EXPERIMENT MANUAL

MECHANICAL ENGINEERING
ROBOTIC ARMS

THAMES & KOSMOS

Franckh-Kosmos Verlags-GmbH & Co. KG, Pfizerstr. 5-7, 70184 Stuttgart, Germany | +49 (0) 711 2191-0 | www.kosmos.de
Thames & Kosmos, 301 Friendship St., Providence, RI, 02903, USA | 1-800-587-2872 | www.thamesandkosmos.com
Thames & Kosmos UK LP, 20 Stone Street, Cranbrook, Kent, TN17 3HE, UK | 01580 713000 | www.thamesandkosmos.co.uk

Safety Information

Warning! Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled. Strangulation hazard — long 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.

Dear Parents and Supervising Adults,

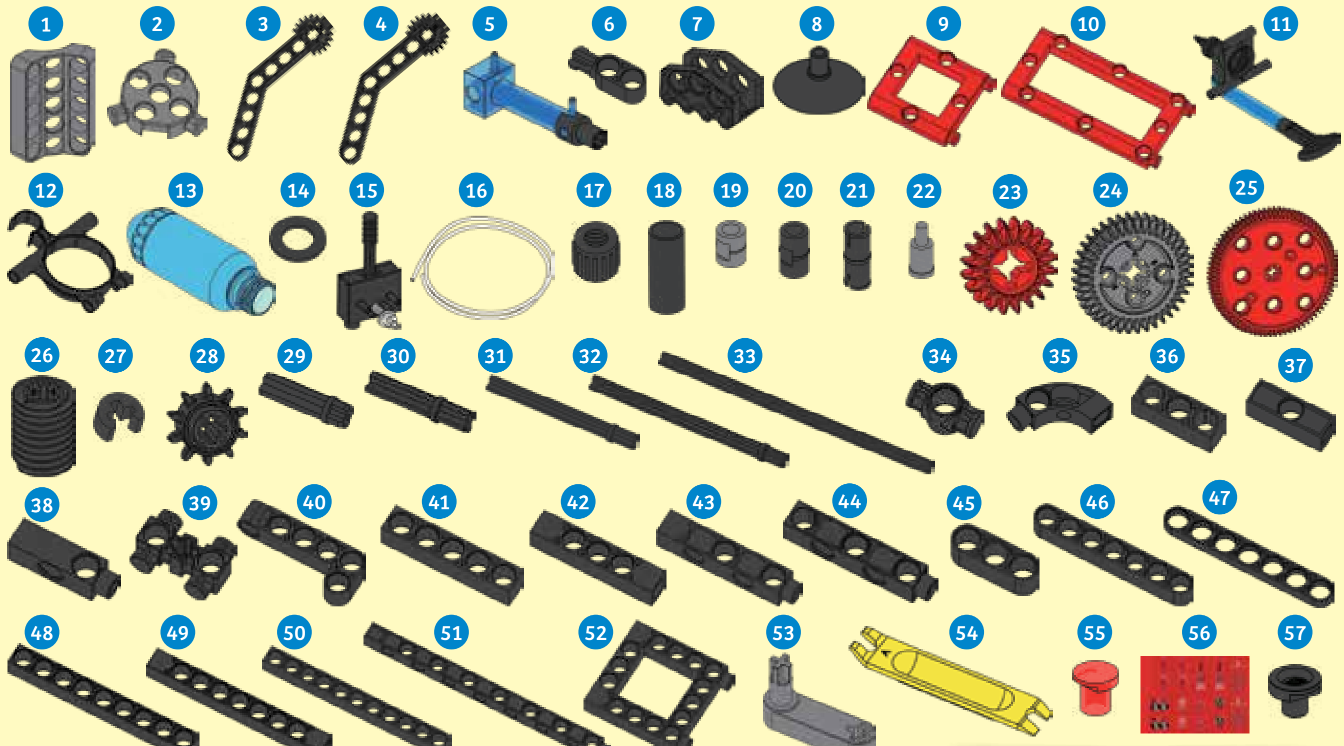
Before starting the experiments, read through the instruction manual together with your child and discuss the safety information. Check to make sure the models have been assembled correctly, and assist your child with the experiments.
We hope you and your child have a lot of fun with the experiments!

