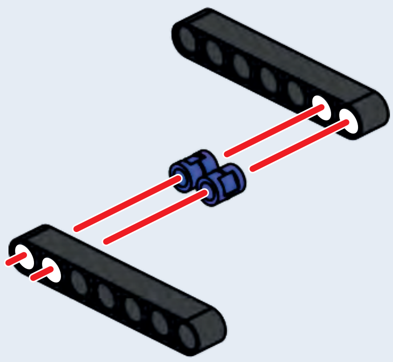

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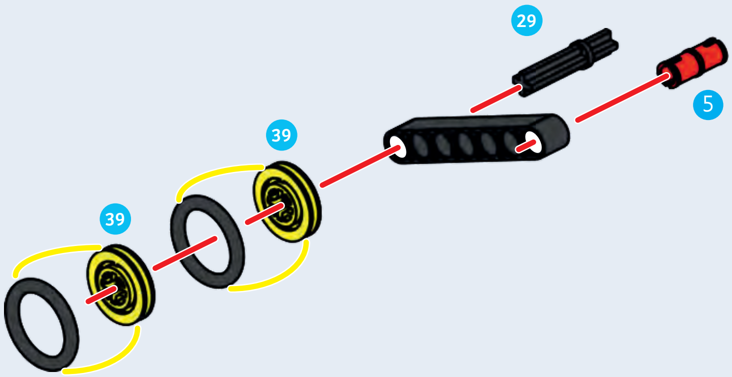

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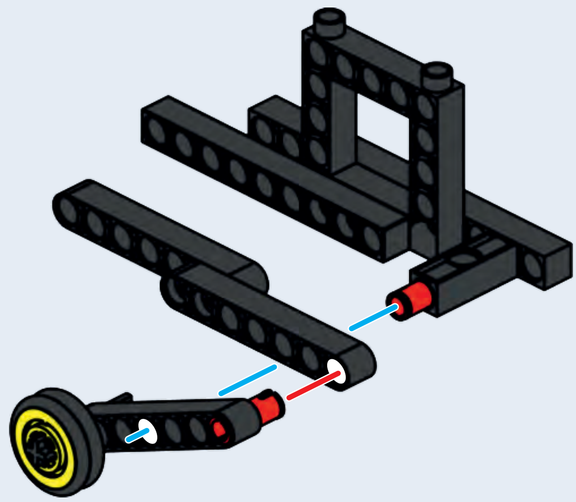

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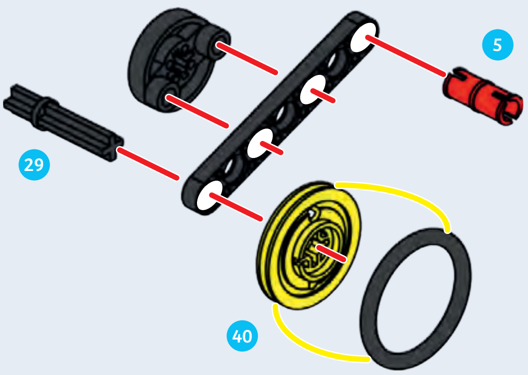

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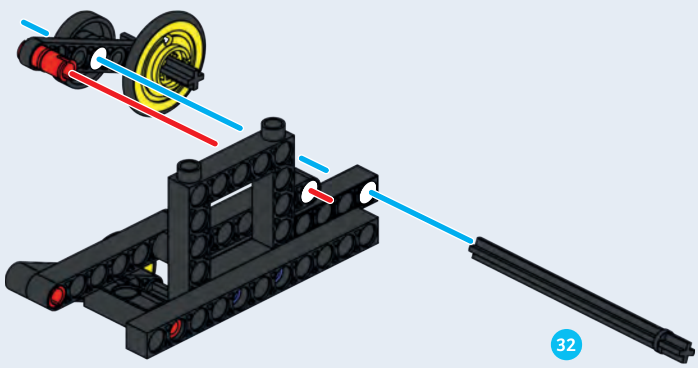

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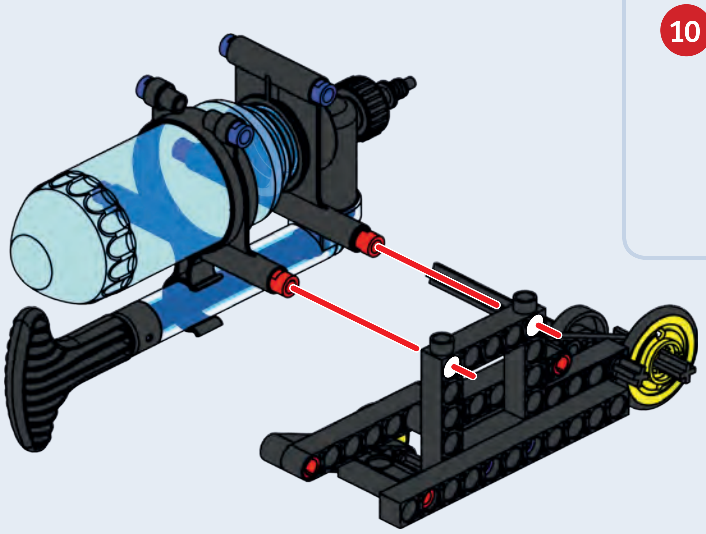

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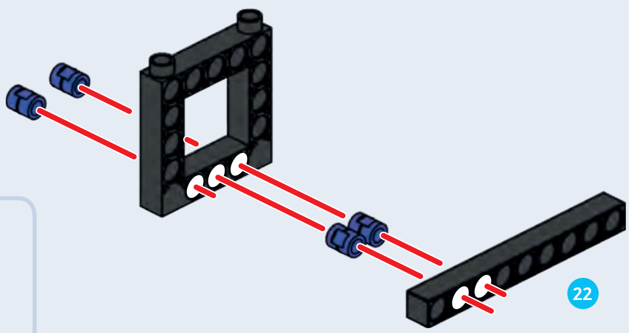

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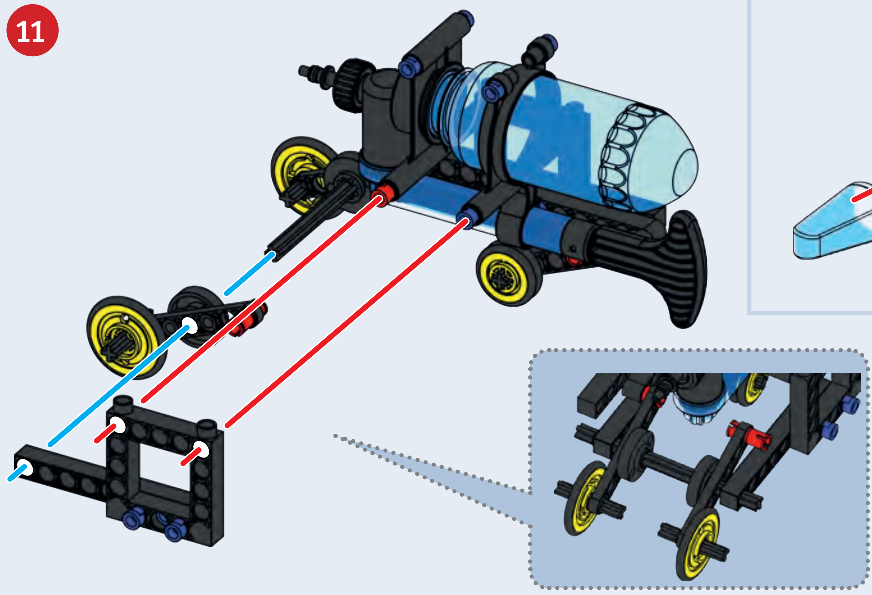

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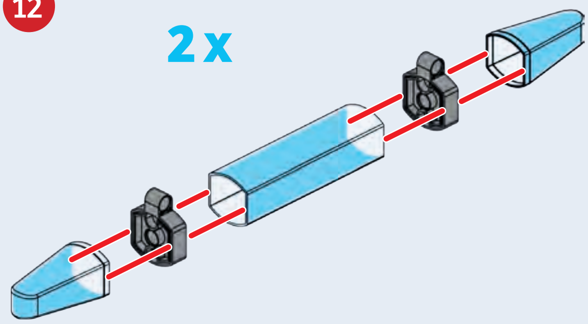

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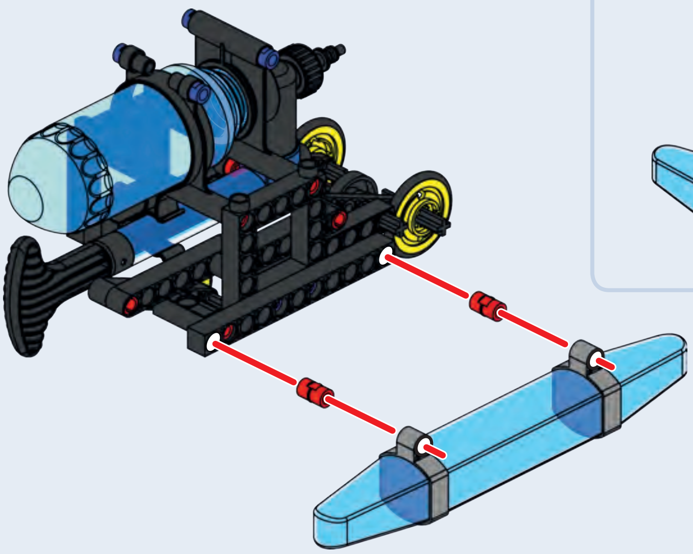

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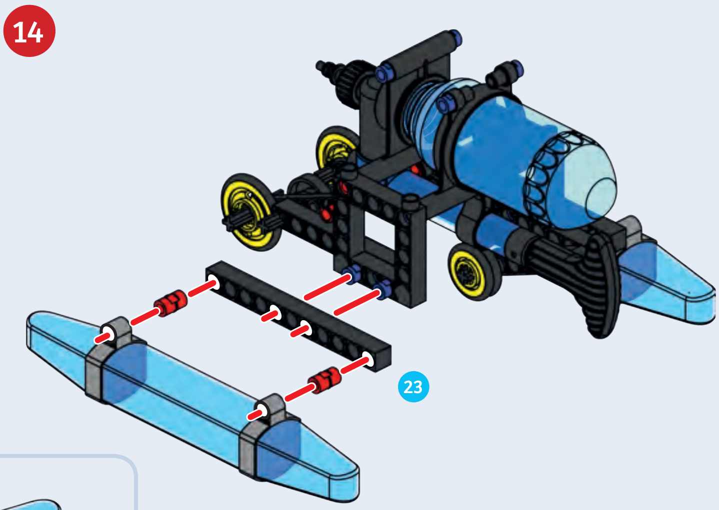

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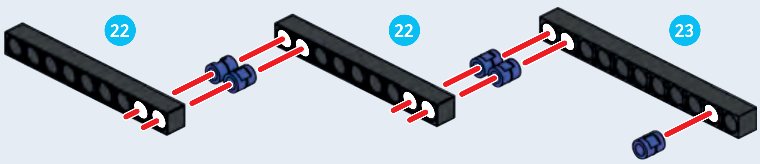

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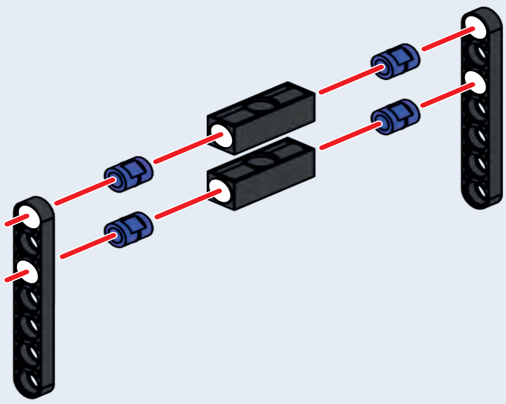

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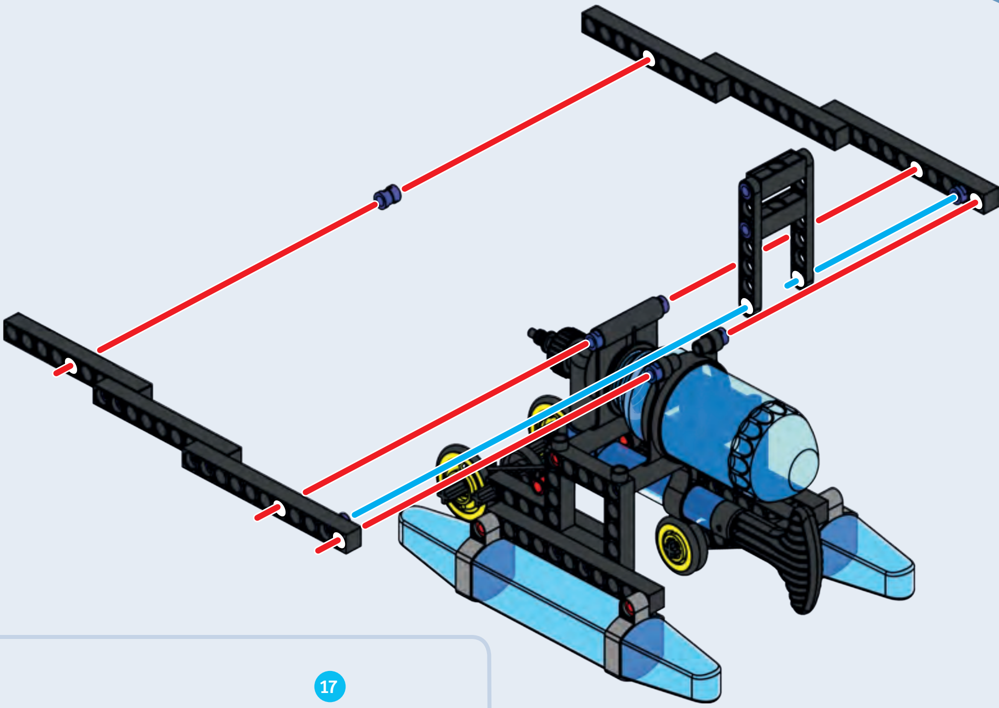

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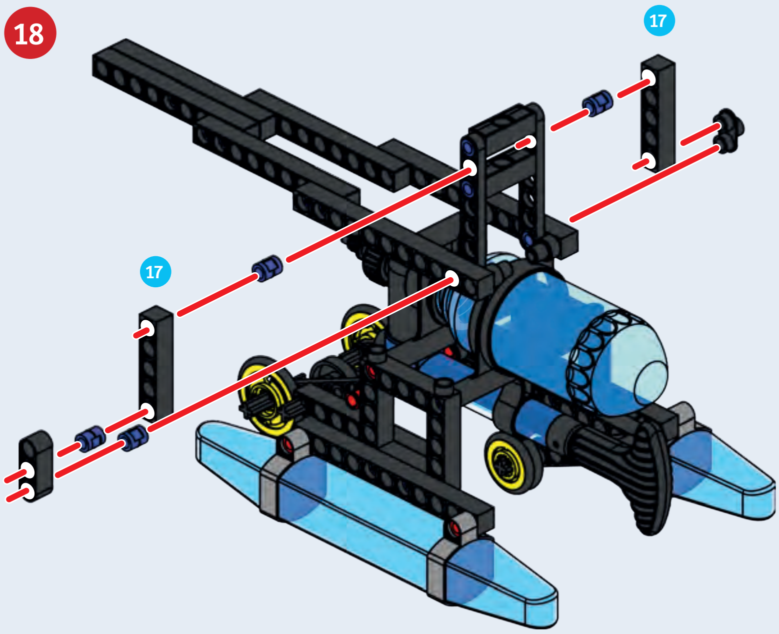

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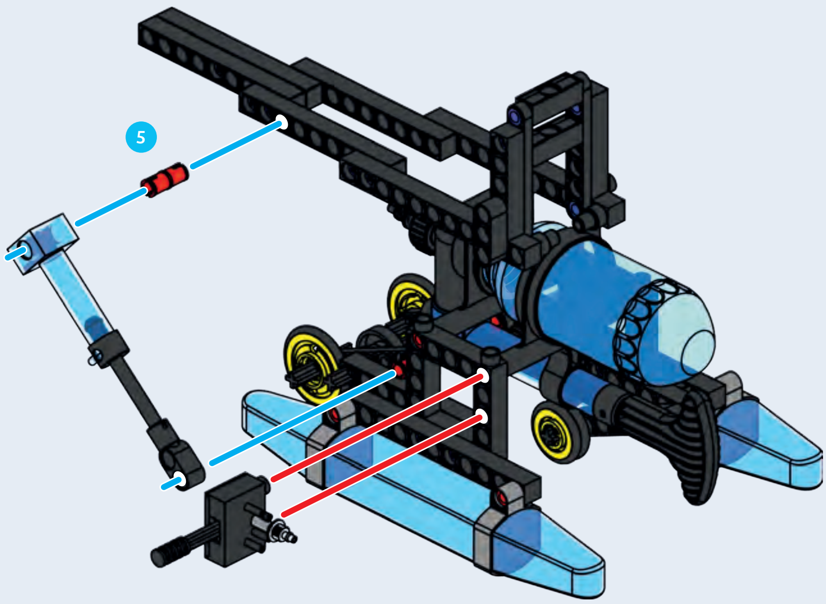

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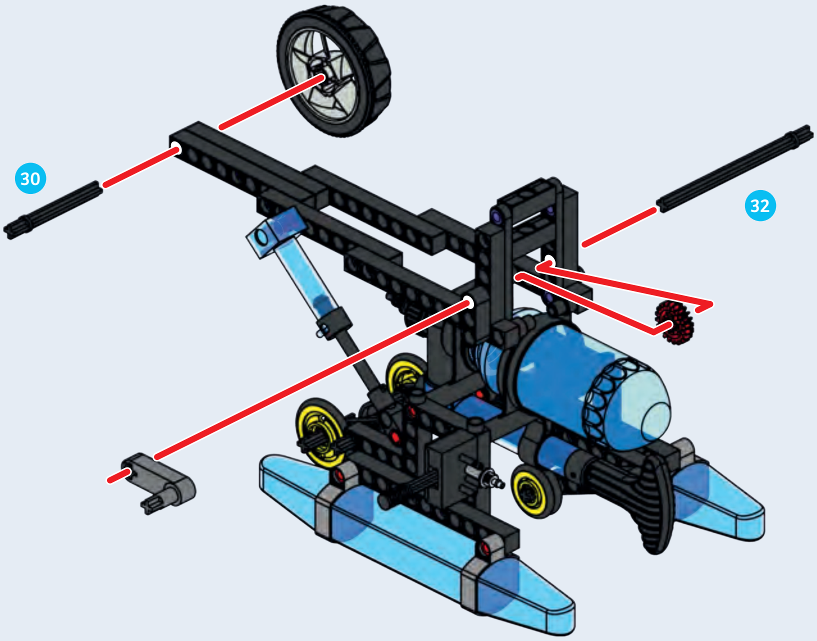

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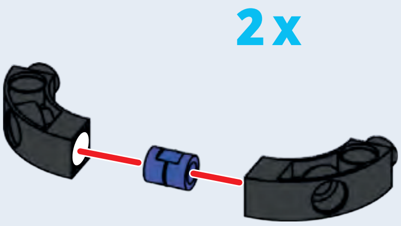

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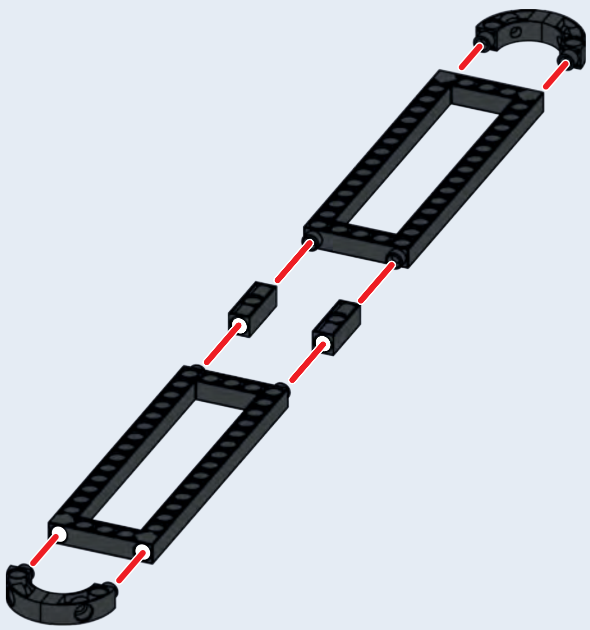

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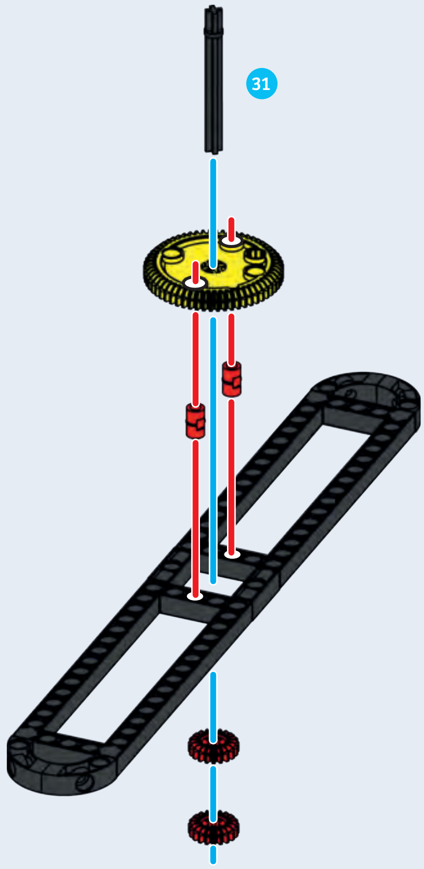

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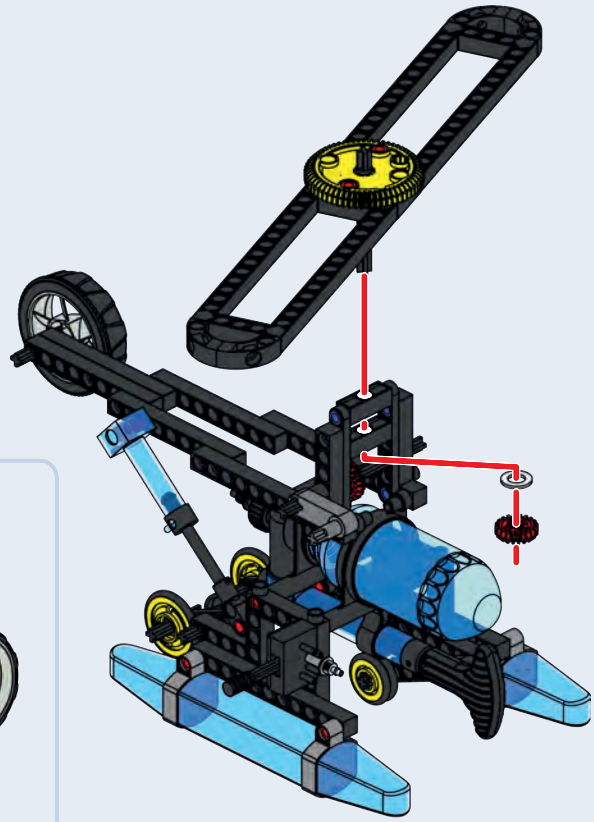