››› **KIT CONTENTS**

GOOD TO KNOW! If you are missing any parts, please contact Thames & Kosmos customer service.

US: techsupport@thamesandkosmos.com
UK: techsupport@thamesandkosmos.co.uk

What's inside your experiment kit:



You will also need:
scissors, ruler or measuring tape

Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
❍	1	120-degree 5-hole connector	3	7411-W10-A1S
❍	2	3-way circular adapter	2	7411-W10-B1S
❍	3	Crankshaft gear A	2	7411-W10-C1D
❍	4	Crankshaft gear B	2	7411-W10-C2D
❍	5	Pneumatic piston cylinder	1	7411-W85-A
❍	6	Pneumatic piston handle	1	7411-W10-D3D
❍	7	Gripper	4	7411-W10-G1D
❍	8	Suction cup	3	R12-25
❍	9	Rounded square frame,red	2	7411-W10-F1R
❍	10	Rounded short frame, red	12	7411-W10-E1R
❍	11	Pump	1	7389-W85-A1D
❍	12	Air tank bracket	1	7389-W10-B2D
❍	13	Air tank	1	7389-W11-A1B
❍	14	O-ring	1	R12-05
❍	15	Switch	1	1155-W85-I4DN
❍	16	Tube, 1200 mm	1	1155-W85-120
❍	17	Small (S) security nut	1	1156-W10-J1D
❍	18	Tube, 20 mm	4	7400-W10-G2D
❍	19	Short anchor pin, gray	25	7344-W10-C2S
❍	20	Anchor pin, black	26	7061-W10-C1D
❍	21	Joint pin	13	1156-W10-A1D
❍	22	Shaft pin	2	7026-W10-J3S
❍	23	Small gear, red	2	7026-W10-D2R
❍	24	Medium gear, gray	2	7346-W10-C1S
❍	25	Extra large gear, red	1	7328-W10-G2R
❍	26	Worm gear	3	7344-W10-A1D
❍	27	Axle lock	7	3620-W10-A1D
❍	28	Small sprocket	1	3569-W10-D2D
❍	29	Motor axle	3	7026-W10-L1D

✔	No.	Description	Qty.	Item No.
❍	30	35-mm axle	1	7413-W10-O1D
❍	31	70-mm axle	2	7061-W10-Q1D
❍	32	100-mm axle	4	7413-W10-L2D
❍	33	150-mm axle	2	7026-W10-P1D
❍	34	1-hole connector	5	7430-W10-B1D
❍	35	Curved rod	2	7061-W10-V1D
❍	36	3-hole rod	1	7026-W10-Q2D
❍	37	3-hole cross rod, black	4	7026-W10-X1D
❍	38	3-hole dual rod, black	2	7061-W10-R1D
❍	39	3-hole bolt rod, black	1	7406-W10-B1D
❍	40	5-hole L rod	1	7406-W10-B2D
❍	41	5-hole rod	4	7413-W10-K2D
❍	42	5-hole cross rod	1	7413-W10-K3D
❍	43	5-hole dual rod C, black	2	7026-W10-S3D
❍	44	5-hole dual rod B, black	2	7026-W10-S2D
❍	45	3-hole wide rounded rod	2	7404-W10-C1D
❍	46	7-hole wide rounded rod	2	7404-W10-C2D
❍	47	7-hole flat rounded rod	2	7404-W10-C3D
❍	48	9-hole rod	2	7407-W10-C1D
❍	49	9-hole cross rod	2	7407-W10-C2D
❍	50	11-hole rod	3	7413-W10-P1D
❍	51	15-hole dual rod	5	7413-W10-H1D
❍	52	Square frame	1	7026-W10-T2D
❍	53	Crank	2	7063-W10-B1S1
❍	54	Anchor pin lever	1	7061-W10-B1Y
❍	55	Long button pin	16	7061-W10-W2TR
❍	56	Die-cut plastic sheet	1	K41#7411
❍	57	Tube bolt cap	3	7409-W10-F2D

››› TABLE OF CONTENTS

TIP!