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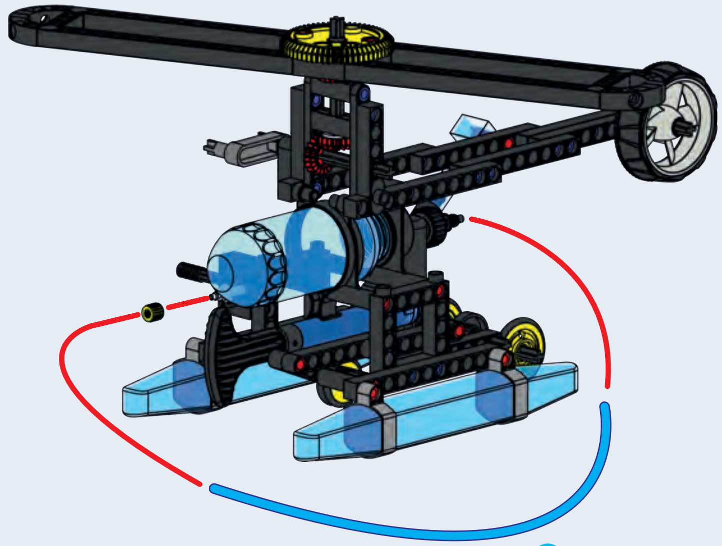
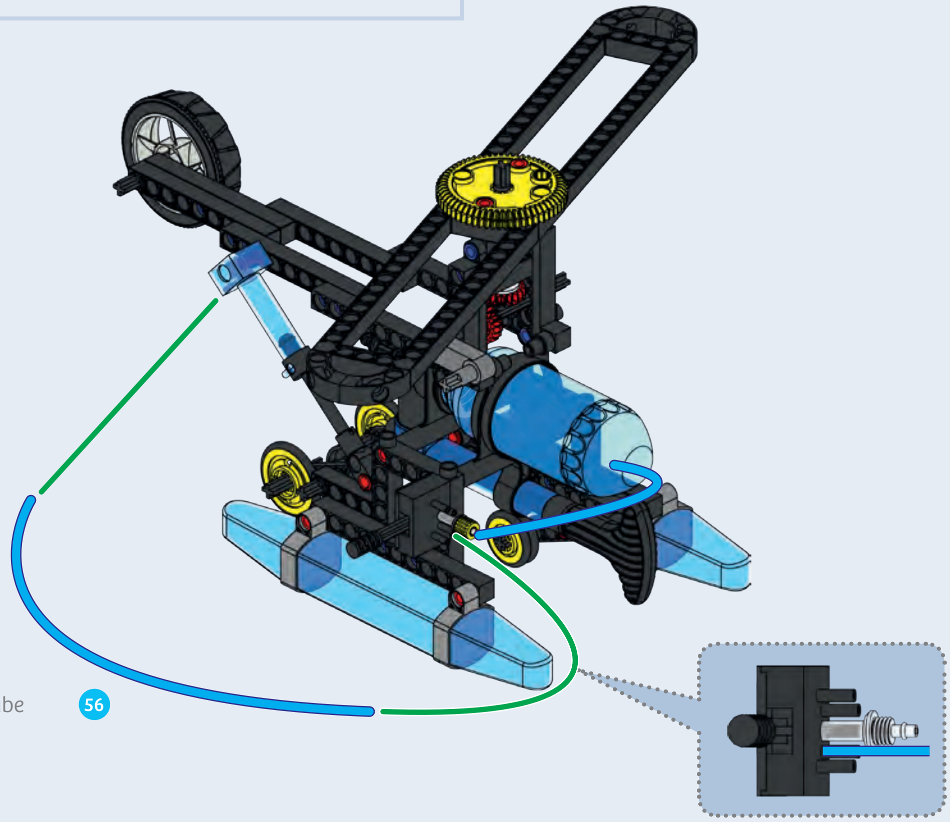


56 25-cm tube

26



40-cm tube 56

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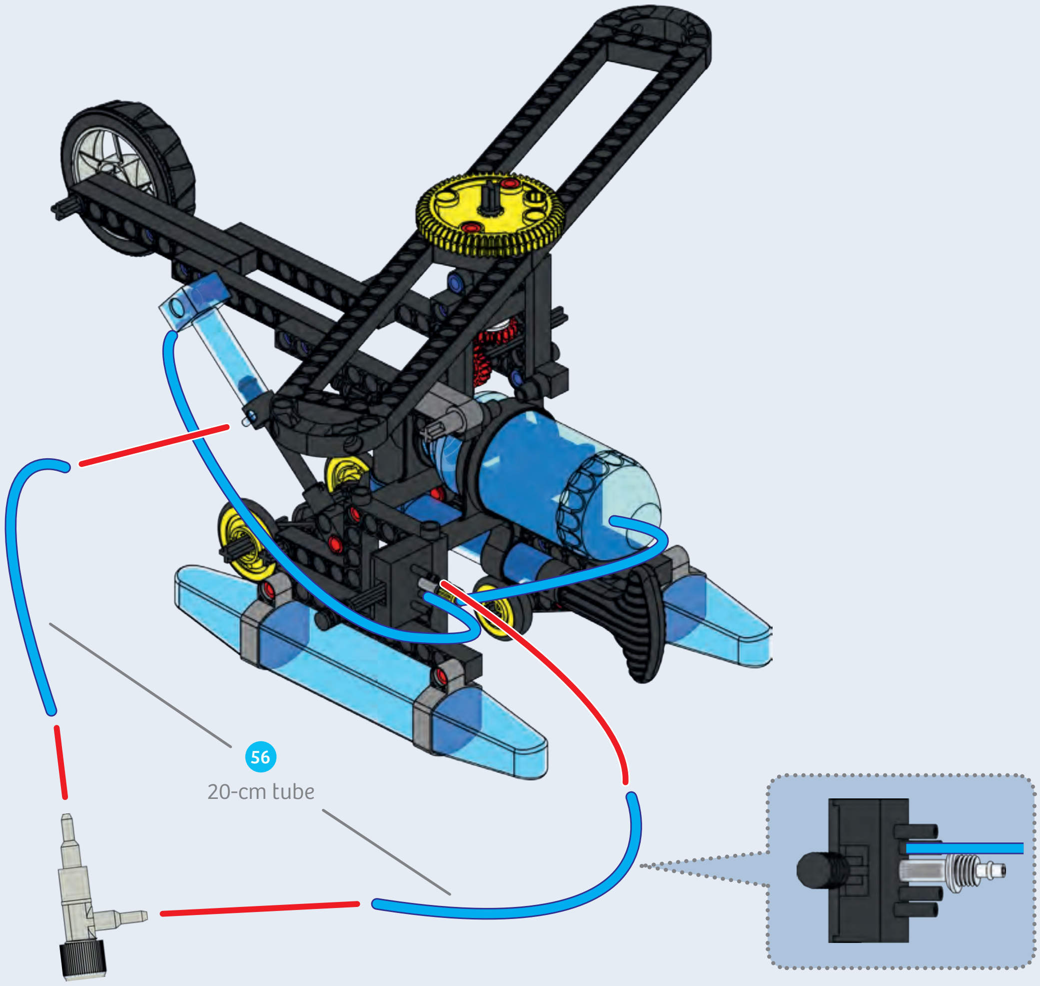
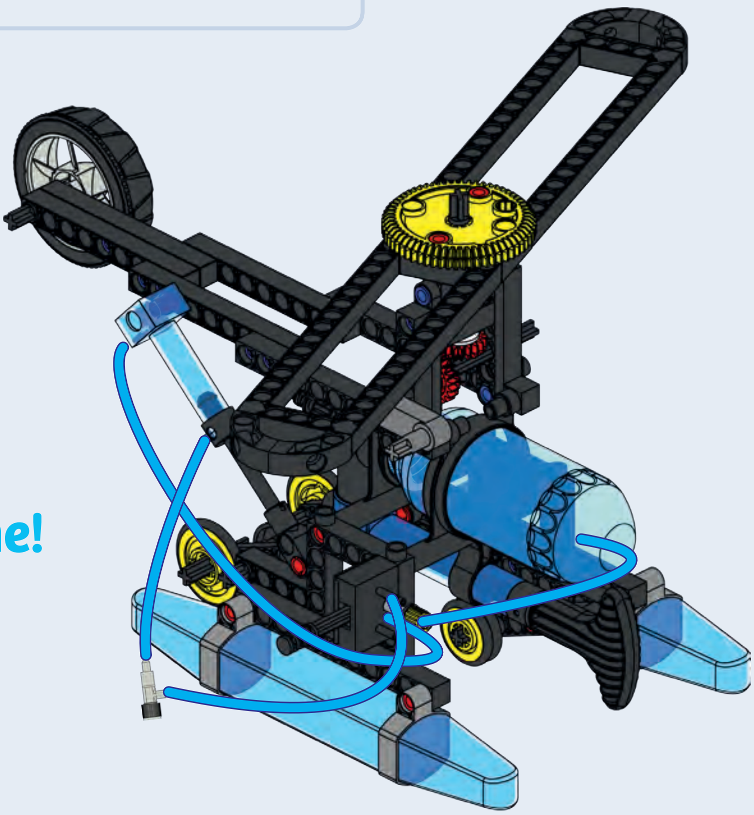
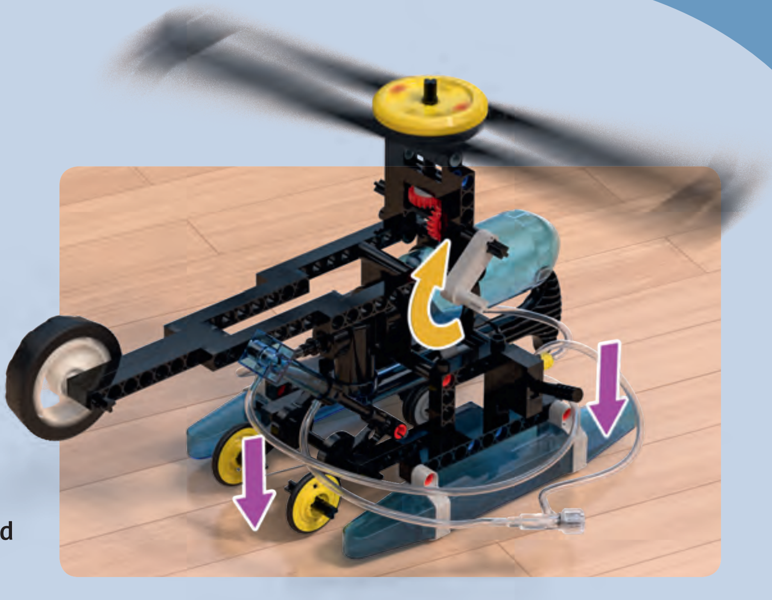




Done!

EXPERIMENT 17

Helicopter



YOU WILL NEED

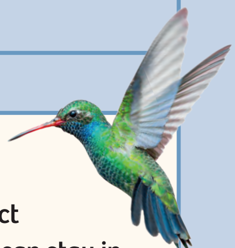
› **The assembled helicopter**

HERE'S HOW

1. The helicopter has two rotors. You can turn the main rotor with the crank, while the small tail rotor is turned directly at the shaft.
2. Move the lever on the switch to the center position.
3. Pump air into the pressurized air tank (pump between 30 and 50 times).
4. Next, move the lever back and forth — the landing gear will now move up and down.

DID YOU KNOW?

Since helicopters can take off vertically, they're often used in tight landing situations. They're able to take off and and on solid ground, in swamps, on snow and ice, and even on the water. When landing on soft ground or water, special equipment called pontoons are used. In this case, any landing gear that the helicopter is equipped with folds up.



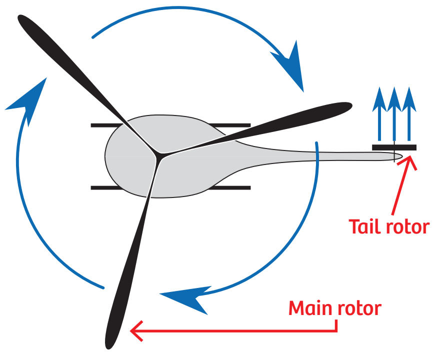
KEY CONCEPT: HOVERING

The helicopter is the only man-made object that is capable of hovering. This means it can stay in the same position in the air without falling. In the natural world, several species have mastered the ability to hover, such as bu erflies and **hummingbirds**.

WHAT'S HAPPENING?

If you turn the crank of the main rotor, the bevel gear changes the direction of rotation by 90°. The rotation speed stays the same, since both gears have the same number of teeth.

When the main rotor is turned, a force counteracts the rotation. This force would cause the helicopter to rotate around its own axis, so to prevent this, a tail rotor is used. This rotates so fast that it produces a compensating counterforce, which stabilizes the movement.



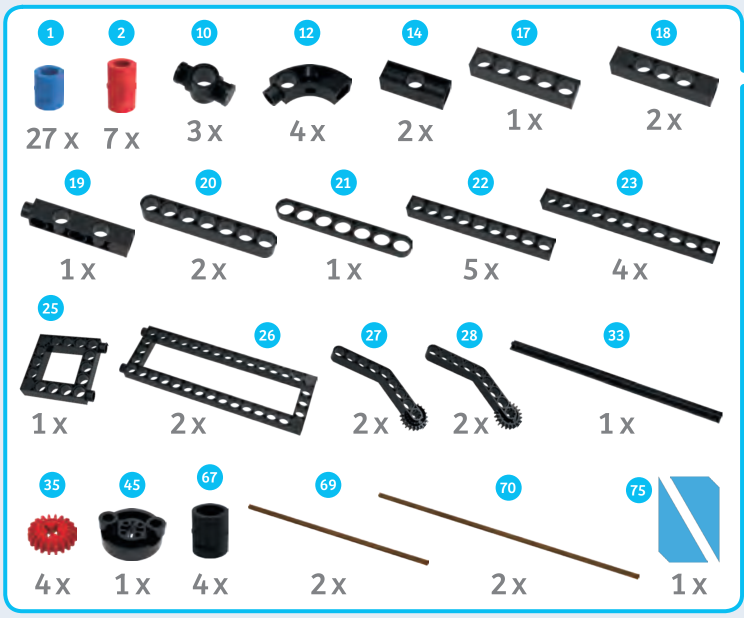
If the lever is turned and air ows into the pneumatic cylinder, the piston is pushed out. The landing gear is extended and retracted by means of the linkage.

WARNING! Keep your face well away from the spinning blades, or else you could get hurt.

WANT TO FIND OUT MORE?

For this experiment, you'll need the wind turbine part of the windmill. A ach it to the helicopter where the main rotor is positioned now. To do so, simply swap out the parts. What happens when you turn the crank with one hand and hold your other hand above or below the blade? Can you feel the air current traveling upward or downward, depending on the direction you turn the crank? When the air current travels downward, this is the point at which your helicopter could start to y — if it was light enough and if you continued turning the crank while in flight, that is

WINDMILL



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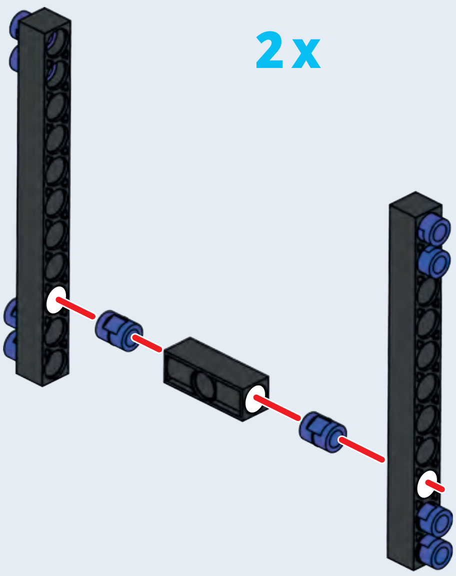

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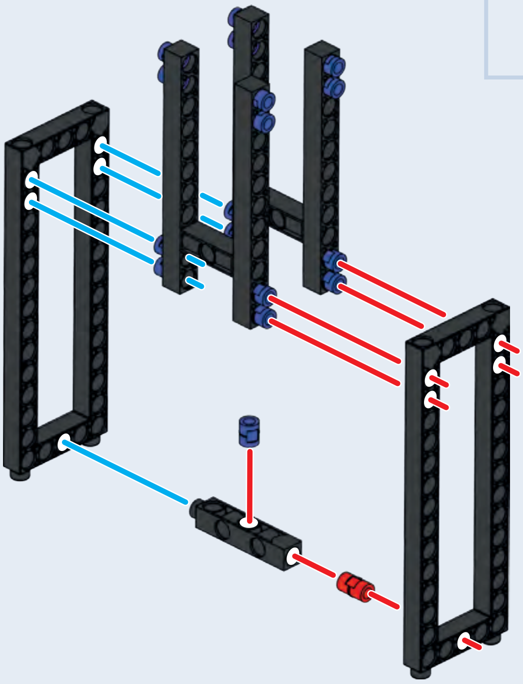

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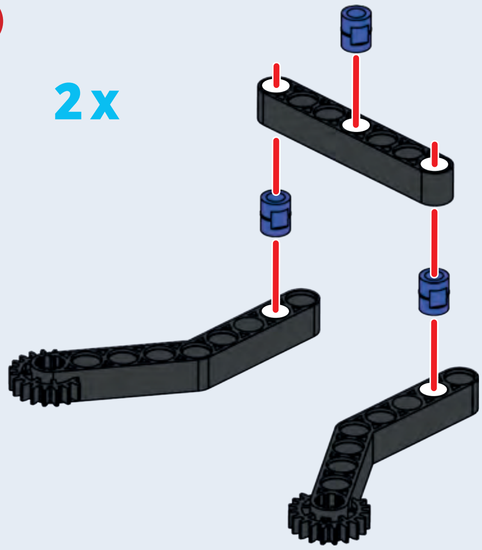

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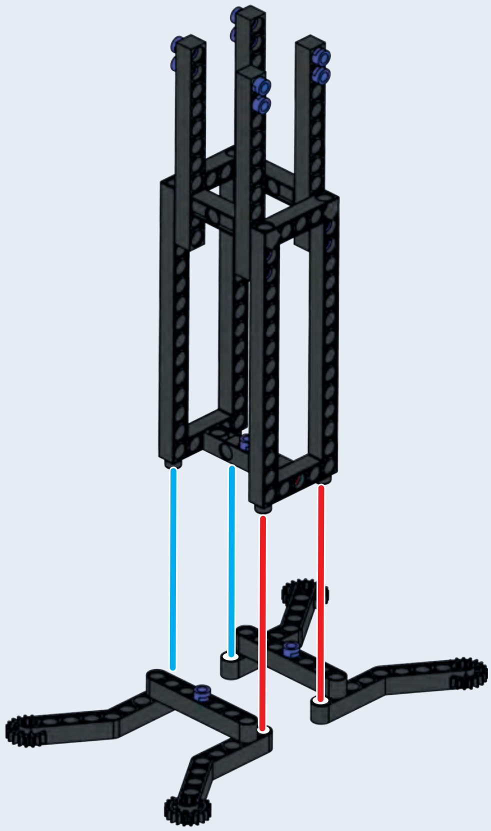

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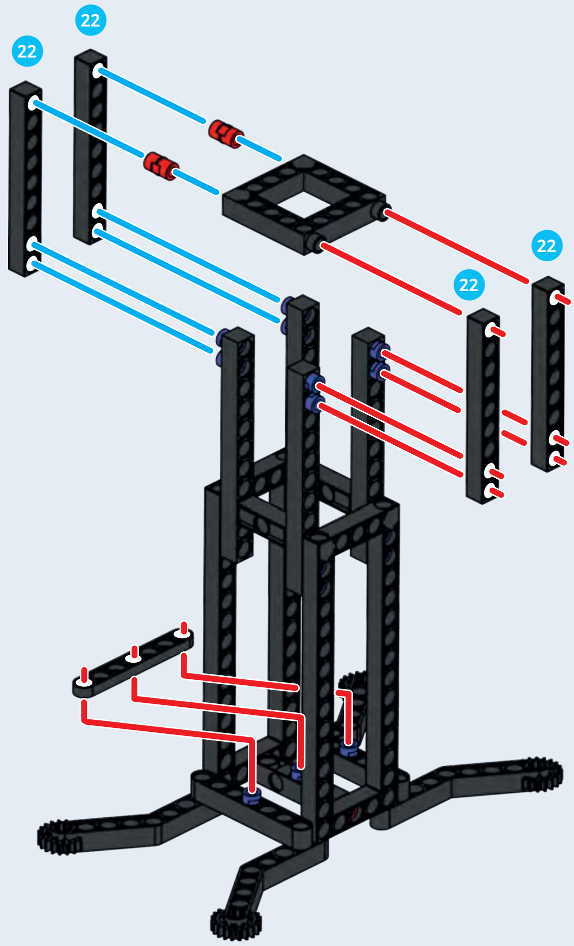

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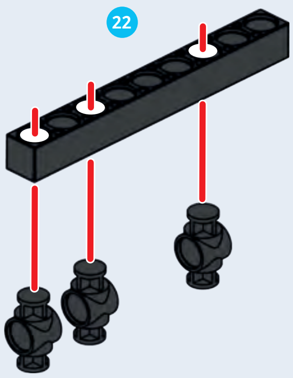

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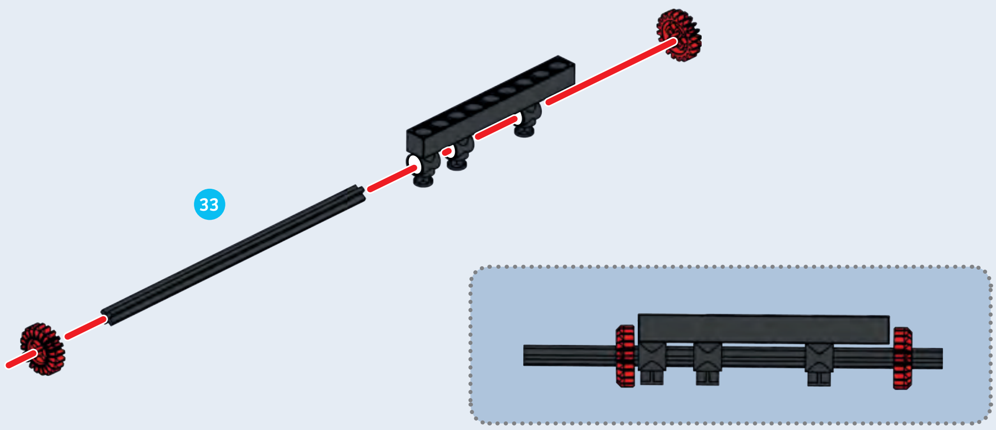

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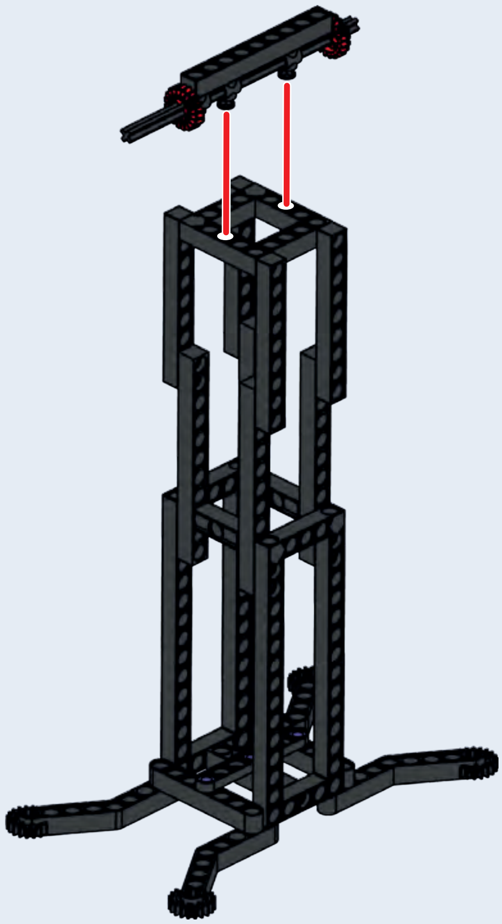

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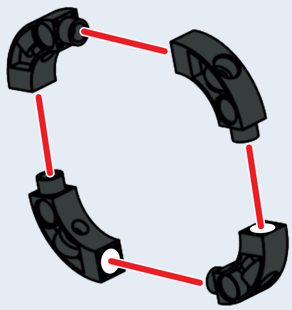

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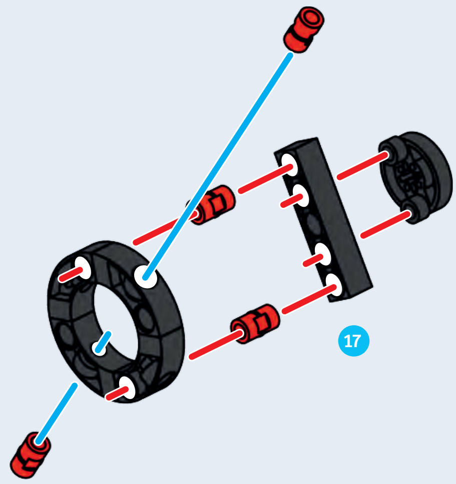

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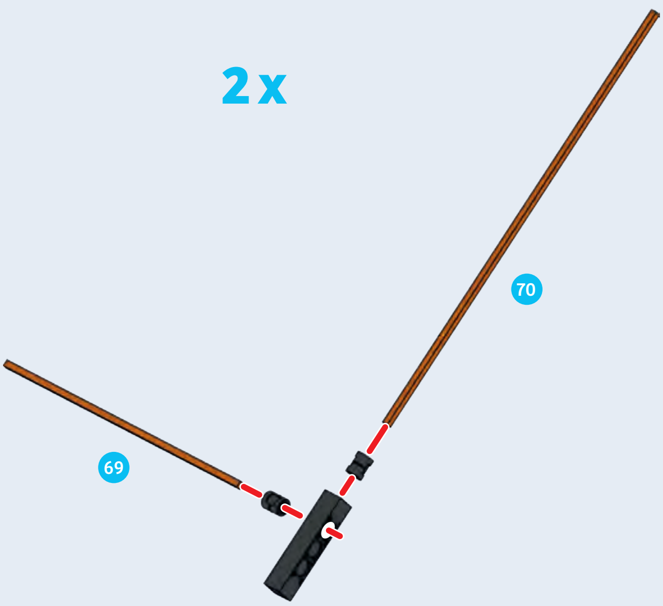

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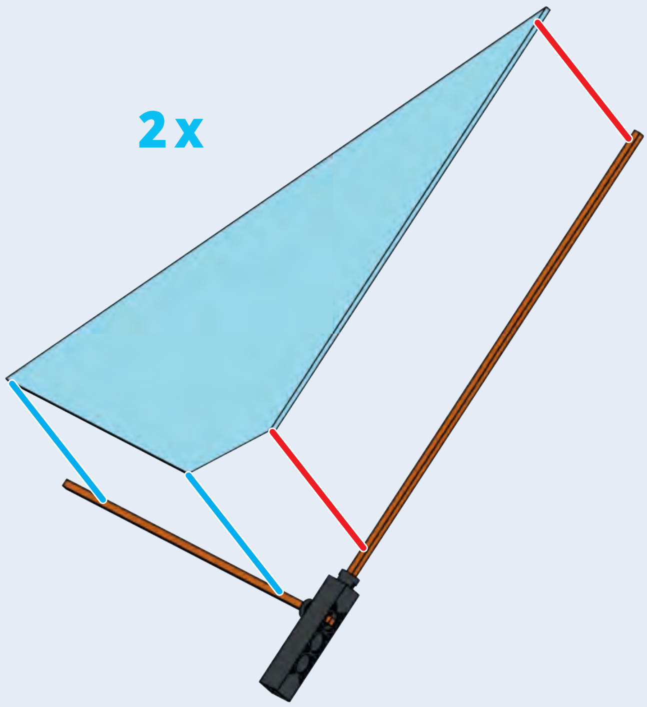
TIP!
Place the edges of the sheet onto the bamboo sticks. Then a ach two pieces of adhesive tape to each of the edges of the sheet, roll these edges around the sticks, and then stick to the back of the sheet.