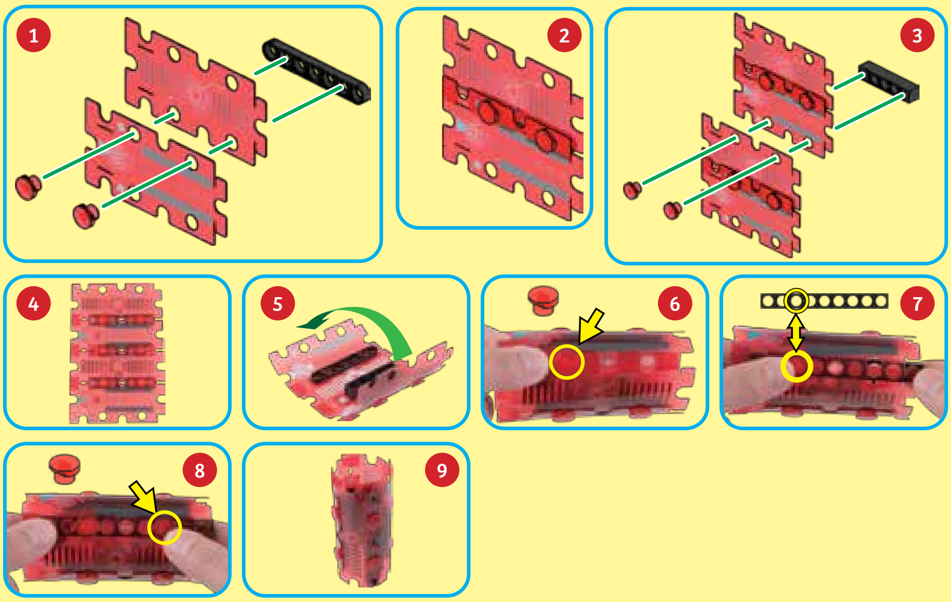
At the top of each model assembly page, you will find a red bar:

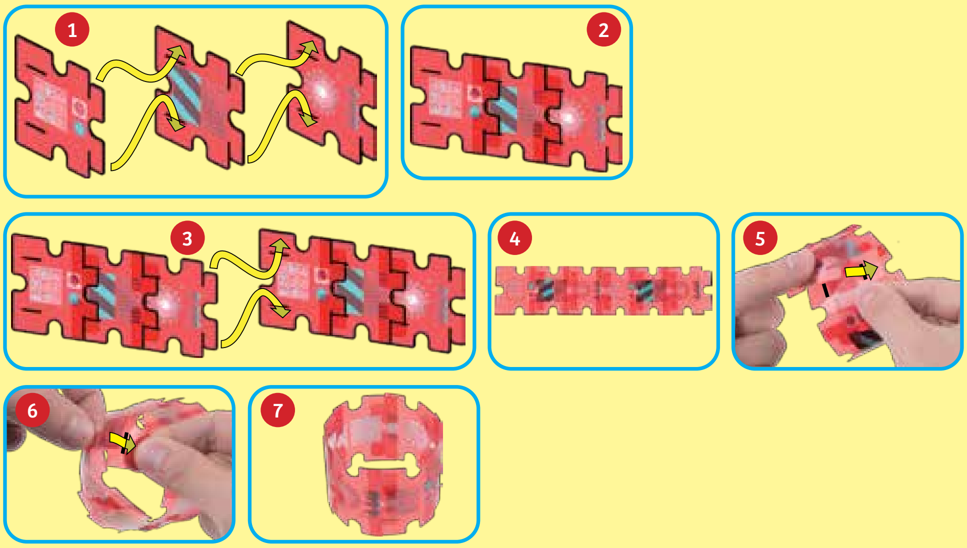
››› It shows how difficult the model's assembly will be:

easy | medium | hard

Making the test objects

You can make these objects and use them to test your robotic arms. Trying picking these objects up with each robotic arm.