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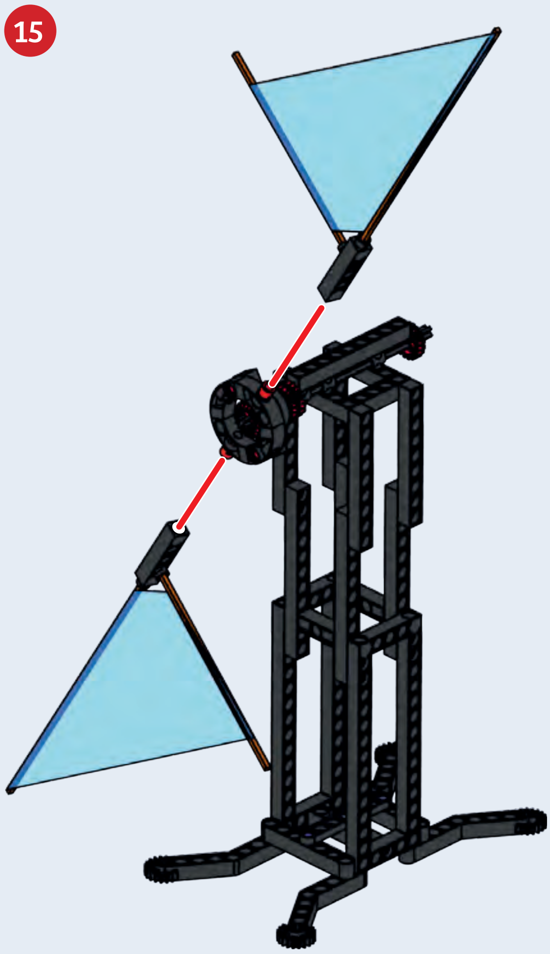
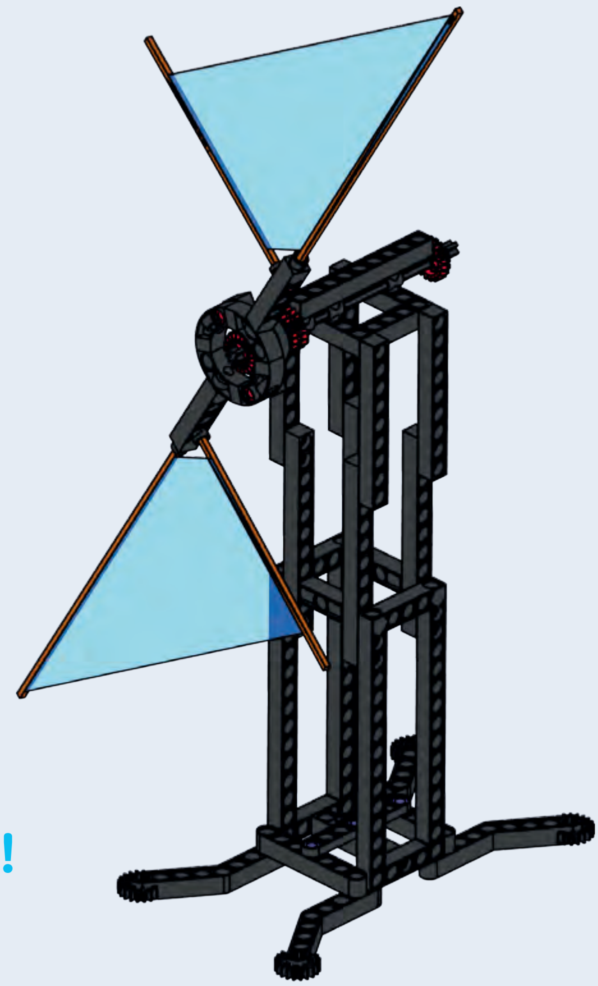
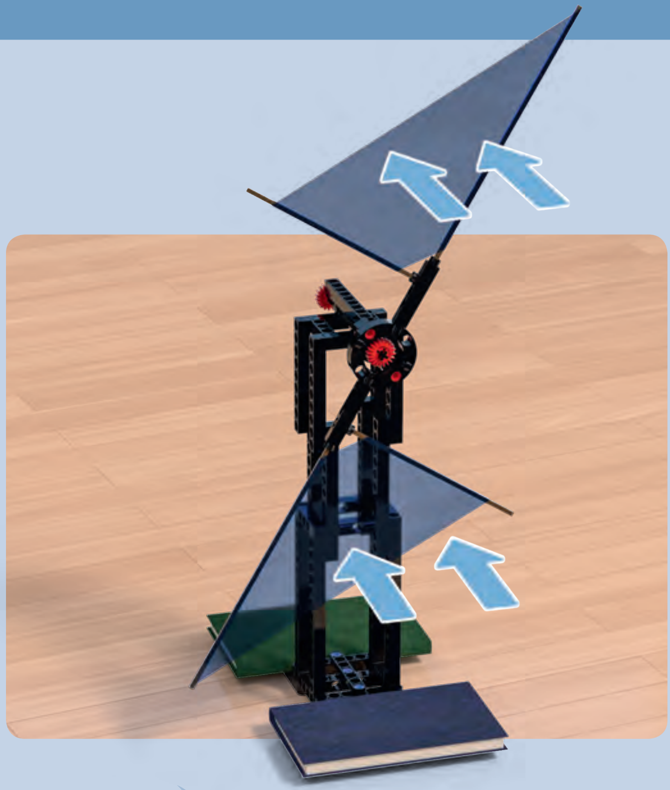




Done!

Windmill



YOU WILL NEED

› **The assembled windmill**
› *Some books*

HERE'S HOW

1. First, place the books on the base of the windmill so that it won't fall over.
2. Next, take the end of each short bamboo stick and push it backward slightly, but just far enough to stop the blades from getting aught on the base.
3. Then blow on the blades from the front.
4. If it's a windy day, you can try out the windmill outdoors. You can work out the wind direction by picking up a few blades of grass and sca ering them in the air.

WHAT'S HAPPENING?

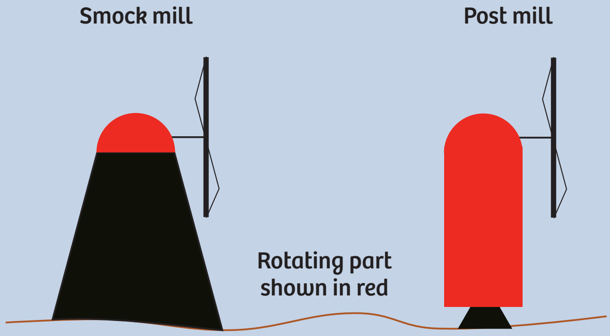
When the wind blows on the blades, which are positioned at an angle, it creates the same e ect as we see in sycamore maple seeds. The ow of air along the blades causes a rotational movement. If the blades have the right shape, they'll work the same way as a glider. The di erence in pressure between the two sides intensifies the otational movement. The rotating shaft can then be used to power a pump, a generator, or a millstone. If the wind direction changes, the blades will need to be repositioned so they are still facing the wind.

KEY CONCEPT: WINDMILLS

In modern windmills — also known as **wind turbines or wind power plants — that are used to generate electricity,** only the top part, called the nacelle, is positioned to face the wind. During a storm, the nacelle can be turned to face away from the wind in order to prevent it from getting damaged. In the e wind turbines, the rotational movement powers a generator that converts the kinetic energy to electric energy. This energy can then be supplied to customers through wires.

DID YOU KNOW?

Windmills have been in use for several thousand years. The various designs we know today were developed over the course of time. Examples include smock mills, which have a rotating top on a fi ed body, and post mills, which have a rotating body positioned on a base.



CHECK IT OUT

Light or heavy?

Aircraft, or machines that can y, can be divided into two categories. Some are light enough to y using lift force alone, while others are too heavy and have to y extremely fast to compensate. The first ategory includes **zeppelins** and ...

... hot-air balloons, which are fi led with a gas that's lighter than air. Examples of gases that can be used include helium and hot air. On the other hand, airplanes and helicopters are too heavy. They must have curved wings, propellers, or rotors that must be able to move fast enough to achieve lift by means of the Bernoulli principle.

What's faster than sound?

Airplanes are very fast. But how fast do they need to be to y faster than the sounds they produce? The speed of sound depends mainly on air temperature. At 20 °C, it's approximately 1,236 km/h. In or der to y that fast, an airplane needs to be extremely slender and have powerful engines. When the airplane reaches the speed of sound, the air is compressed so intensely that it produces a loud bang called a "sonic boom." As a result, airplanes are only allowed to break the sound barrier when ying over unpopulated areas.

One example of a supersonic airplane is the **Concorde.** This aircraft made it possible to y from Paris or London to New York in just a few hours. Because of its powerful engines, the Concorde was very loud and used a lot of fuel. A serious accident in the year 2000 revealed a aw in the wing structure, and as a result, all Concordes were retired in 2003. Today, they can be seen in a number of museums.

CHECK IT OUT

Biotechnology

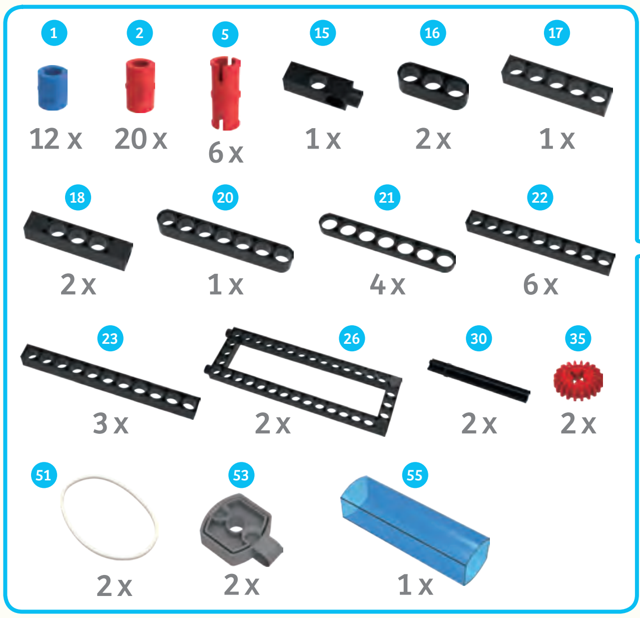
There is a branch of science called "bionics," which focuses on applying observations from nature to technology. Many technical inventions would not have been possible without the inspiration provided by nature, such as **self-cleaning surfaces** (lotus effect), lightweight construction materials (structure of bones), airplane airfoils (wings), Velcro (burdock seeds), and many more.

A helicopter's **main rotor blades** have the same shape as the wings of a sycamore maple seed. But unlike **sycamore maple seeds**, helicopters often have several blades. This makes them quieter and more stable when flying. With sycamore maple seeds, it doesn't matter if they sway while flying, as their sole purpose is to fall to the ground as slowly as possible. In nature, only the precise amount of material that is needed is used and no more.

All Things Camera

Modern photography and video technology makes use of a wide range of technical achievements. This makes it possible to record steady video footage and wide panoramas. Whether we're capturing very large objects like stars and galaxies through a camera on a tripod or very small things under a microscope, the thing that counts is that we set the image angle correctly and record it without shaking.

CAMERA STABILIZER MOUNT



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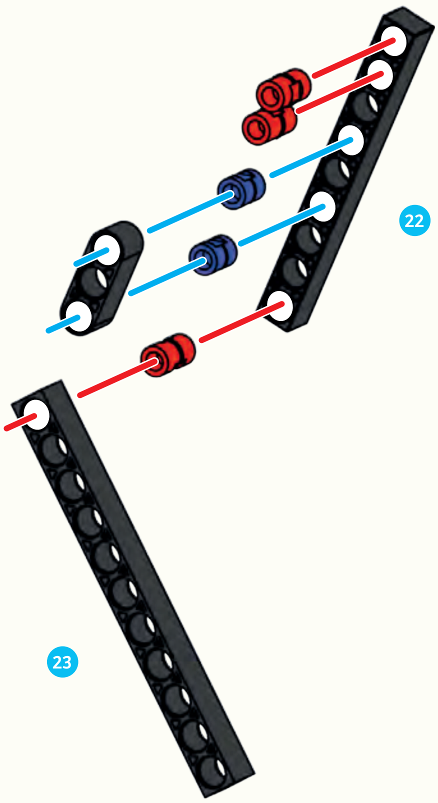

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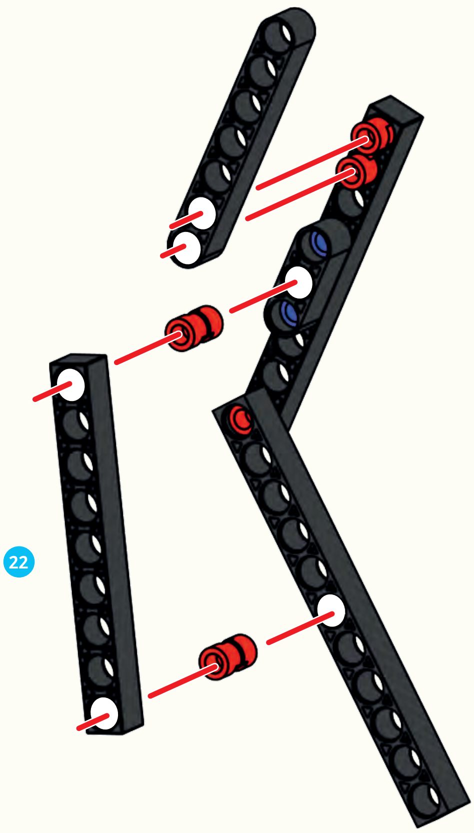

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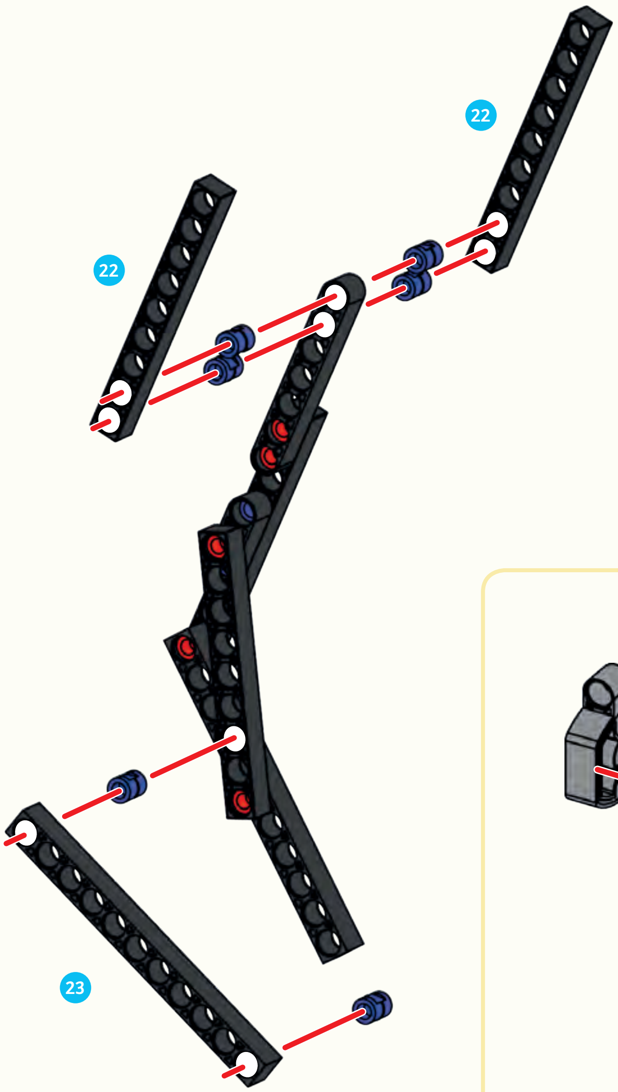

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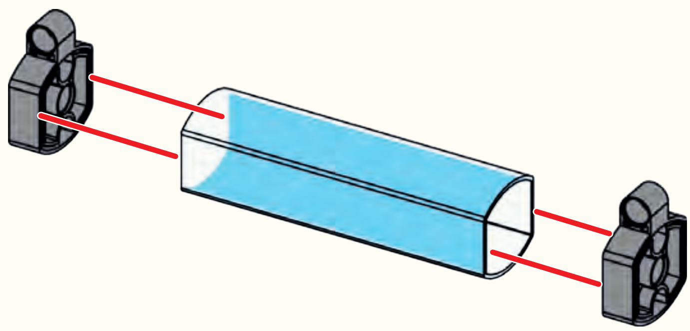

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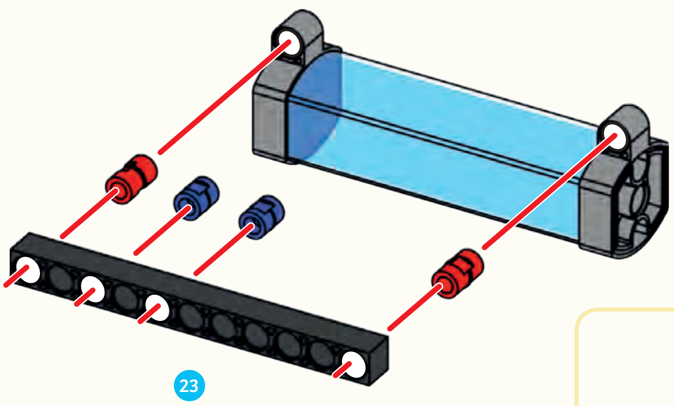

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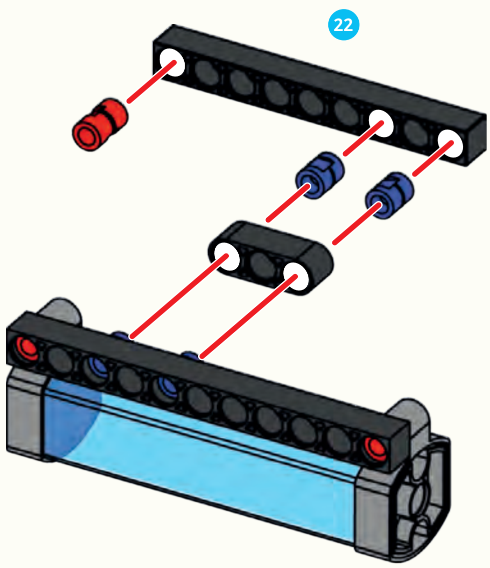

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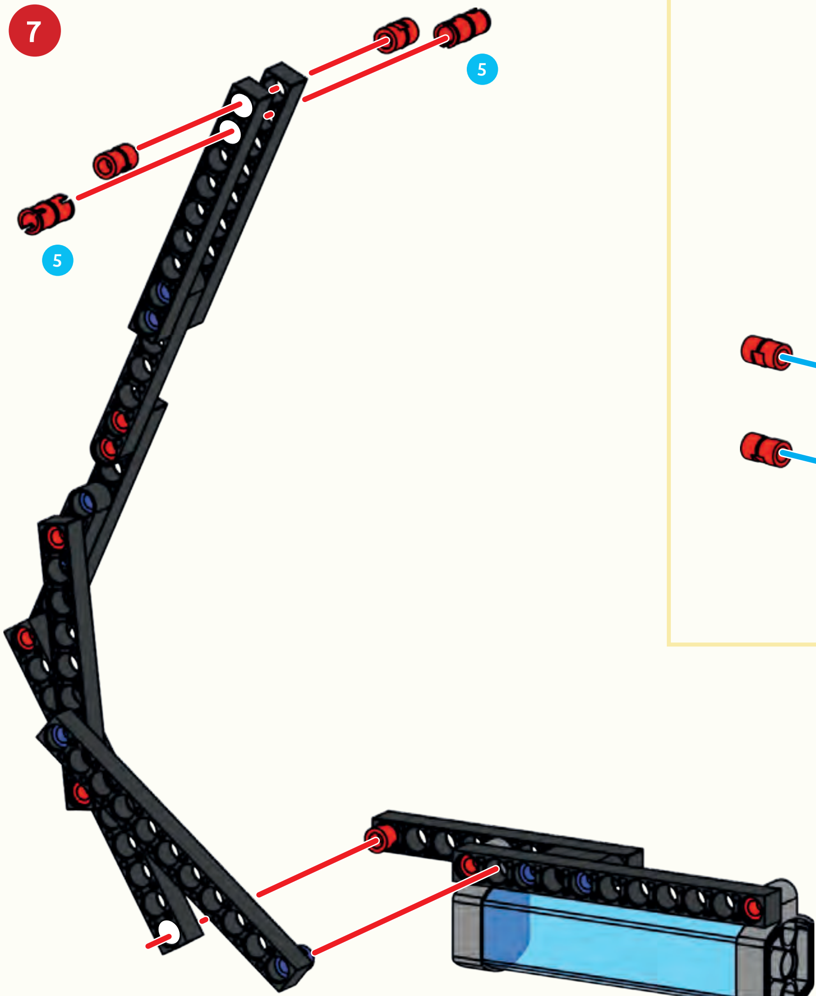

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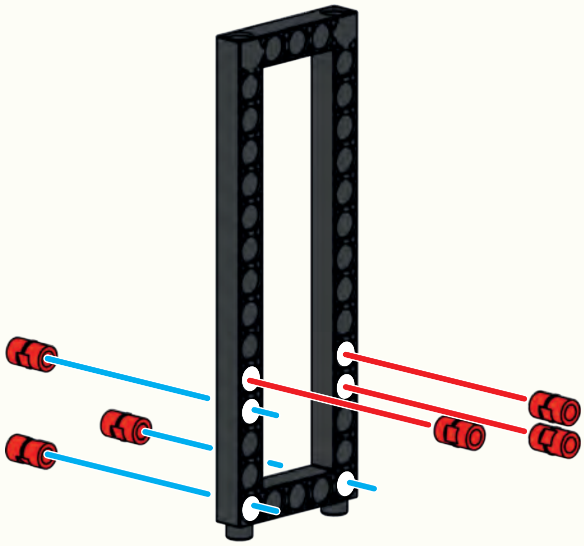

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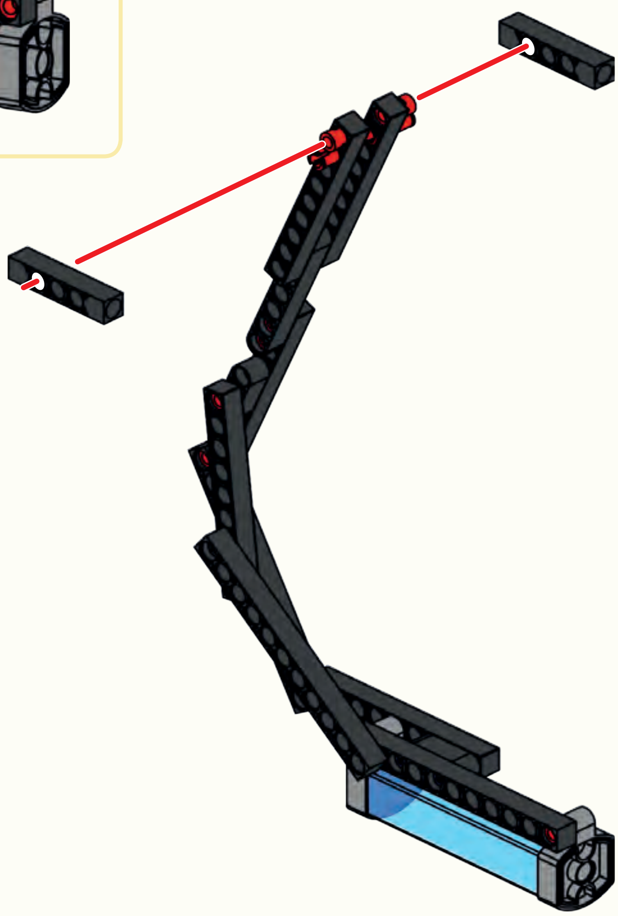

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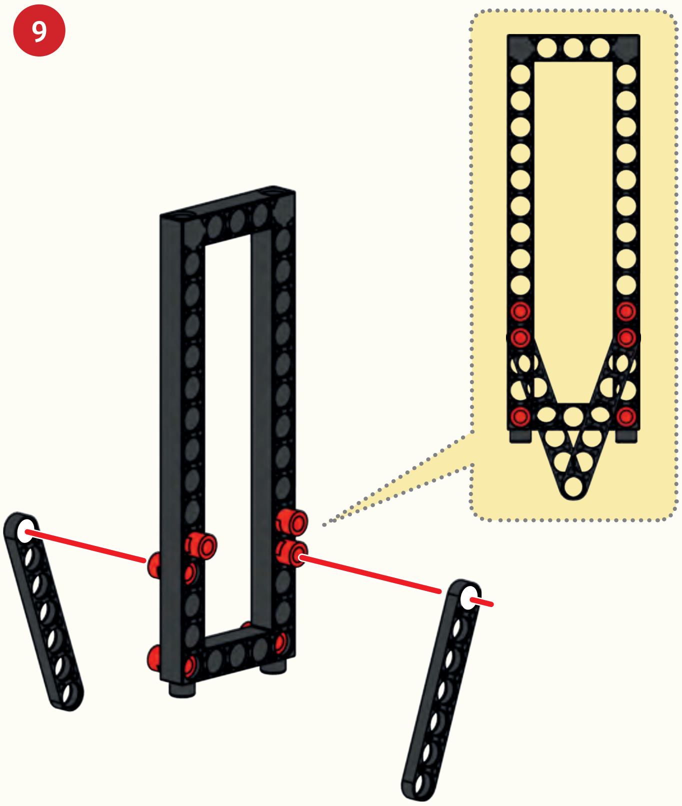

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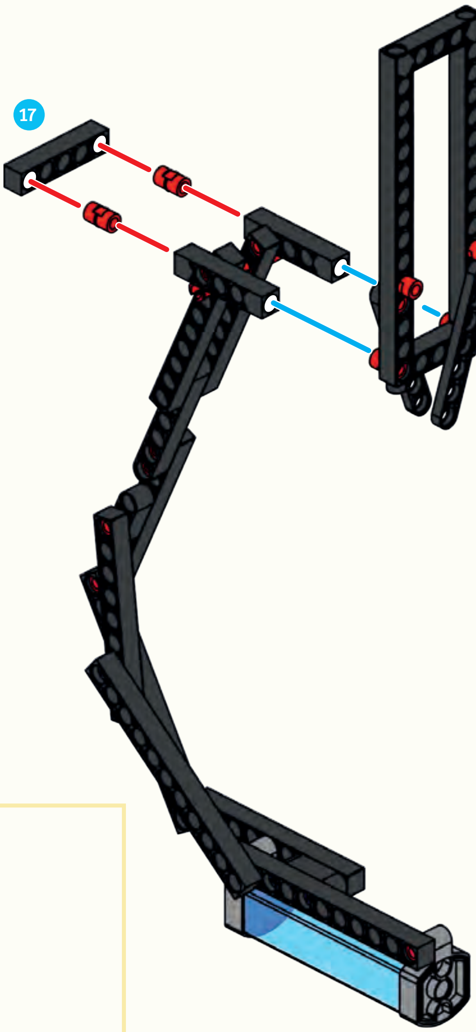

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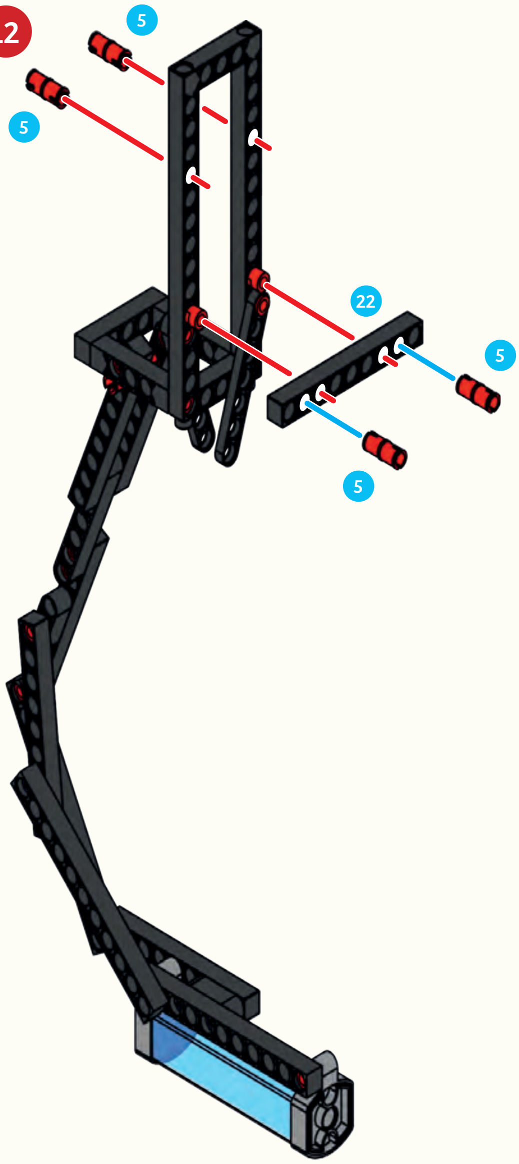

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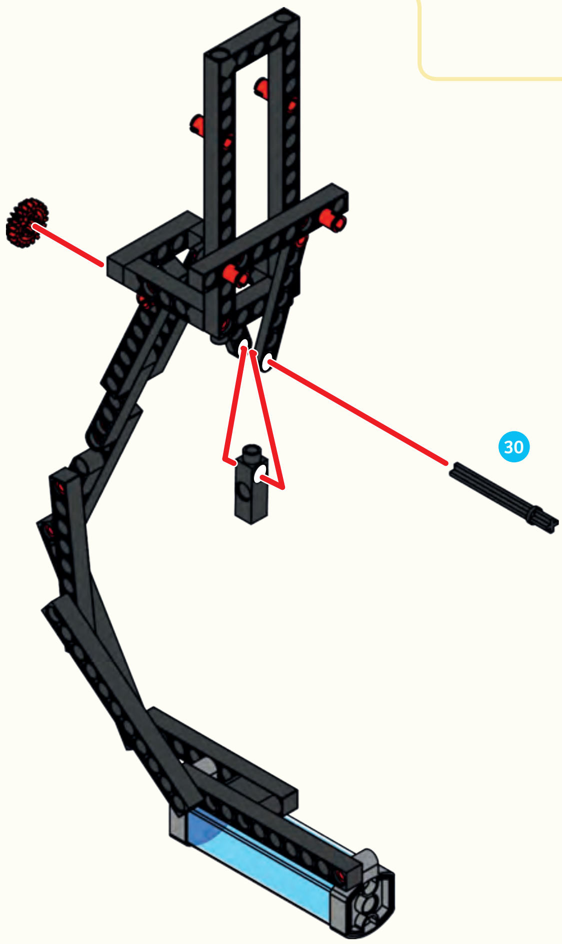

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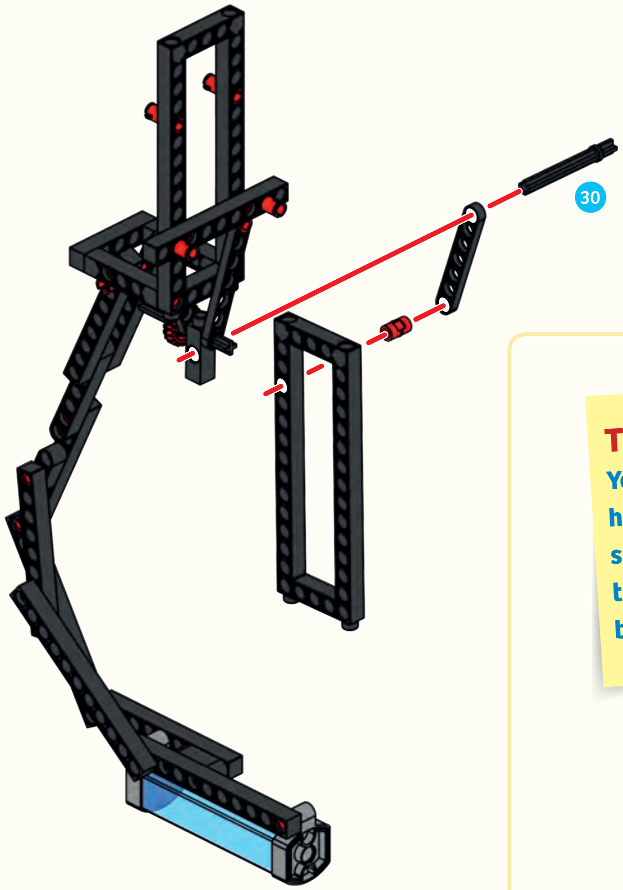

TIP!
You can easily adjust the holding bracket for your smartphone by changing the position of the rubber bands and joint pins.

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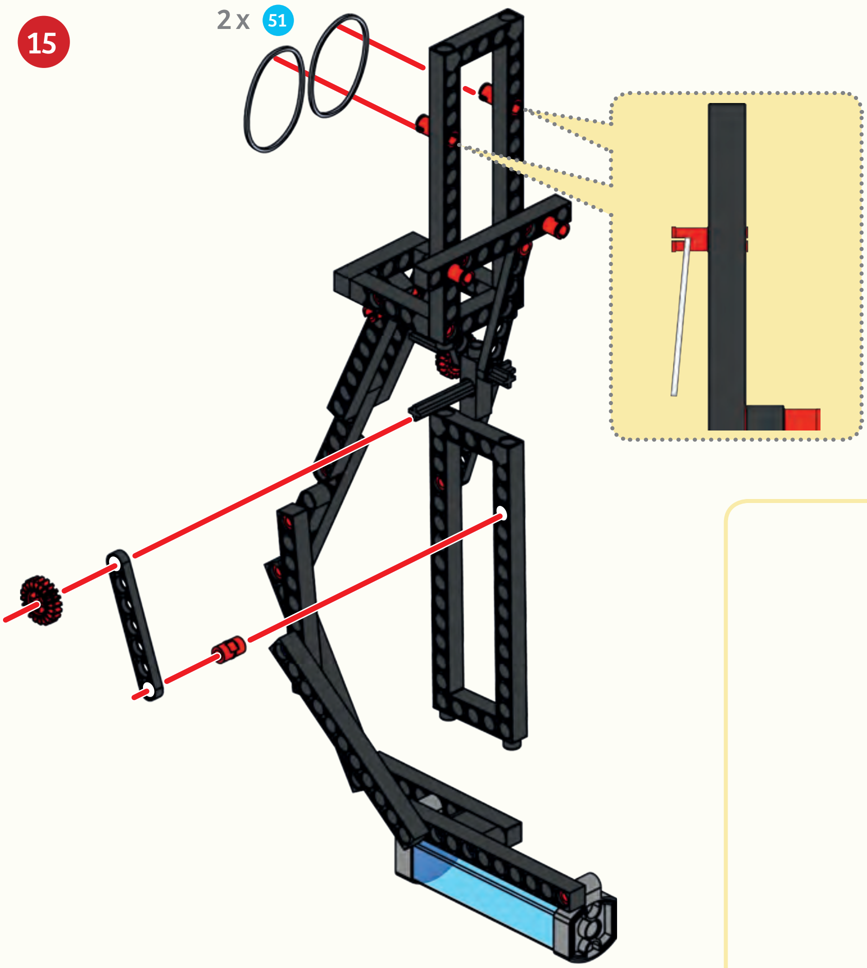
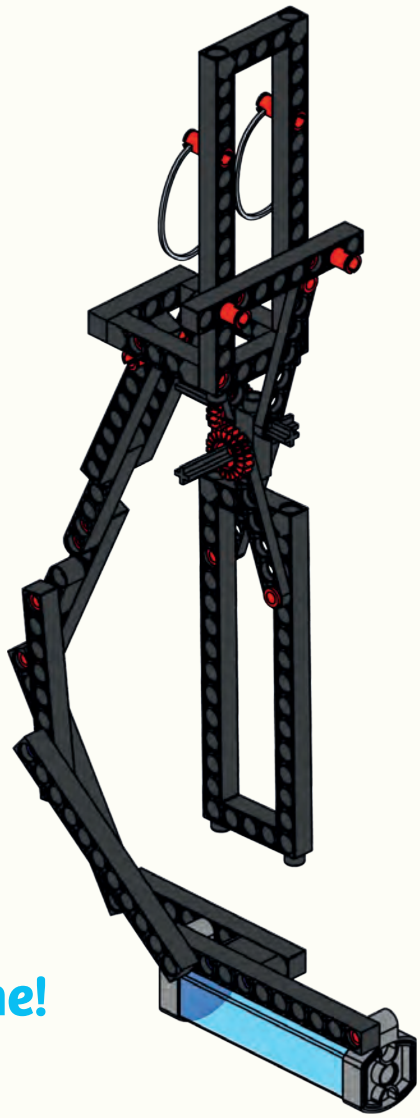




Done!

EXPERIMENT 19

Camera stabilizer mount

YOU WILL NEED

› **The assembled camera stabilizer mount**
› *A smartphone (belonging to your parents, for example)*
› *125 grams of small stones, washers, or 22 quarters (coins) for ballast*

HERE'S HOW

1. A ach the smartphone using the rubber bands so that the lens of the rear camera is "looking" forward, past the frame.
2. Fill the container underneath the camera stabilizer mount with enough weight (approx. 125 g) and adjust the stabilizer arm until the smartphone is in a secure, upright position.
3. Next, open the camera app on the smartphone and start video mode.
4. Hold the camera stabilizer mount by the handle and move your hand in di erent directions — try turning and tilting it.
5. Watch the screen to see what happens when you move your hand.

WHAT'S HAPPENING?

The camera stabilizer mount (often called a "steady-cam") is made up of two parts that are connected via a universal joint. You hold one part in your hand, and the other part is a ached to the smartphone. For the smartphone to stay upright, the center of gravity must be below the joint. That's what the ballast is for, which we place underneath on the movable part of the camera stabilizer mount. No ma er how far you turn or tilt your hand now, the smartphone will always be directly above the joint in an upright position. The joint transfers the movement and allows you to record steady footage with virtually no shaking.

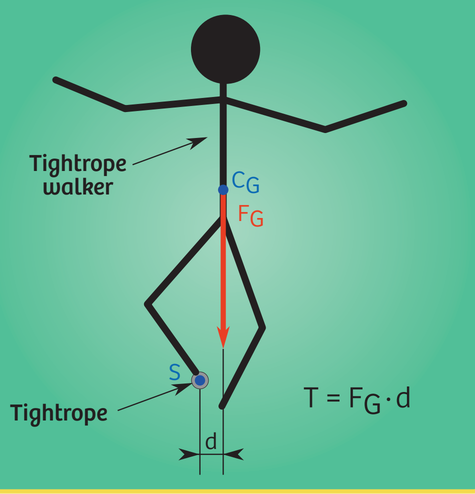
DID YOU KNOW?

A universal joint makes it possible to transfer a rotational movement from one rotating shaft to another, without the need for the two shafts to be in a straight line. You've probably seen bicycles with a single-wheel trailer. The trailer is connected to the bicycle via a universal joint and will tilt in the same way as the bicycle when going around bends.

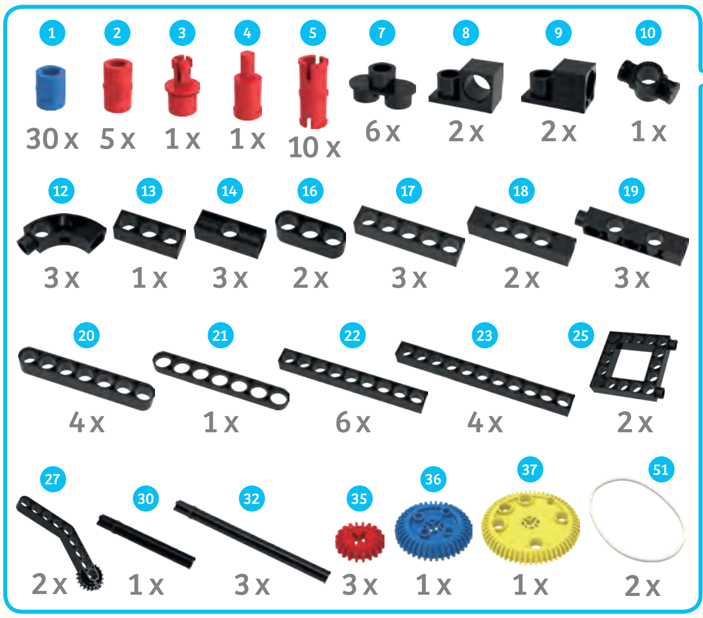
KEY CONCEPT: CENTER OF GRAVITY

The **center of gravity** of a body of ma er is an imaginary point. If you take hold of the body at this point, it will not move. However, if you take hold of it at a di erent point, the body will try to turn — i.e. a **torque (T)** is exerted. The further from the center of gravity you take hold of the body, the stronger the torque.

If the **center of gravity** is located below the point at which a body is supported, the body is stable. This means that small changes to the body's position will be balanced out, and it will be able to return to its original position. This e ect is put to use in the camera stabilizer mount, and also demonstrated when tightrope walkers stick their arms out to balance themselves.



TRIPOD



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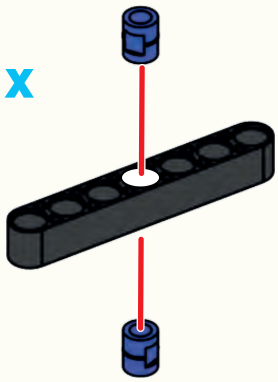

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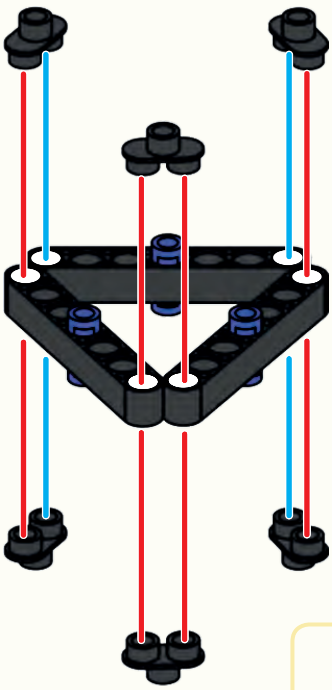

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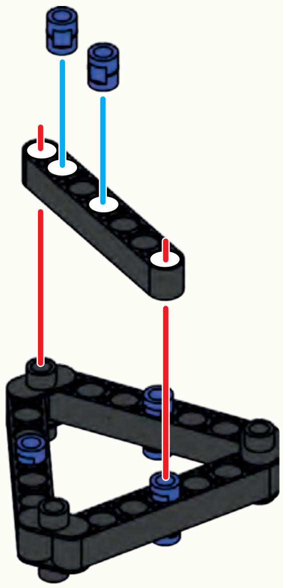

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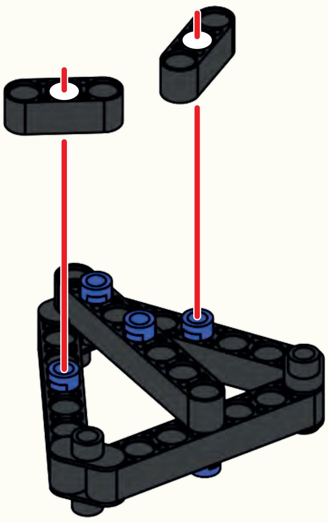

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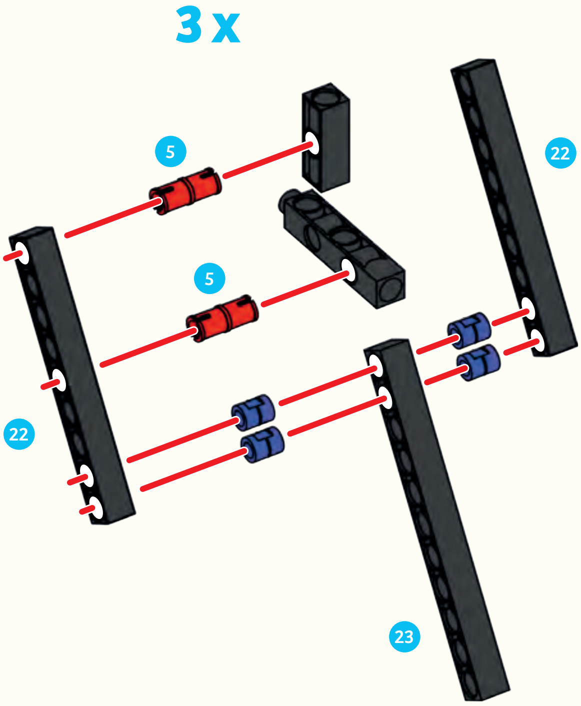