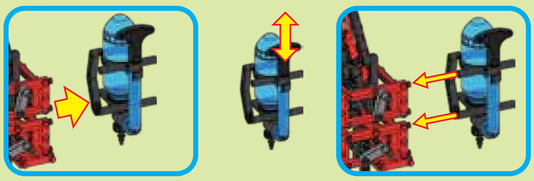
Cutting the tube to length

You must cut the 1200-mm tube into these lengths. The specific lengths needed for each model are indicated in the assembly instructions for each model. You can also write the lengths on the tubes with a pen so they are easier to tell apart.

450 mm x 2 **300 mm x 1**

Tips for operating the pump

To operate all the models, you must pump up the air tank. Always set the switch lever to the center position before pumping, so the air pressure builds up in the tank. Pump the air pump 30-40 times. To operate the models, move the switch lever to one side or the other. For some models, it is easier if you remove the pump and air tank first and then reattach them to operate the model. Pumping 30 times can operate model 10–15 times. The carbon rod inside the pump can withstand the maximum bending force of 4 kg. (8.8 lb.).

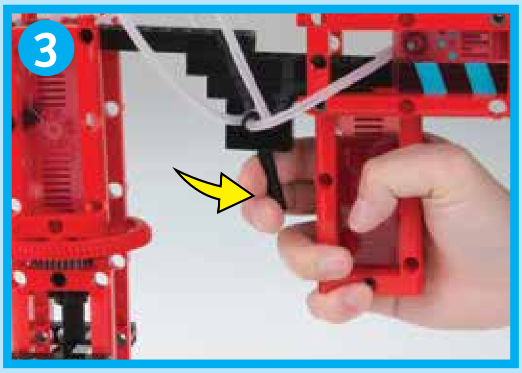


General instructions for using the pneumatic system

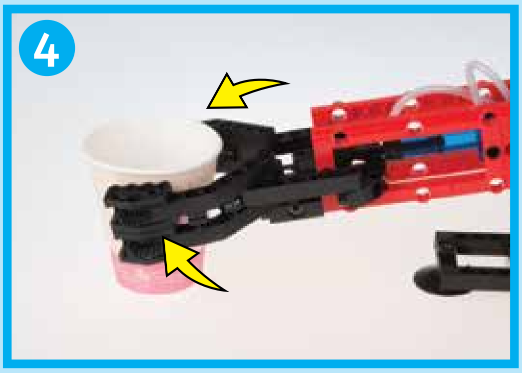
After following the step-by-step instructions to build one of the models (starting on page 6), follow these general instructions to operate the pneumatic system in the model. Each model works a little differently. There are specific instructions for using each model at the end of each set of assembly instructions. See page 25 for an explanation of how the pneumatic system works.

Put the switch lever in the center position.

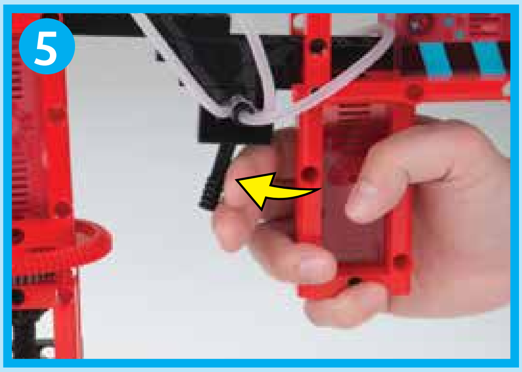
Pump about 30 times to fill the air tank.



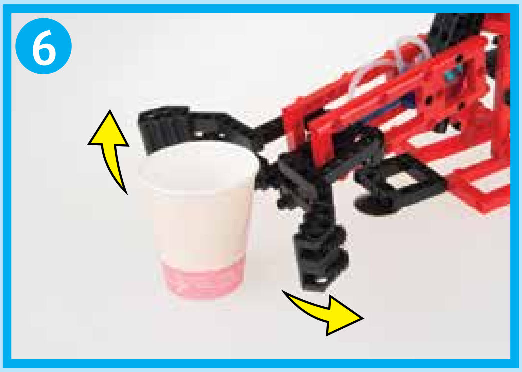
Depending on the model, you will need to push or pull the switch lever to operate the device in one direction.