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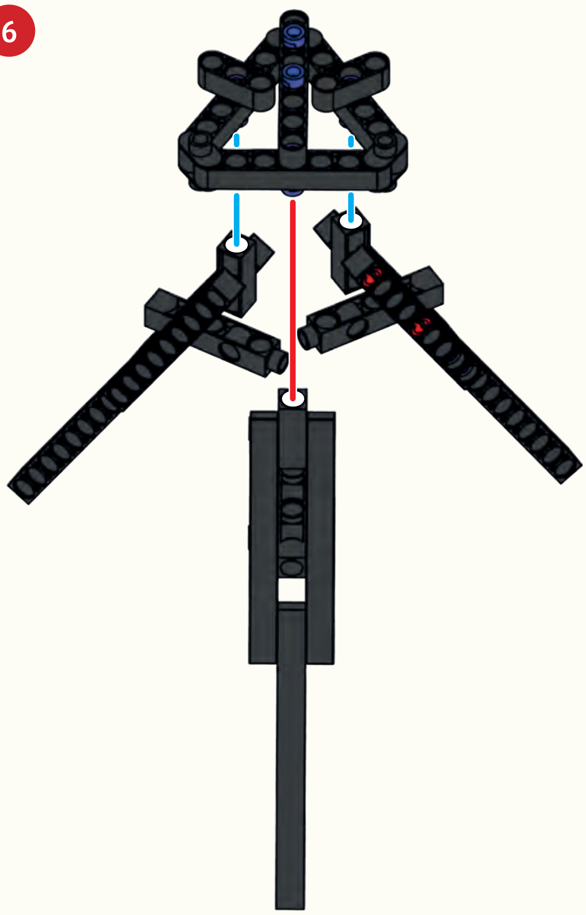

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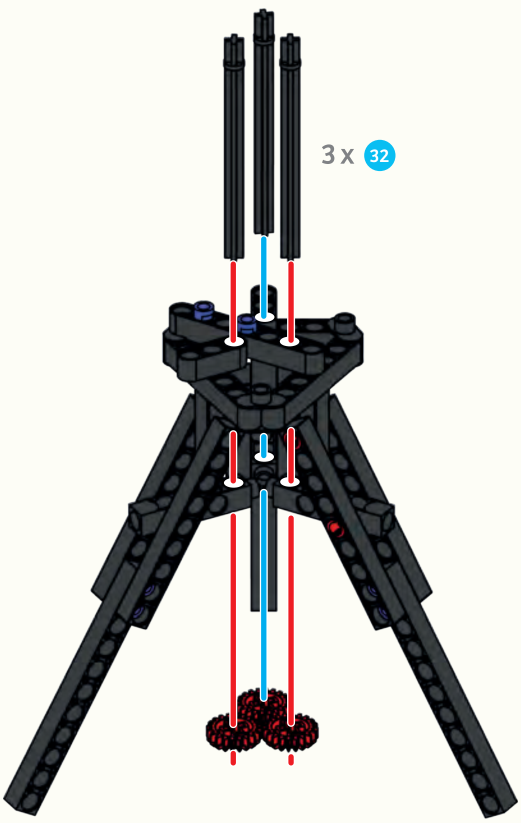

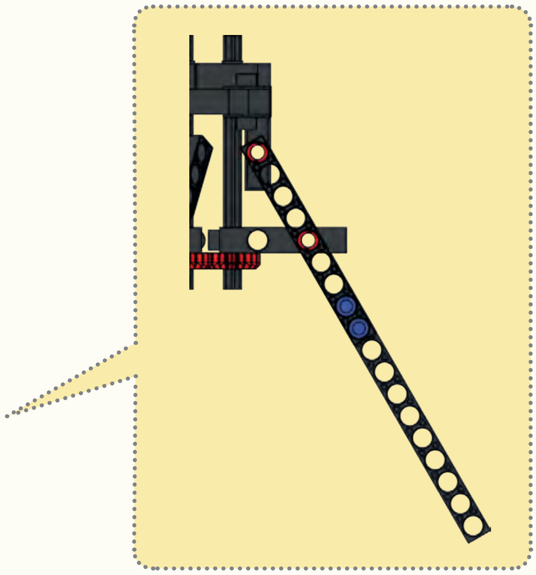

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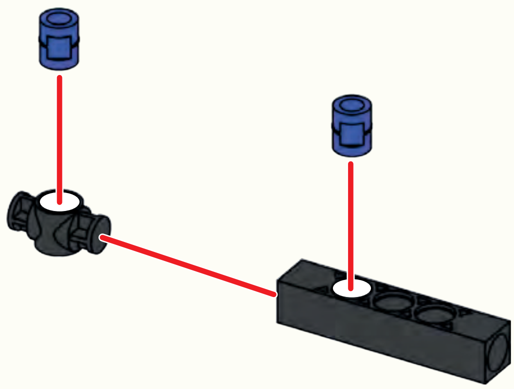

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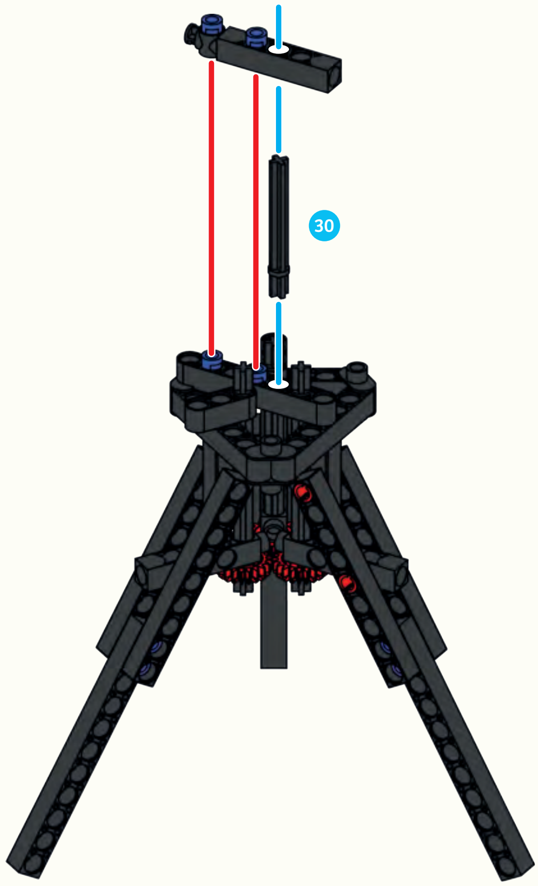

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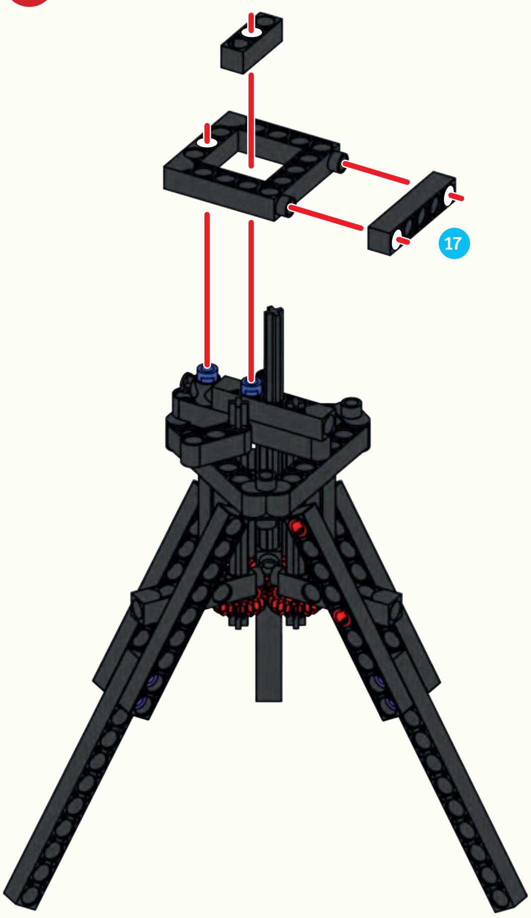

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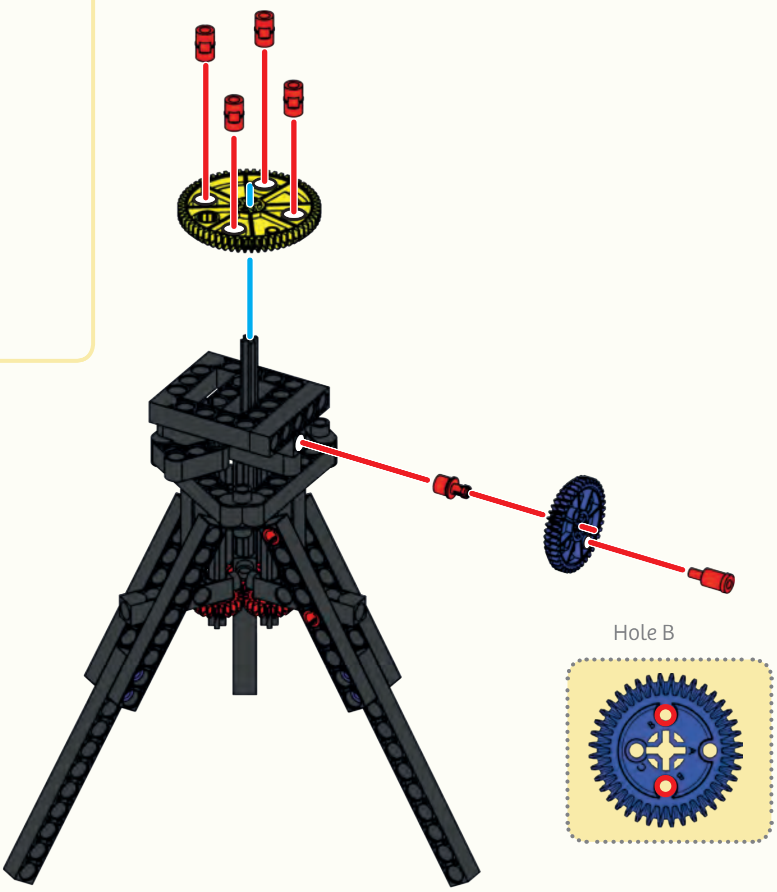

Hole B

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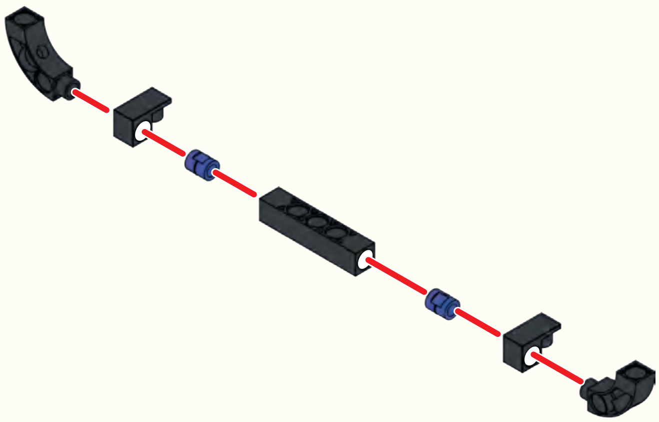

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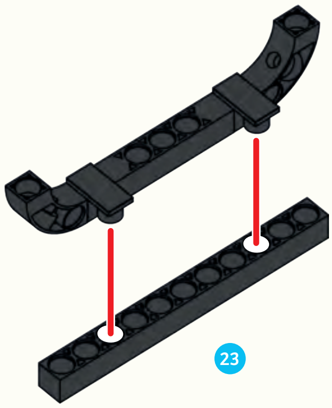

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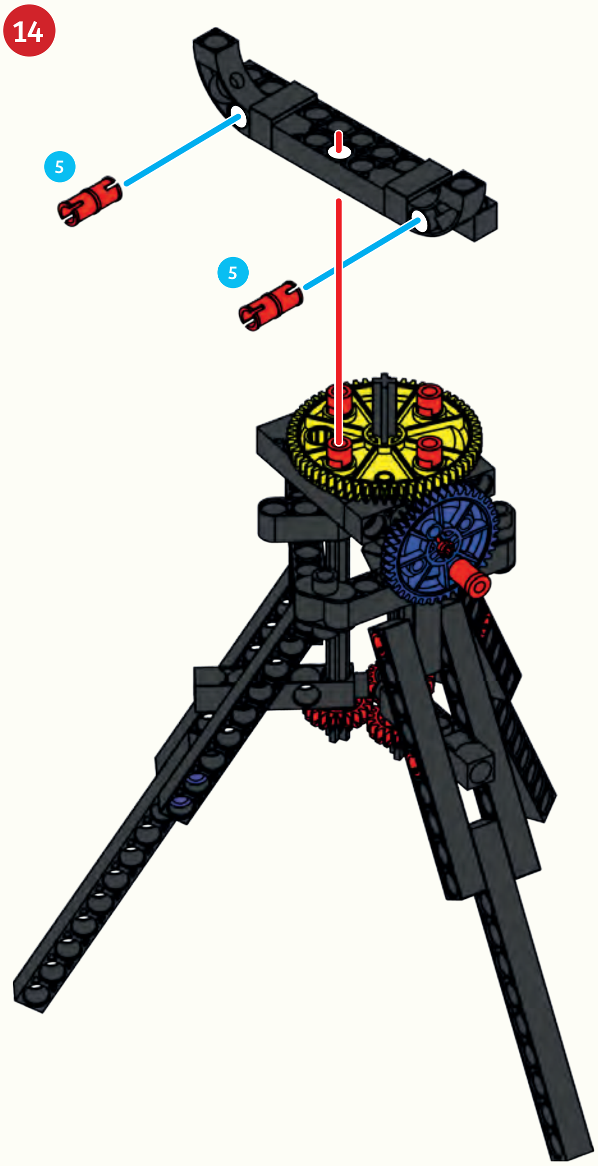

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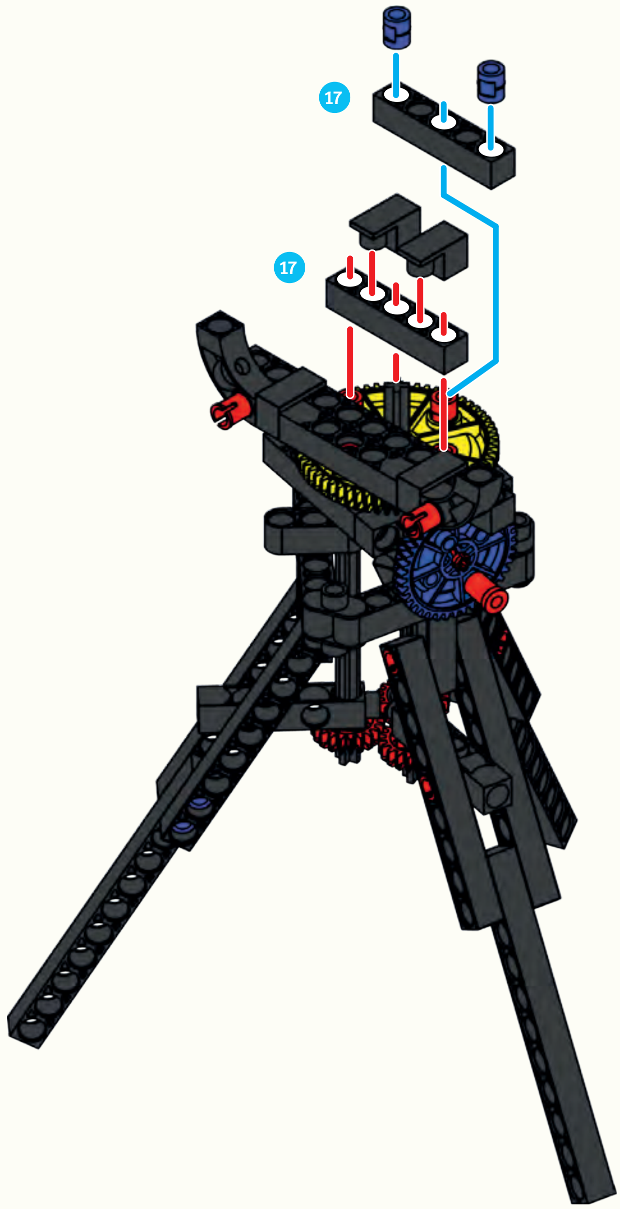

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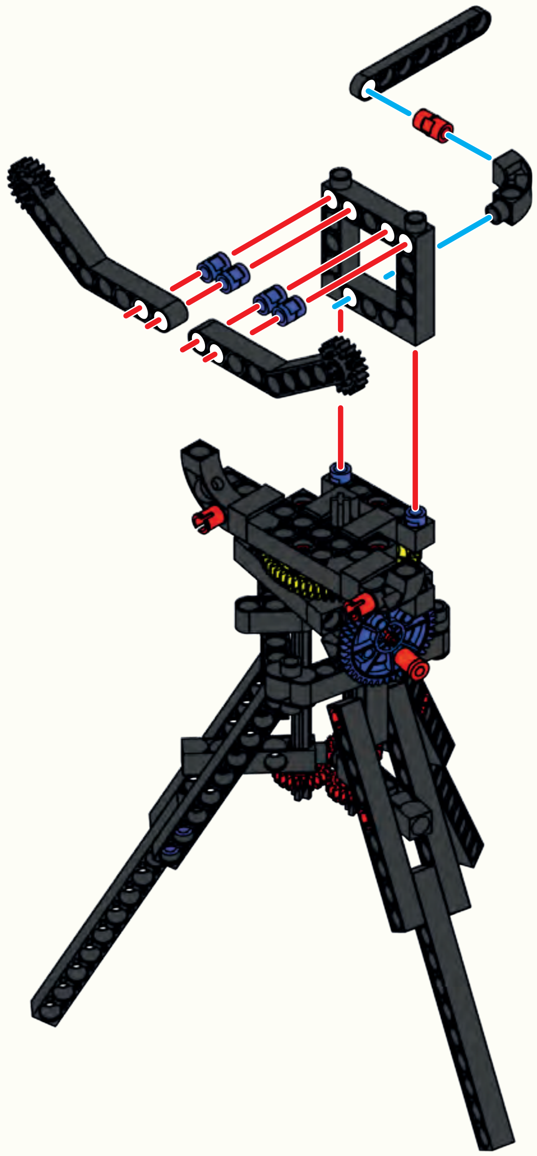

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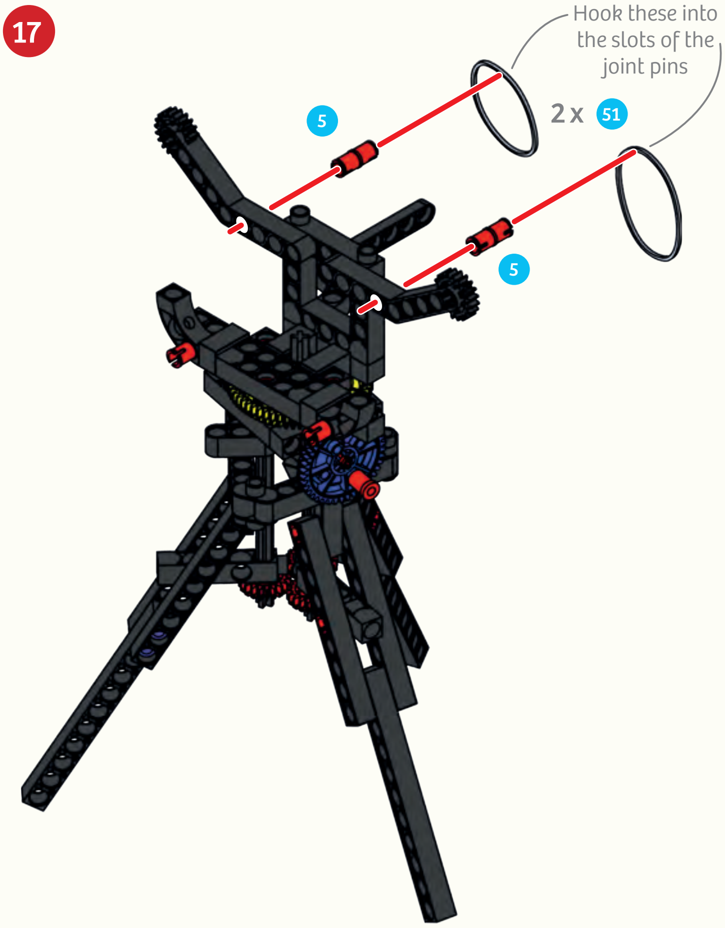
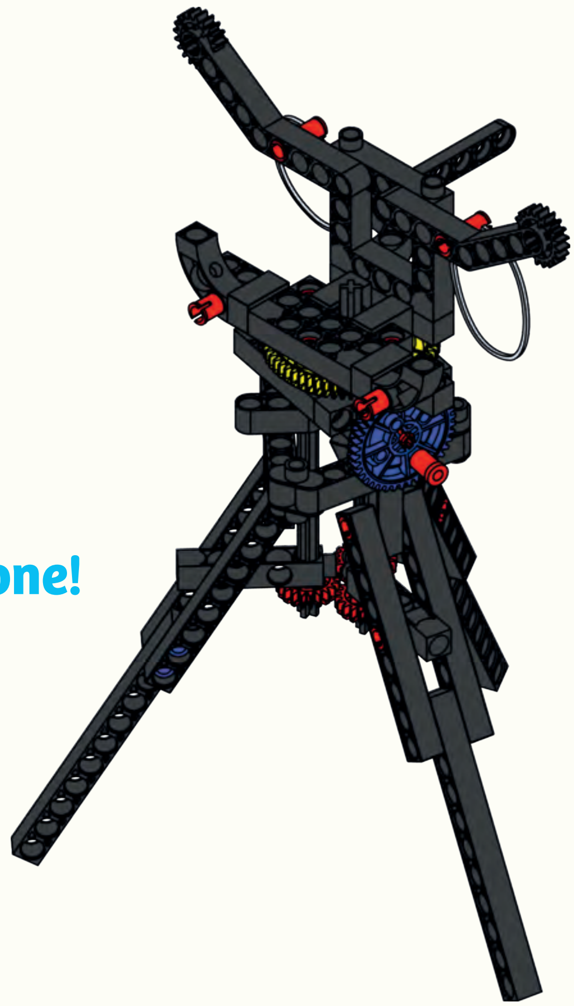


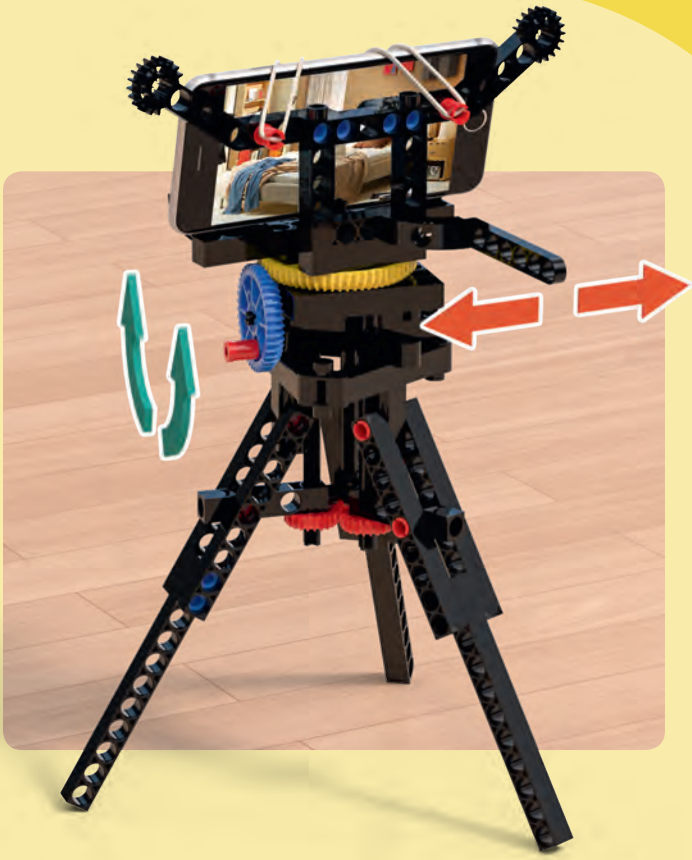


Done!

TIP!
You can easily adjust the holding bracket for your smartphone by changing the position of the rubber bands and joint pins.

EXPERIMENT 20

Tripod



YOU WILL NEED

› **The assembled tripod**
› *A smartphone (belonging to your parents, for example)*

HERE'S HOW

1. Open the camera app.
2. A ach the smartphone to the tripod using the two rubber bands. These should be crossed in the middle so that they're not covering the camera lenses (the rear camera should be "looking" forward).
3. Next, adjust the camera by turning the crank or the handle.
4. You can now take a photo or video. If your smartphone has a panorama mode, you can also take a panoramic shot.

WANT TO FIND OUT MORE?

Why not use the tripod to send a message in Morse code? Morse code can be used to send information across great distances. To do so, you'll need to a ach a flashlight, bicycle light, or headlamp to the tripod. You can create the long and short light pulses either by covering the beam of light or by turning off the light

A	• —	N	— •
B	— • • •	O	— — —
C	— • — •	P	• — — •
D	— • •	Q	— — • —
E	•	R	• — •
F	• • — •	S	• • •
G	— — •	T	—
H	• • • •	U	• • —
I	• •	V	• • • —
J	• — — —	W	• — —
K	— • —	X	— • • —
L	• — • •	Y	— • — —
M	— —	Z	— — • •

WHAT'S HAPPENING HERE?

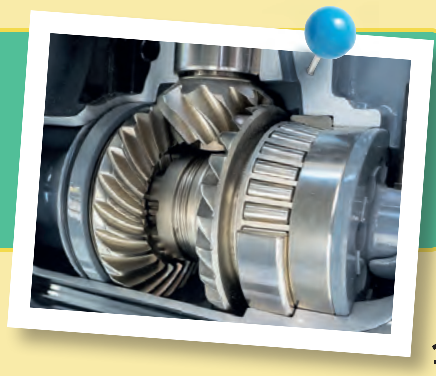
The bevel gear transfers the rotation from the crank to the camera holder. As the crank has a smaller number of teeth than the holding bracket, the holding bracket will turn more slowly than the crank. This makes it possible to position the camera with precise accuracy.

DID YOU KNOW?

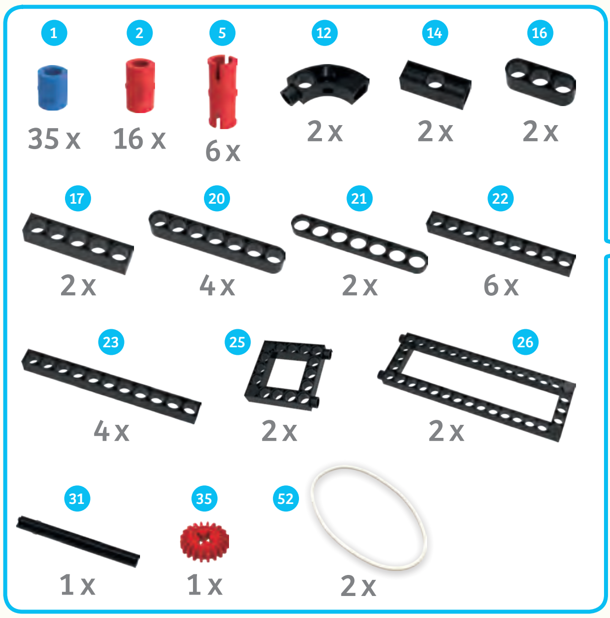
The tripod is stable because it has three legs. With two legs, it would tip over its single axis, while with four legs, it could wobble back and forth. A tripod needs three points of contact with the ground to remain stable. With four or more points of contact there is a chance that one of the points won't touch the ground if the ground is uneven. Geometrically speaking, one plane is defined by th ee points. The three points of the tripod legs form a single, stable plane.

KEY CONCEPT: BEVEL GEARS

A **bevel gear** is used to change the direction of a shaft's rotation. Usually, the drive shaft and output shaft are at a right angle to each other. For the movement to be transferred, the gears must be in a slanted position.



SELFIE STICK



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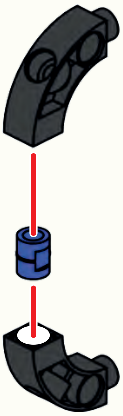

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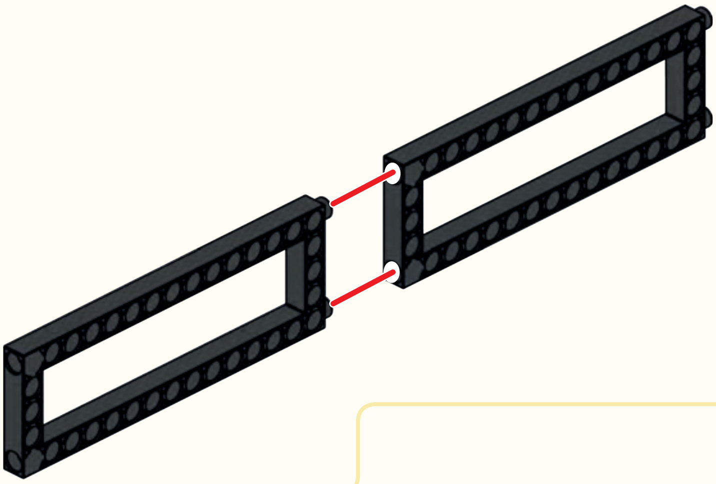

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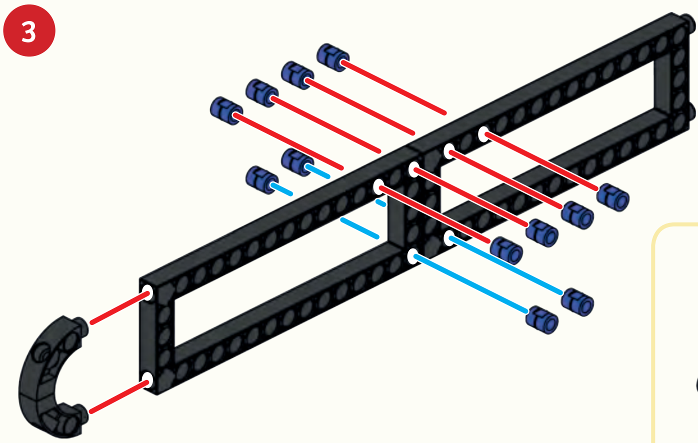

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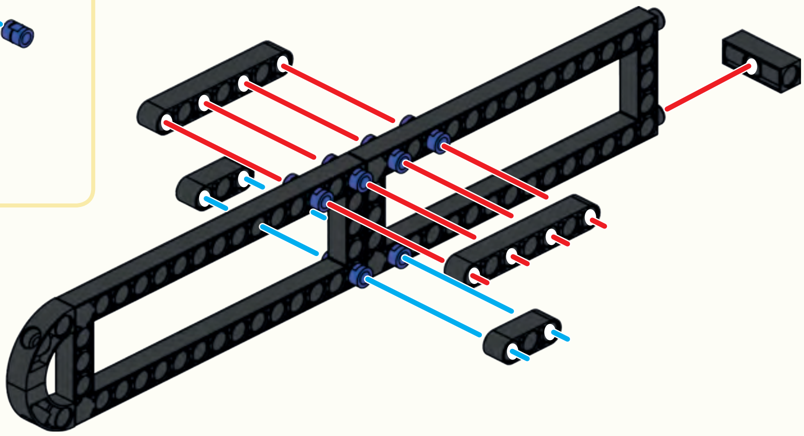

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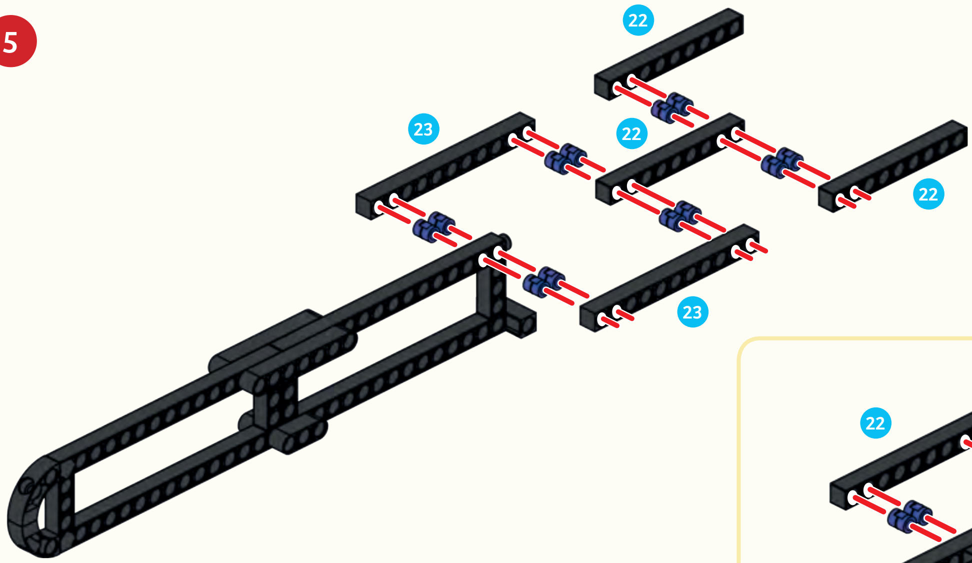

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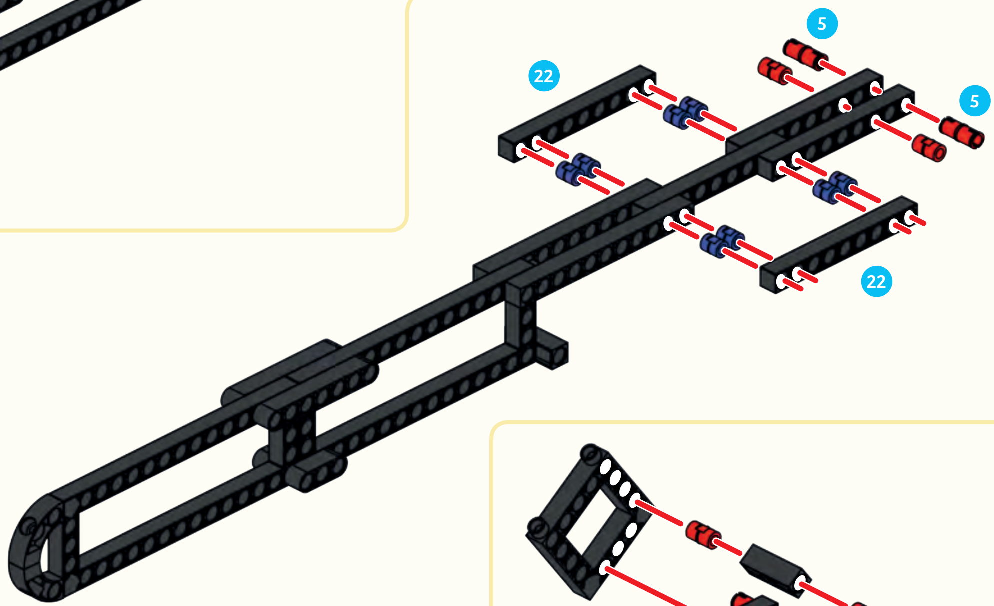

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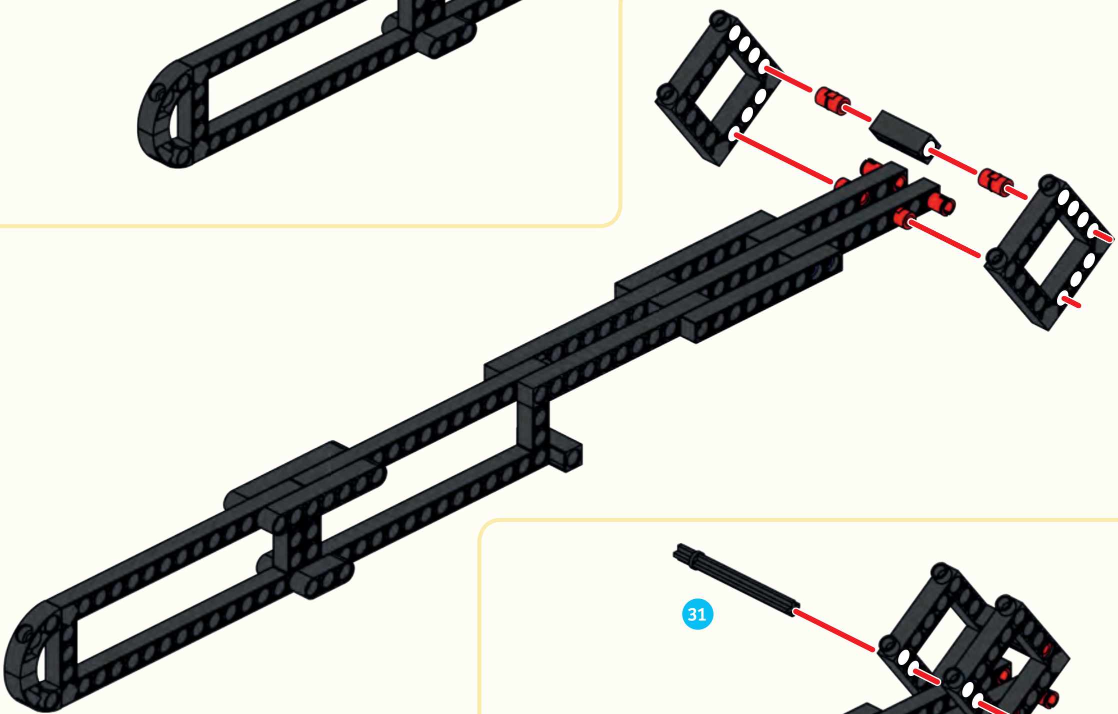

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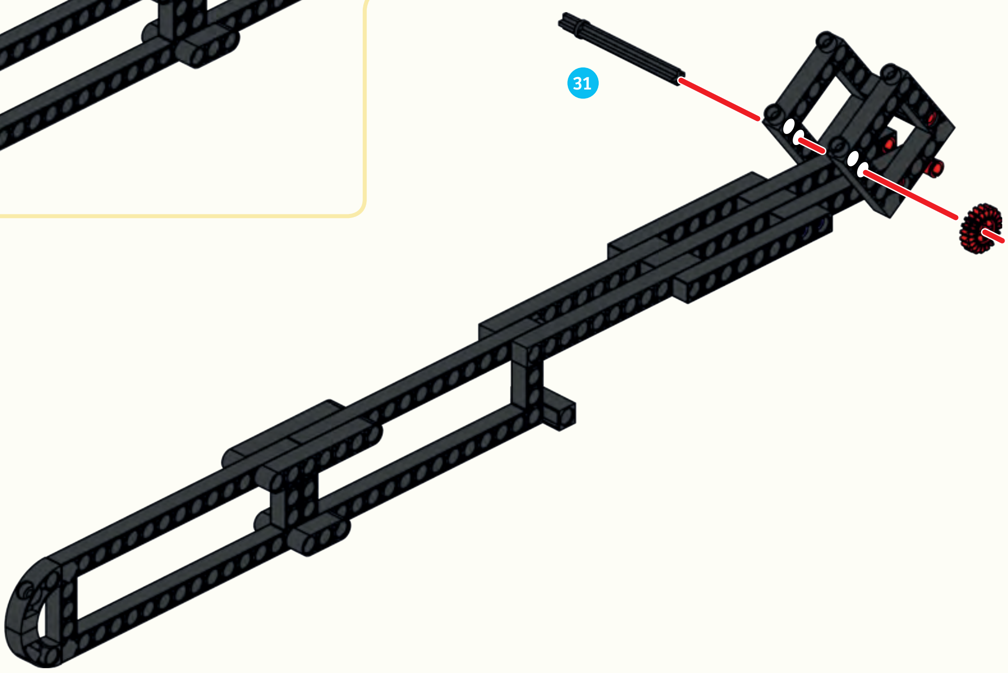

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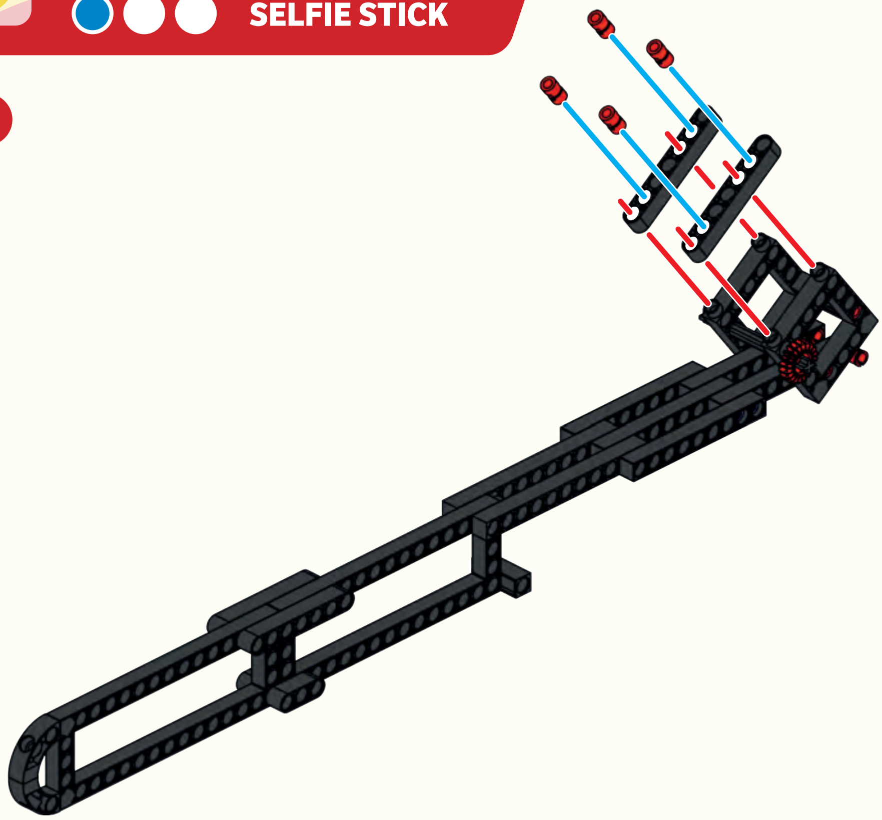

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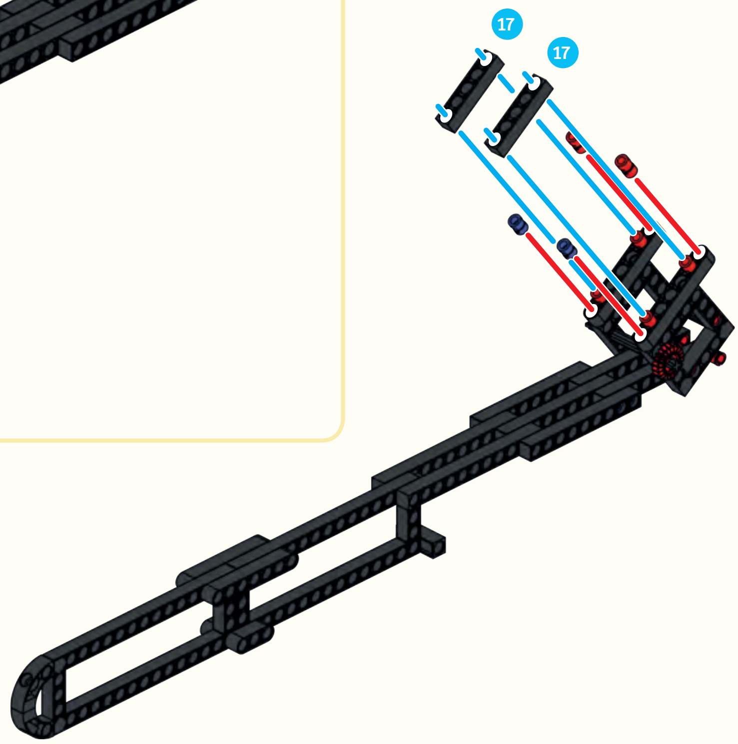

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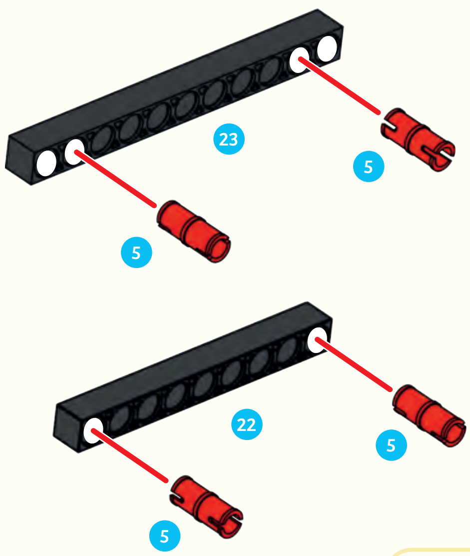

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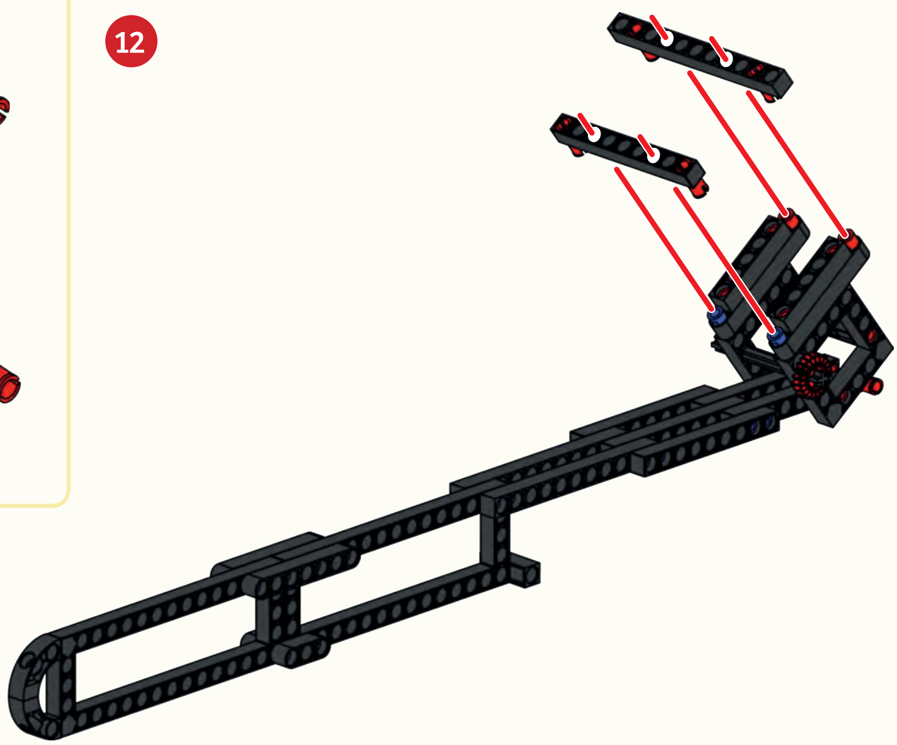

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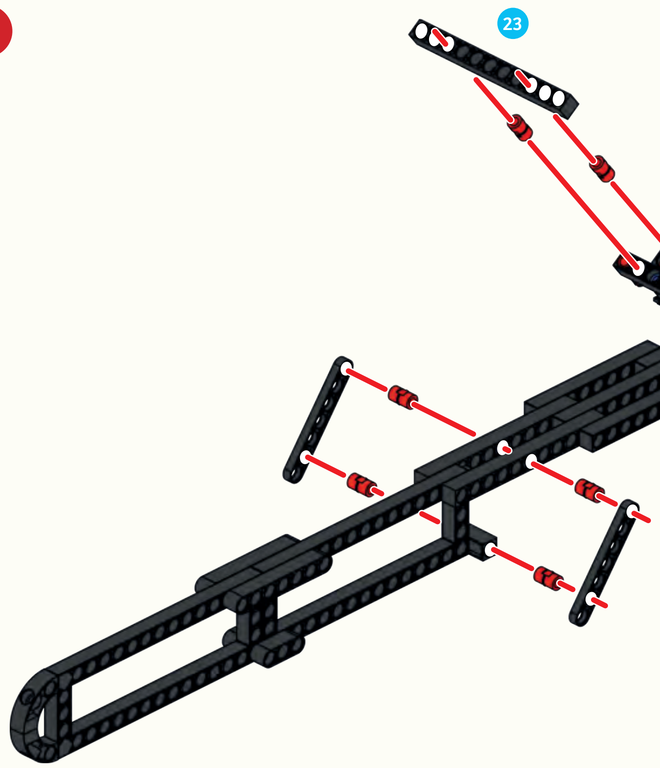