For example, here the gripper closes when you pull the lever.



Again, depending on the model, you will need to push or pull the switch lever to operate the device in the other direction.

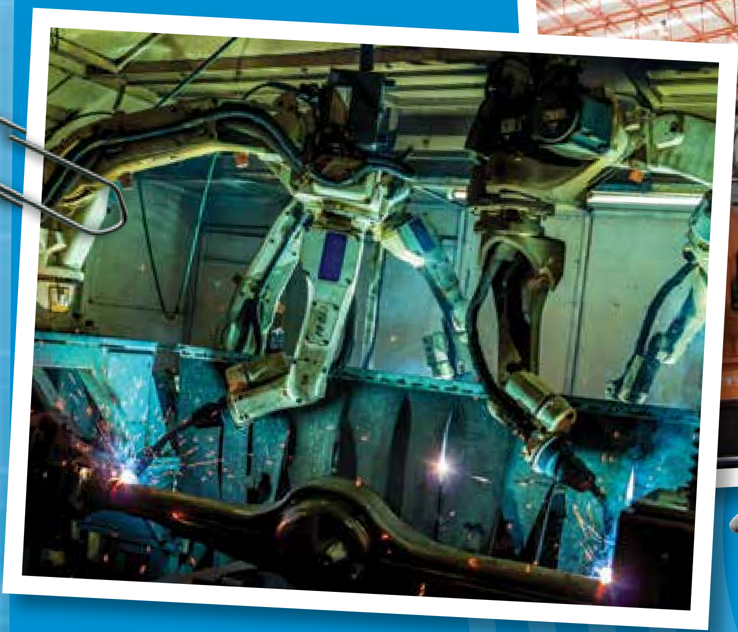


In this example, the gripper opens when you push the lever.

What Is a Robotic Arm?

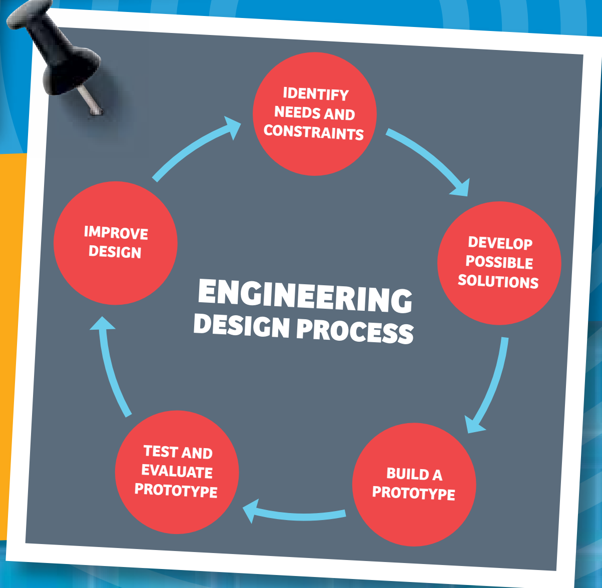
A robotic arm is a machine that may look and function somewhat like a human arm, but is able to perform tasks with greater strength, accuracy, and speed, or perform tasks that are too dangerous for a human. Robotic arms are one of the most common types of robots used in manufacturing.

A robotic arm is a combination of mechanical, electrical, and computer systems. This kit focuses on the mechanical portion of designing robotic arms, which is the expertise of mechanical engineers. Engineers apply physical laws and empirical knowledge to build complex systems. Empirical knowledge is simply information you learn by observing the results of experiments and observing occurrences in the world around you. Mechanical engineers focus on the design, construction, and operation of machines.