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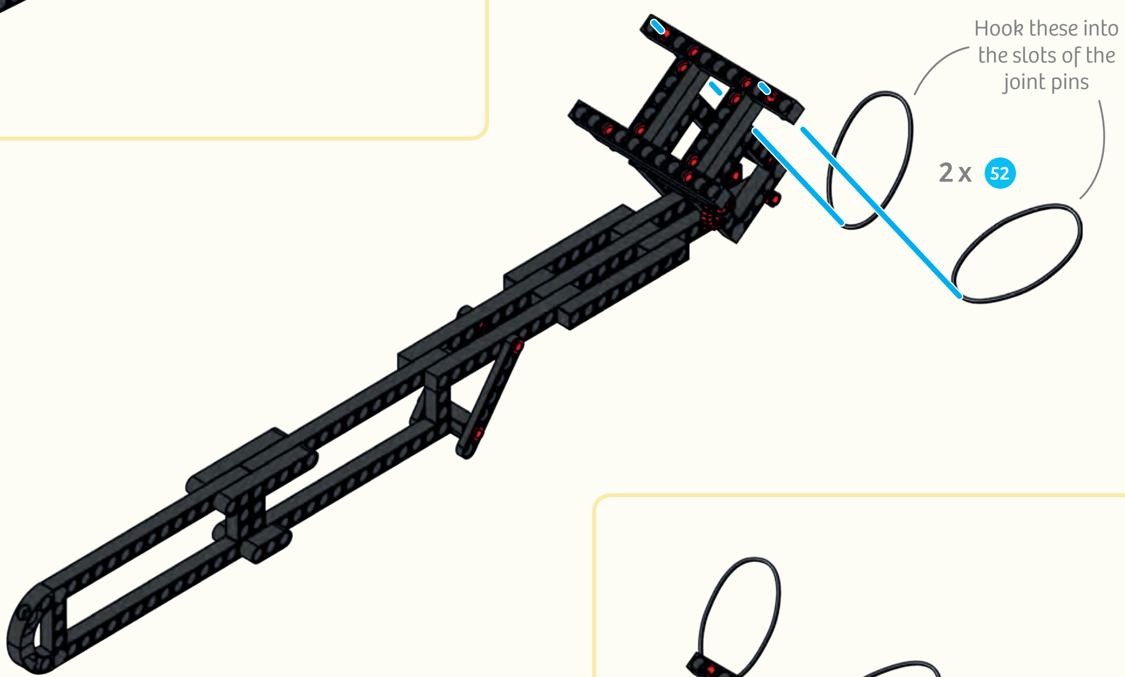
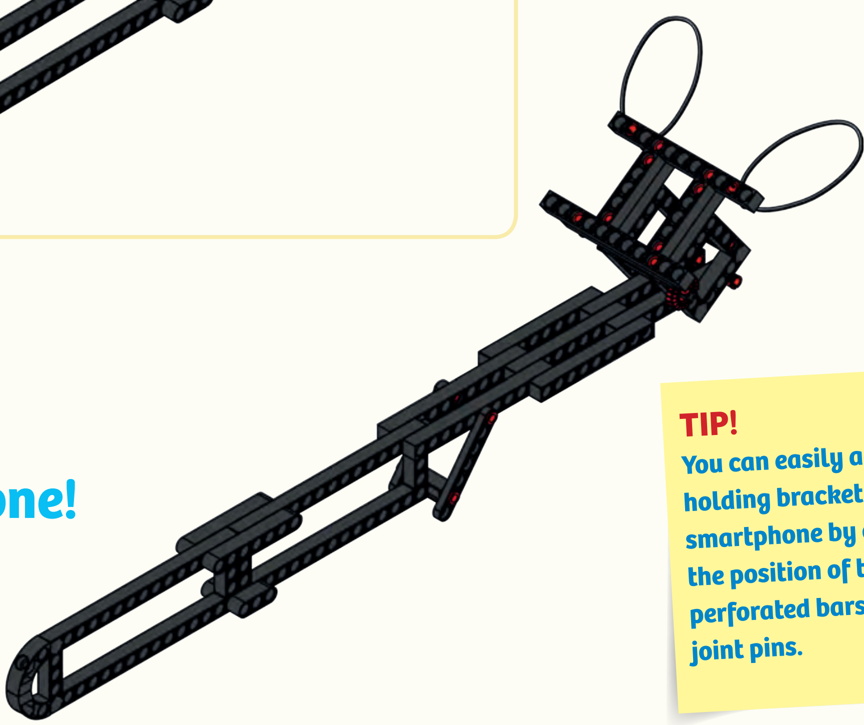




All done!

TIP!
You can easily adjust the holding bracket for your smartphone by changing the position of the perforated bars and joint pins.

EXPERIMENT 21

Selfie stick

YOU WILL NEED

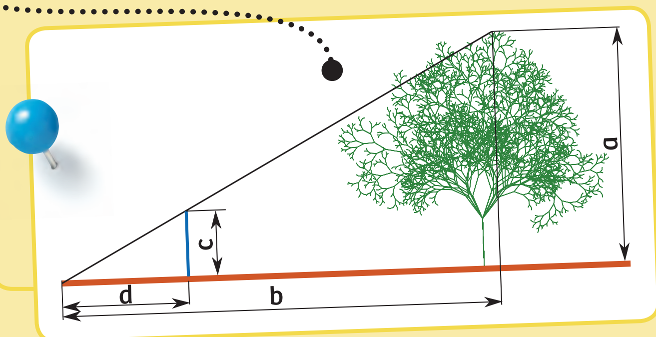
› **The assembled selfie stic**
› *A smartphone (belonging to your parents, for example)*

HERE'S HOW

1. A ach the smartphone using the rubber bands so that the lens of the front-facing camera is "looking" toward you, clear of the bands.
2. Next, open the camera app on the smartphone and start selfie mode
3. Hold the selfie stick by the hand e so that the smartphone is at the top.
4. When you're angling the smartphone, it's important to move the holding bracket in such a way that the camera correctly frames the image you want to take.
5. Move the stick toward and then away from yourself.
6. Watch the screen to see what happens when you move the selfie stick.
7. To test the stability of the selfie stick, ho d it vertically with one hand on the handle and try bending at the other end. Then hold the handle horizontally and try bending again.

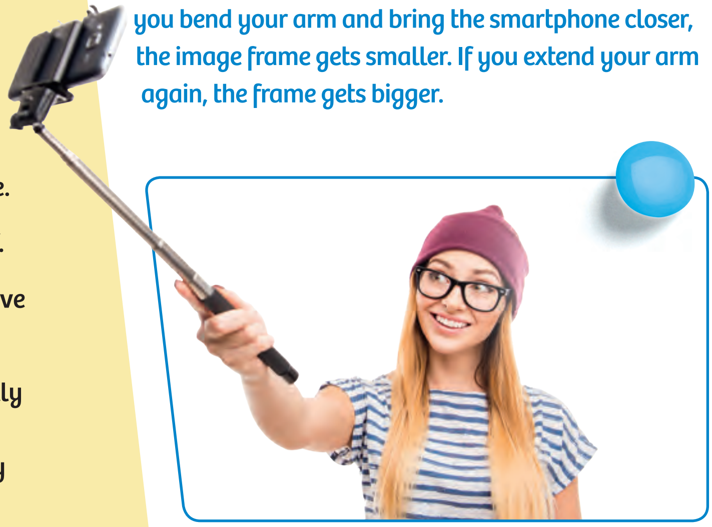
DID YOU KNOW?

When you move the selfie stick further away, you an see more of yourself; when you move it closer, the image frame gets smaller. Using this principle, which is known as the intercept theorem, you can find out the height of a ower or a tree. To do so, the di erent lengths are expressed as a ratio as follows: a/b = c/d, where a = Height of tree, b = Distance to tree, c = Height of measuring stick, d = Distance to measuring stick.



WHAT'S HAPPENING?

Selfie sticks help you o take photos of yourself. They not only make the process easier, they also increase the size of the image that's visible on the screen. The reason for this is that the selfie stick ma es your arm longer. If you bend your arm and bring the smartphone closer, the image frame gets smaller. If you extend your arm again, the frame gets bigger.

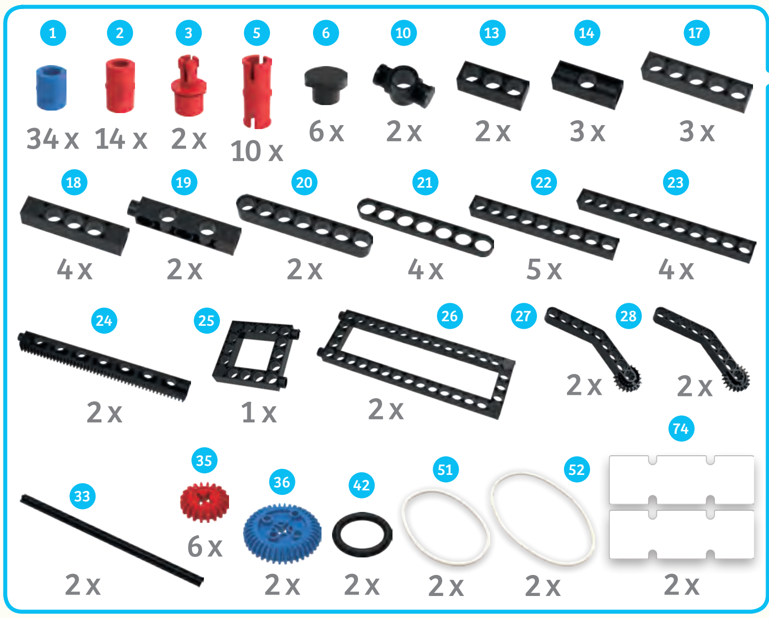


To stop the selfie stick f om bouncing or bending, the handle is made of two rectangular frames at the point where it supports the most weight. Above this, several bars are arranged at right angles to each other. This also helps to stabilize the stick. In this experiment, you'll see that holding the handle vertically is much more stable than holding it horizontally. The angled bars provide additional stability for the connection point.

WANT TO FIND OUT MORE?

You can also use the selfie stick to look around corners. To do so, you'll need to either switch on video mode or a ach a small pocket mirror instead of the smartphone. This means that if you're playing hide-and-seek, for example, you can peek out of your hiding place without revealing yourself.

MICROSCOPE



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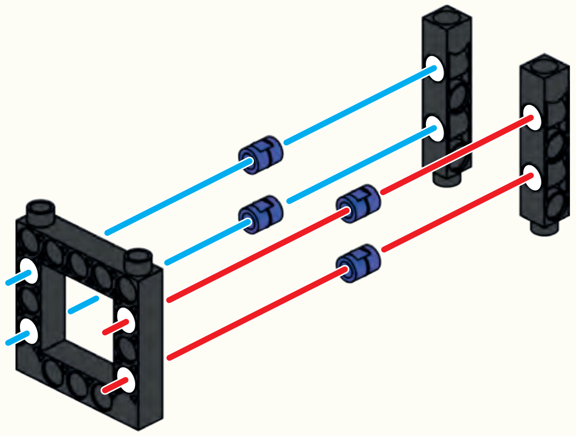

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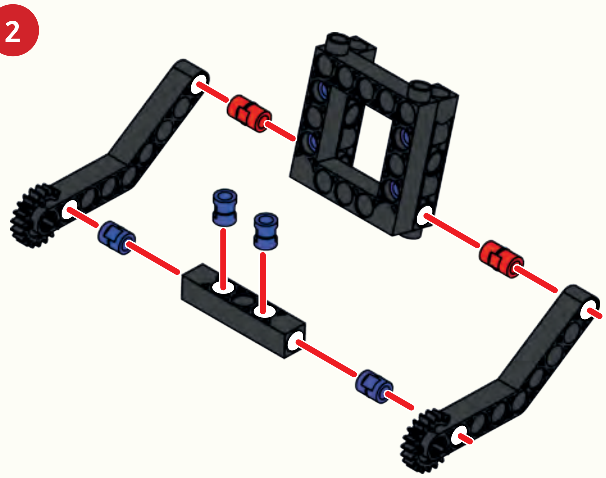

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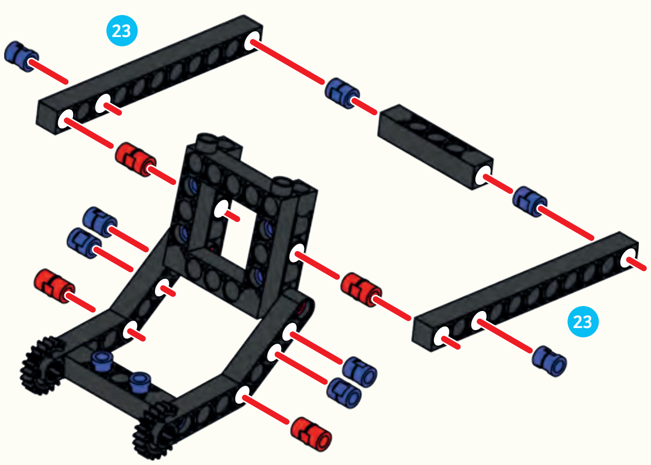

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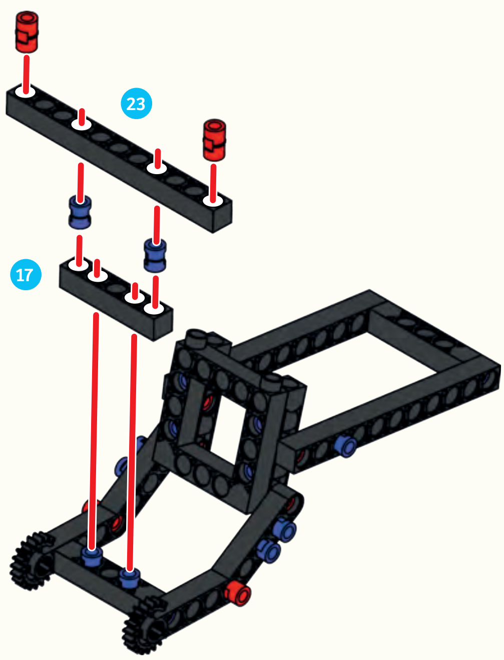

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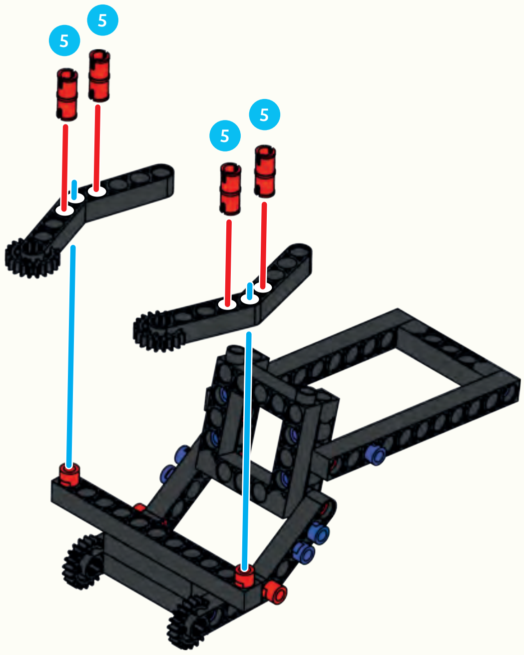

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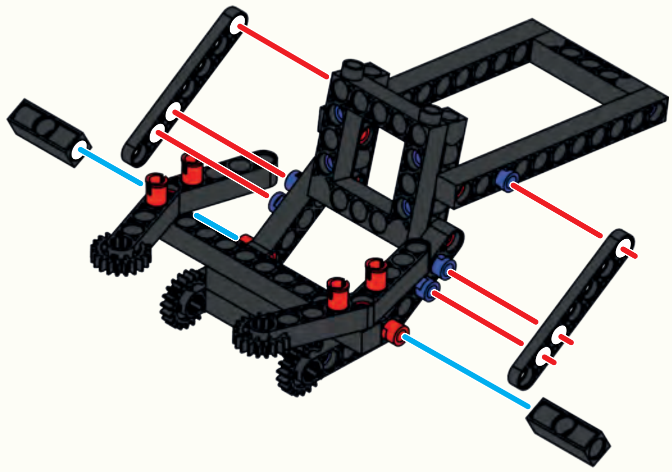

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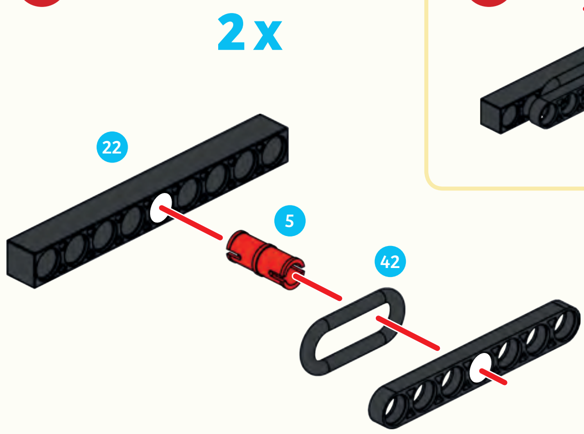

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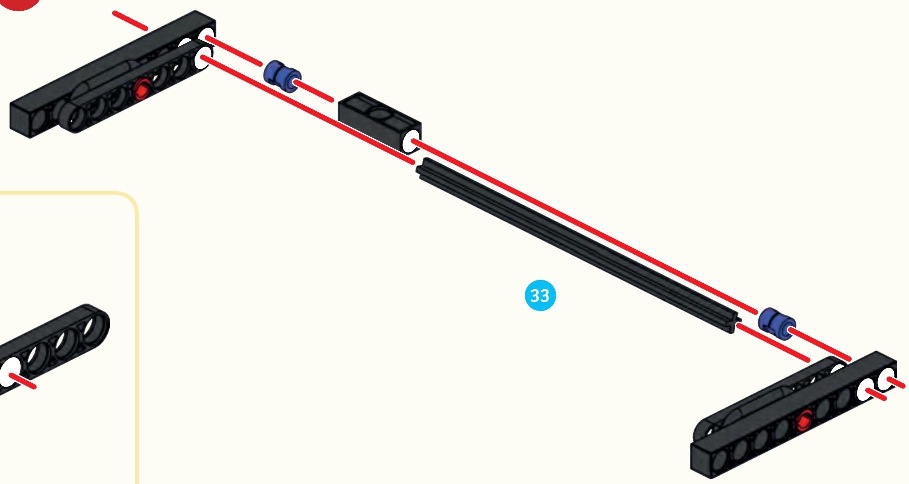

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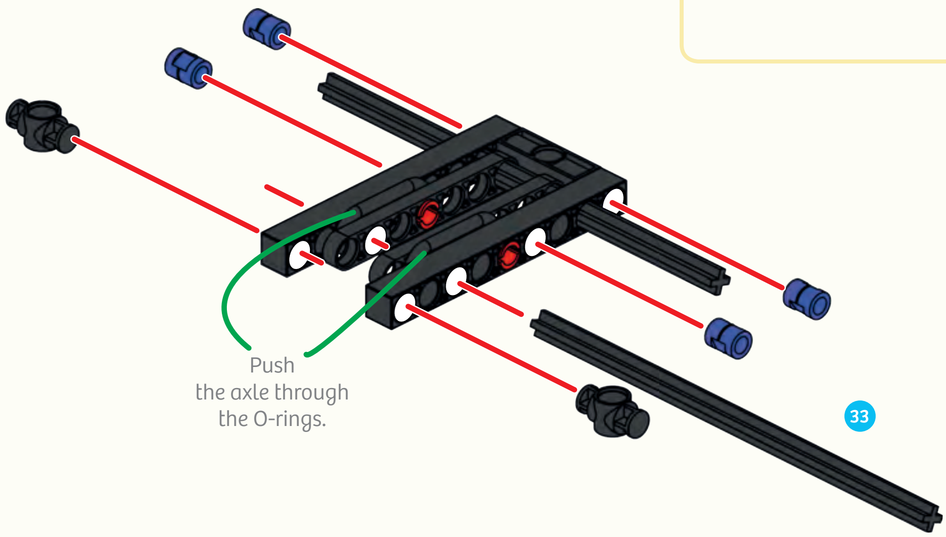

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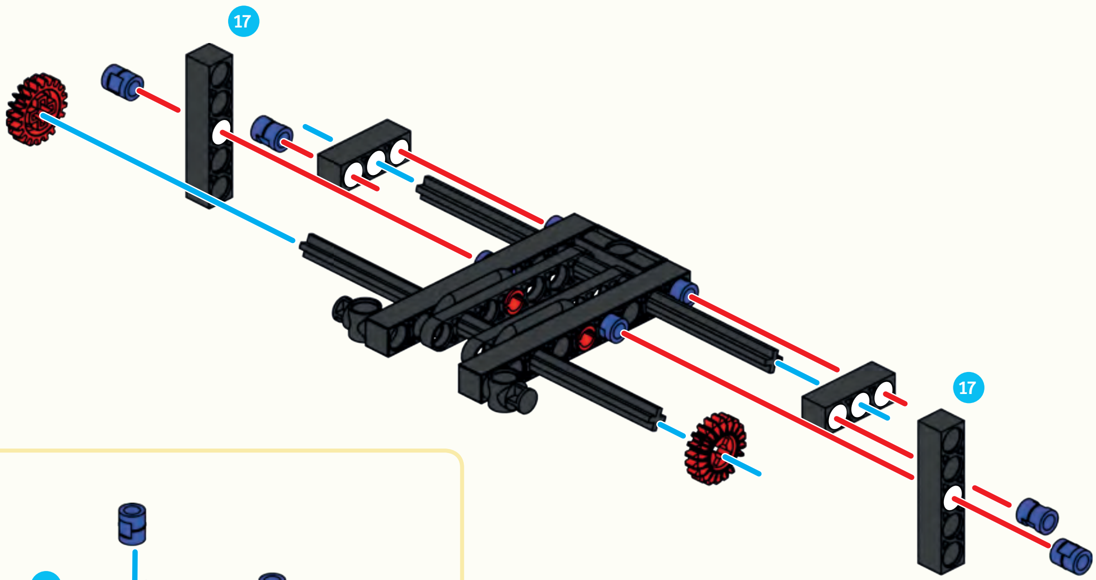

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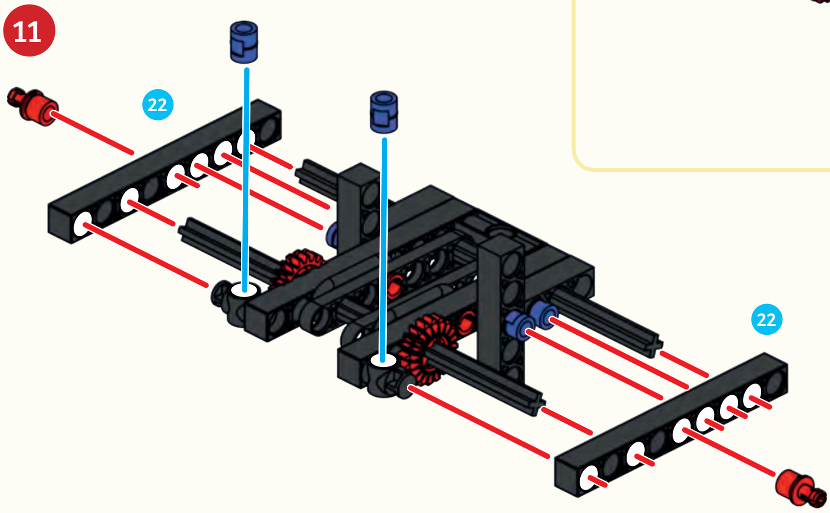

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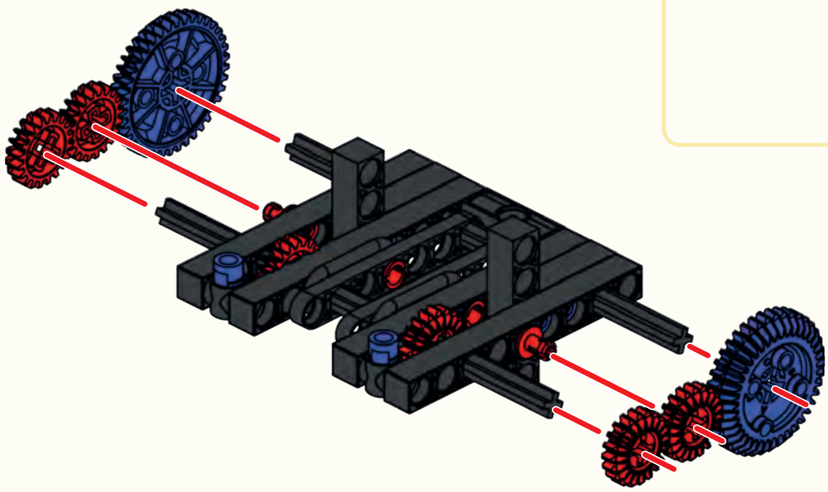

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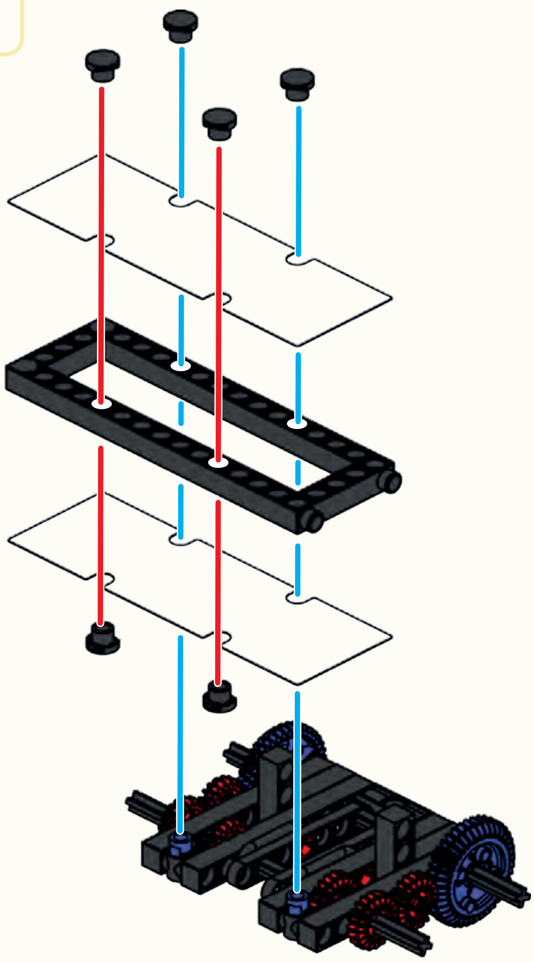

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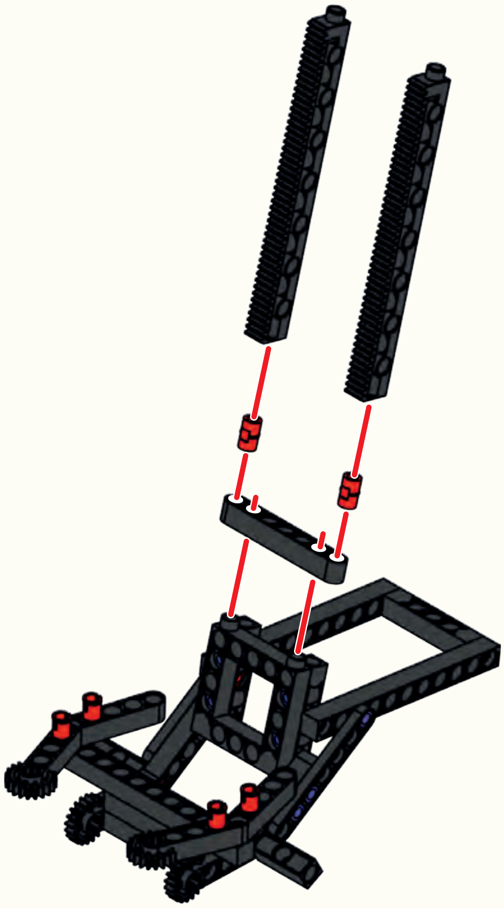

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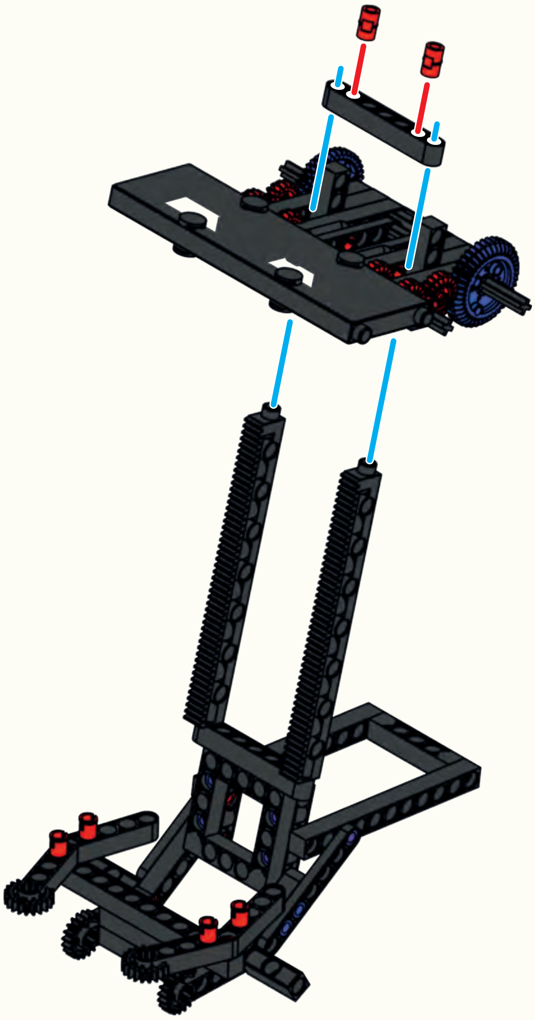

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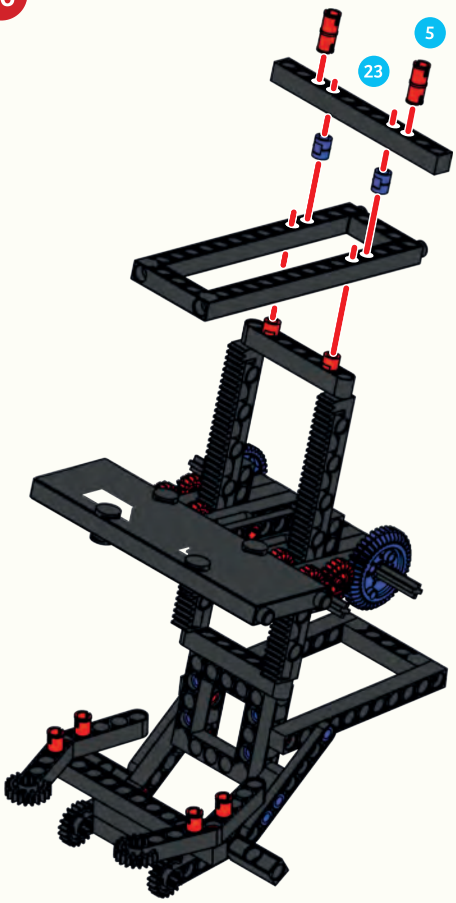

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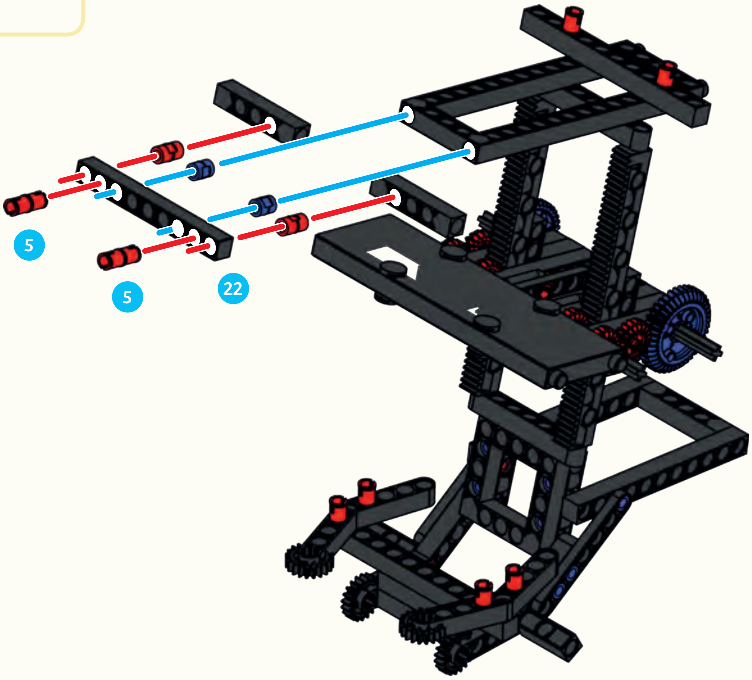

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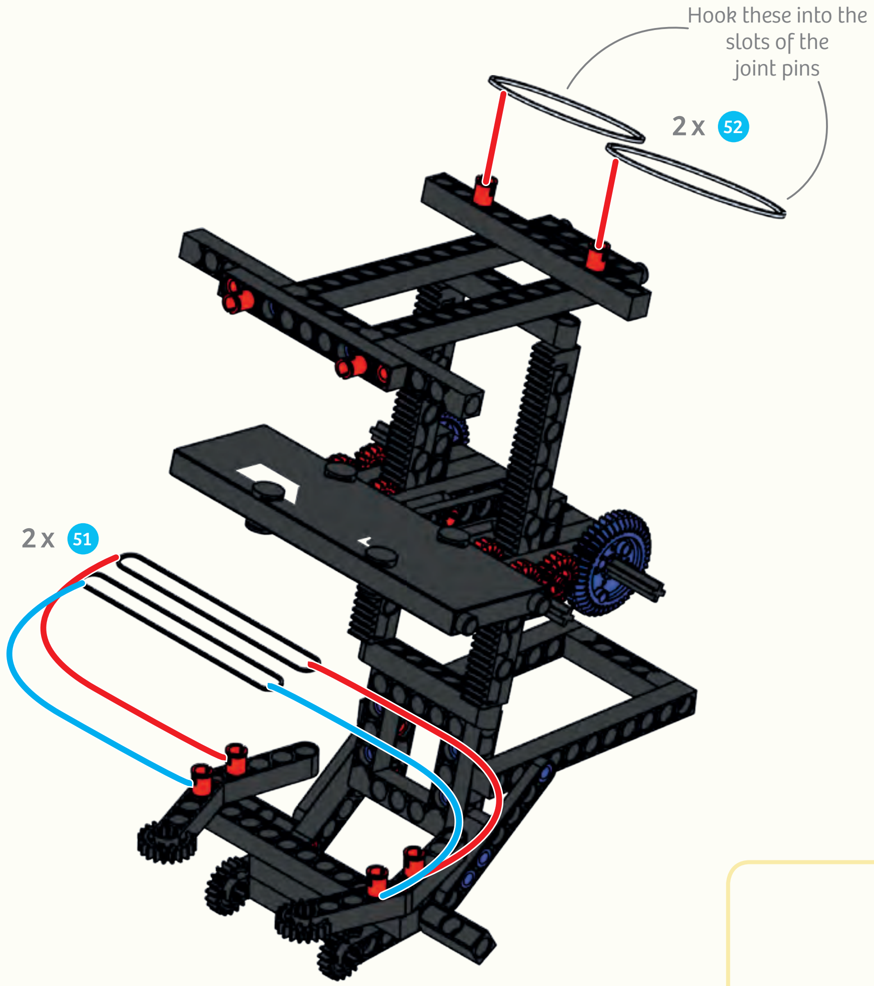
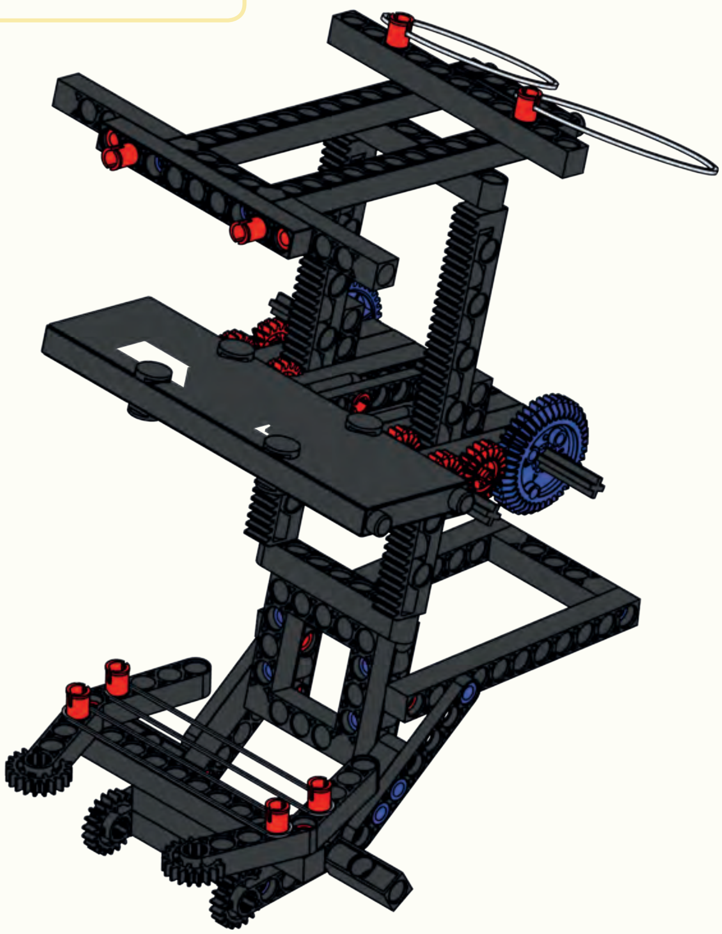




TIP!
You can easily adjust the holding bracket for your smartphone by changing the position of the rubber bands and joint pins.

Done!

EXPERIMENT 22

Microscope

YOU WILL NEED

› **The assembled microscope**
› *A smartphone (belonging to your parents, for example)*
› *A   ashlight, bicycle light, or headlamp*
› *Small transparent objects to examine with your microscope: leaves, petals, etc.*

HERE'S HOW

1. Open the camera app and start macro or close-up mode, if your smartphone has this feature.
2. Next, a   ach the smartphone using the rubber bands so that the rear camera is pointing downward, past the frame.
3. Adjust the light so that it's facing upward and can shine through the transparent bracket (called the microscope's stage) from below, then switch it on.
4. Next, place an object on the stage.
5. Turn the blue gears to move the stage up and down.
6. Examine the di   erent objects you have collected.

WHAT'S HAPPENING?

The light emi   ed from the light source illuminates the object. The light is transmi   ed to the sensor through the lenses of the smartphone's camera, and the photo or video is created. If you raise the stage higher, the image frame gets smaller and small details are more clearly distinguishable.

KEY CONCEPT: MICROSCOPES

In principle, a normal **microscope** is constructed in exactly the same way as the one you've just built. It consists of a series of lenses arranged in a mostly lightproof tube. One of these lenses is placed in an interchangeable eyepiece. This allows the magnifi ation level to be adjusted. In your DIY microscope, all of the optical components, including the sensors, are located in the smartphone's camera.

DID YOU KNOW?

The first mic oscopes were built in the Netherlands more than 400 years ago. Over time, the lenses and mechanical components used in microscopes improved. Today, we also have microscopes that work using electrons rather than visible light. This makes it possible to distinguish and display extremely fine de ail, such as molecular structures.

WANT TO FIND OUT MORE?

What happens when you look through the microscope with colored light? To do so, you'll need colored plastic film (f om packaging, for example) or tracing paper. A   ach these above the light. Compare images of the various objects when taken with di   erent colored light.

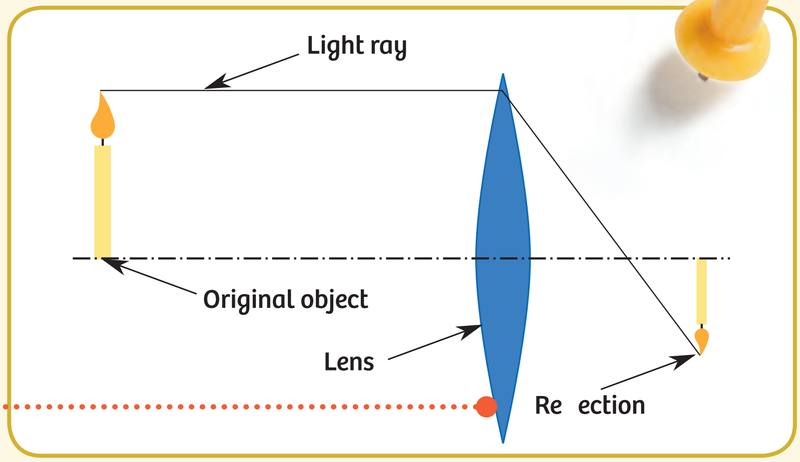
Non-transparent objects can only be studied under the microscope if light is shined on them from above. This technique is known as re   ected-light microscopy. You can recreate it here by a   aching the light to the microscope in such a way that it shines on the stage. Try examining coins or objects with highly textured surfaces, like wood or fabric, for example.

CHECK IT OUT

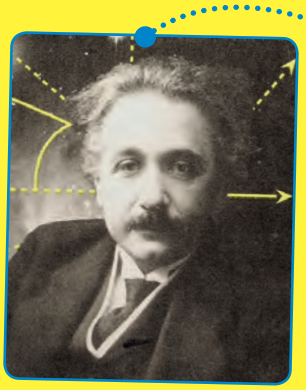
Light

Light rays travel in practically straight lines — at least, as long as they're within a substance that has the same density throughout. As soon as the density changes, however, what's known as the **refractive index** changes too, and the light ray appears to bend. This happens all the time. One example is when air shimmers above a warm surface, because the air density keeps changing.

Lenses are another example. Light rays are also bent — or, to use the scientific erm, "refracted," at the point where air and glass meet.



And it's not just when traveling between substances with di erent densities that light gets refracted. Refraction can also be observed in space — where there's practically no ma er at all. For this to happen, it requires what is known as a gravitational lens, which can be a star or black hole, for example. Their large mass att acts light particles, also known as photons, which then travel along a curved path.



Albert Einstein predicted this. During a total **solar eclipse** it's possible to see stars that are usually hidden by the sun using a telescope. Refraction e ectively allows us to look around the sun.

You'll see a **rainbow** ...

... when it's raining and the sun is shining at the same time. To see a rainbow, you'll need to position yourself so that the sun is behind you. The light rays hit the raindrops and are separated into individual colors at the point where the light meets the water. Inside each drop, the individual colored light rays are re ected back to the observer. Incidentally, for every **rainbow** you see, there are many more formed at di erent locations. If you're lucky, you might spot a second one as well.

Why is the **sky** sometimes blue and sometimes red?

Sunlight is made up of every color of the rainbow. The distance that light has to travel through the atmosphere determines how much light is sca ered by the molecules in the air. Blue light is sca ered more than other colors, making the sky appear blue. When the sun is close to the horizon, light has to travel a much longer distance, and as a result it's pre y much just red light, which travels in longer waves, that's left over. This is what we see at dawn or **sunset**.

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1st edition 2018

Project management: Stefanie Bernhart
Technical product development: Dr. Petra Müller
Author: Dr. Andreas Hantsch

Manual design concept: Atelier Bea Klenk, Berlin
Manual layout and typesetting: Michaela Kienle, Fine Tuning
Manual renderings: Andreas Resch
Manual illustrations: Dr. Andreas Hantsch, and Genius Toy Taiwan Co., Ltd., Taichung, Taiwan, R.O.C.

Manual photos: askaja (all paper clips); Jamie Duplass (all tape); picsfive (all pins); photo 5000, p. 6 tl; Zelfit, p. 6 br; Stefan Körber, p. 28 bl; moZz, p. 79 tr; 2jenn, p. 79 m; Manfred Steinbach, p. 90 bl; flucas, p. 110 m; HMR, p. 111 br (all previous © fotolia.com); microolga, p. 5 t, 6 tr; vuk8691, p. 5 b, 90 br; Bart Sadowski, p. 13 m; Baran Özdemir, p. 13 bl; Oleg Shelmentsev, p. 13 br; Tramper2, p. 6 bl; SKatzenberger, p. 10 br; NNehring, p. 28 m; Fertnig, p. 36 bl; xyno, p. 37 tr; mevans, p. 45 br; Oktay Ortakcioglu, p. 59 br; goce, p. 68 bl; nightman1965, p. 88 ml; okfoto, p. 123 br; Heidi Kristensen, p. 88 tr; ideeone, p. 90 m and b; deliormanli, p. 108 mr (all previous © istockphoto.com); keren-seg, p. 4 (background); Digital Strom, p. 5 m, 37 tl; tsuneomp, p. 5 m, 68 tr; Gabor Tinz, p. 10 l; Richard Thornton, p. 22 br; ESB Professional, p. 35 tr; Rainer Fuhrmann, p. 36 ml; fotum, p. 36 tr; Vlad Kochelaevskiy, p. 37 br; PPstock, p. 37 m; Vlad Kochelaevskiy, p. 37 bl; Ivan Garcia, p. 41 br; Gts, p. 59 tr; ilushutter, p. 65 bl; Lumppini, p. 66 ml; Anastasios71, p. 66 br; JonathanC Photography, p. 67 tr; nng, p. 67 bl; ohrim, p. 68 tl; Christian Musat, p. 68 br; Tawansak, p. 75 br; PHILIPIMAGE, p. 87 br; Ensuper, p. 88 br; thomas koch, p. 89 bl; ymgerman, p. 89 tr; Everett Historical, p. 90 tl; Everett Historical, p. 90 tr; ChristianChan, p. 92 bl; rudolfgeiger, p. 95 b; Glass and Nature, p. 103 m; Horst Lieber, p. 109 tr; Patrick Foto, p. 109 tl; maxim ibragimov, p. 109 bl; travelview, p. 109 br; SeDmi, p. 110 bl; majeczka, p. 110 tr; eranicle, p. 110 m; Doughnut, p. 110 ml; Karsten_1, p. 110 mr; Avigator Thailand, p. 111 tr; RoboLab, p. 111 tl; Sergii Tverdokhlibov, p. 111 bl; Kletr, p. 111 br; Inu, p. 117 tr; Videowokart, p. 117 tr; Room27, p. 123 tr; Lasse_Sven, p. 123 bl; J2R, p. 128 tr; maradon 333, p. 128 tr; Roman Samborskyi, p. 128 mr; Likoper, p. 134 m; vitstudio, p. 134 br; spatuletail, p. 135 bl; muratart, p. 135 br; photowind, p. 136 tr; adamziaja.com, p. 136 bl (all previous © shutterstock.com); Toy Museum Nuremberg, Urs Latus, p. 22 mr; Kiva, p. 35 bl; Pete Markham, © wikipedia CC-BY-SA 2.0, p. 103 m; G. Allen Morris III, © wikipedia CC-BY-SA 3.0, p. 117 um; Jaguar, Castrol, p. 67 ml; David Lentink, © science-photo.de, p. 92 br

Packaging design concept: Peter Schmidt Group GmbH, Hamburg, and Thames & Kosmos
Packaging layout and typesetting: Michaela Kienle, Fine Tuning
Packaging photos: posscriptum (crane and building, © shutterstock.com); Natykach Nataliia (gears, © shutterstock.com); Michael Flaig, Pro-Studios, Stuttgart (kit contents)
Packaging model renderings: Genius Toy Taiwan Co., Ltd., Taichung, Taiwan, R.O.C.

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Editing: Camille Duhamel and Ted McGuire; Additional Graphics and Layout: Dan Freitas

Distributed in North America by Thames& Kosmos, LLC. Providence, RI 02903
Phone: 800-587-2872; Web: www.thamesandkosmos.com

We reserve the right to make technical changes.

Printed in Taiwan / Imprimé en Taiwan

628154-03-311022