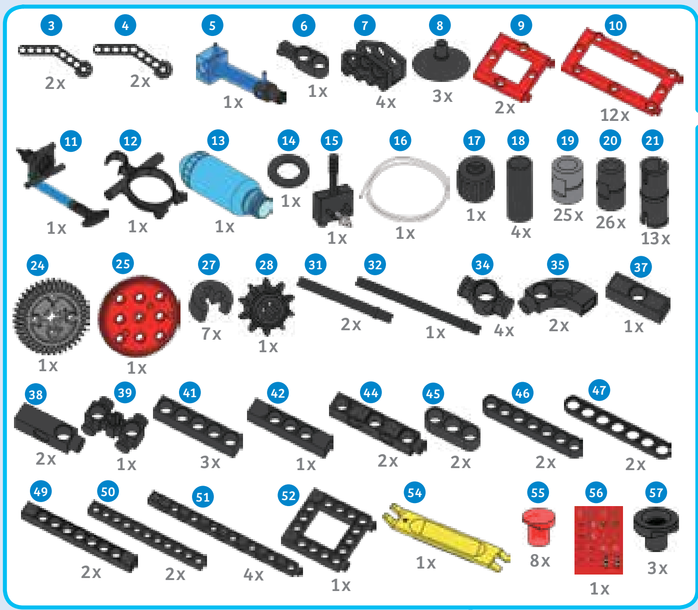


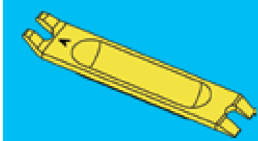
WHAT IS DESIGN?

Engineers often use the word "design" to describe what they do. Design is a sequence of steps that are used to take an idea from concept to functioning product or process. The engineering design process is iterative, meaning steps can be repeated multiple times and then improvements can be made each time, until the correct or optimal outcome is achieved.



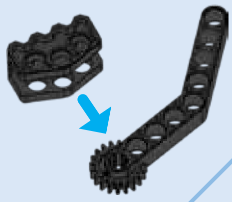
PIVOTING ROBOTIC ARM



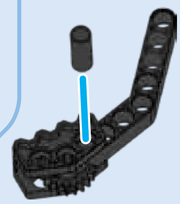


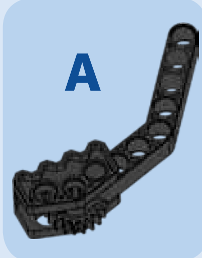
Note: Use the anchor pin lever as a little crowbar when you need to pry anchor pins and other connectors out of holes.

1 4x



2

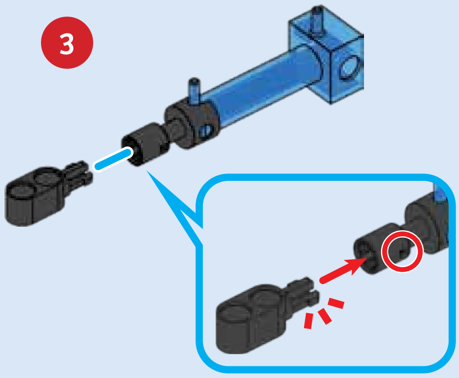




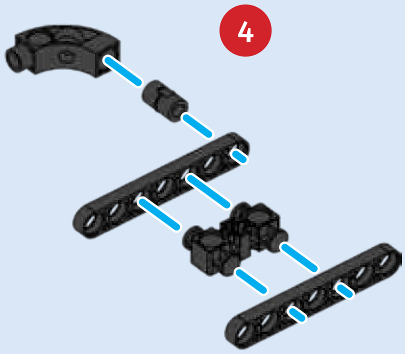
4x

Repeat steps 1 and 2 four times.

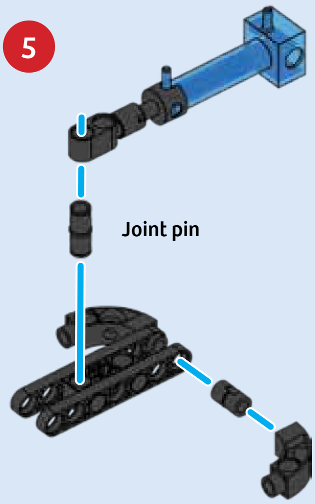
3

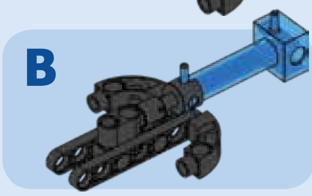


4

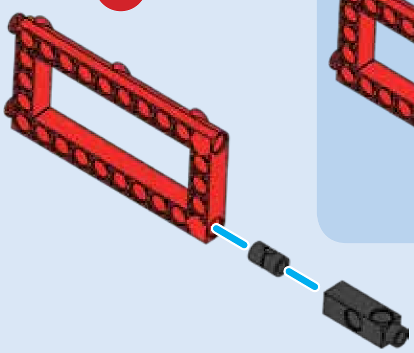


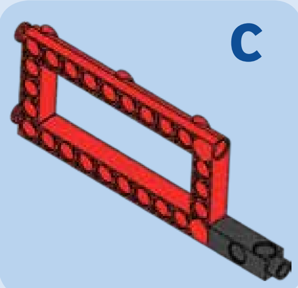
5



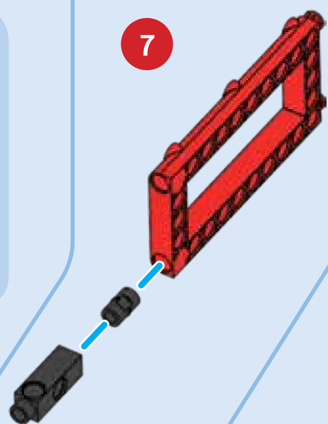


6

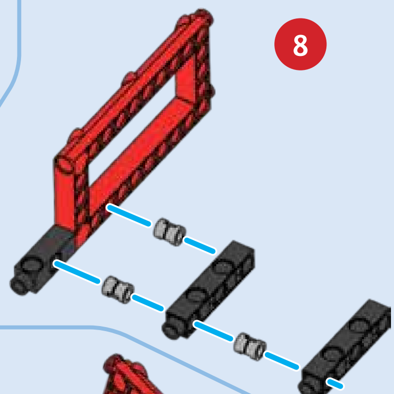




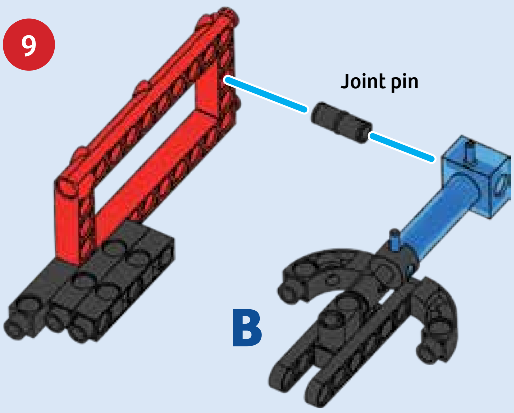
7



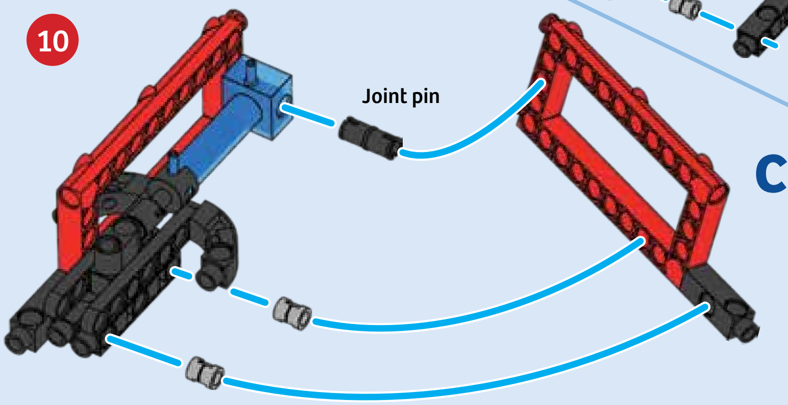
8



9

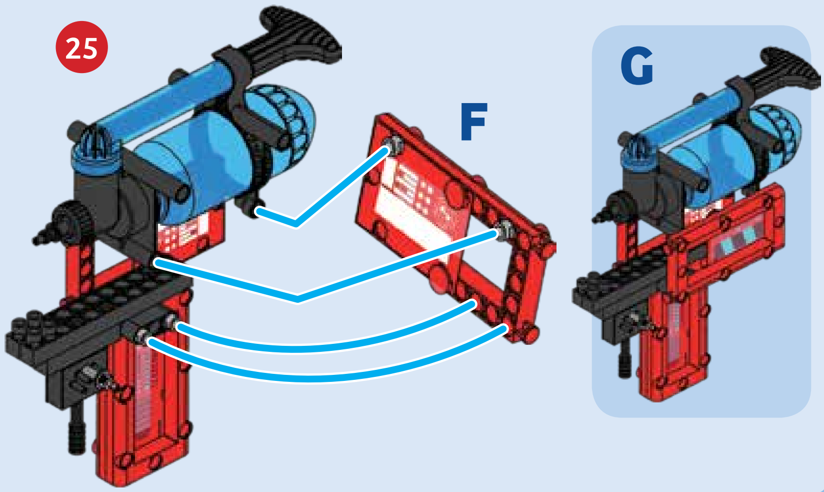


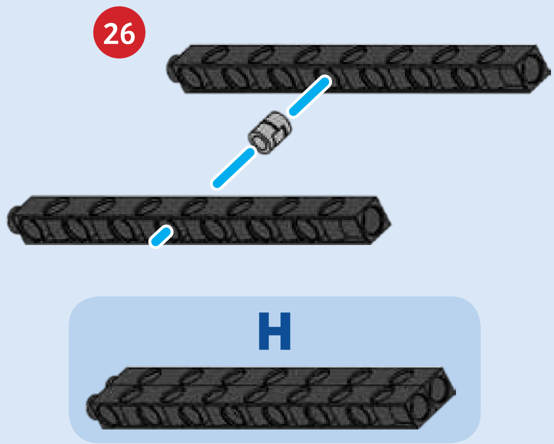
10

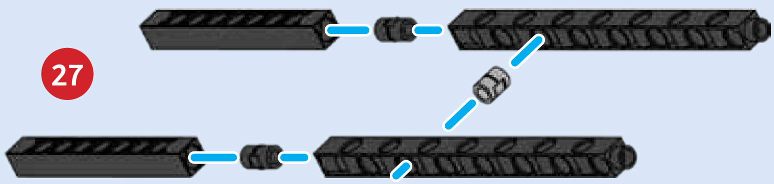


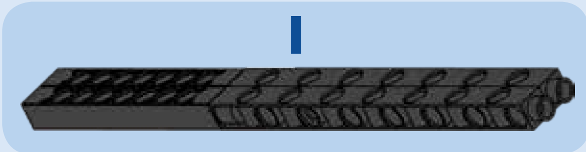

11
A
A
Joint pins
12
Joint pins
A
13
A
D
14
15
16
E
17
F
18
19
20
21
22
23
24
E

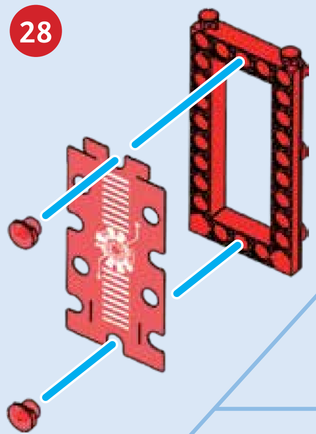
PIVOTING ROBOTIC ARM

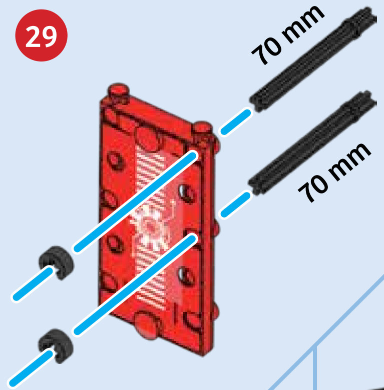


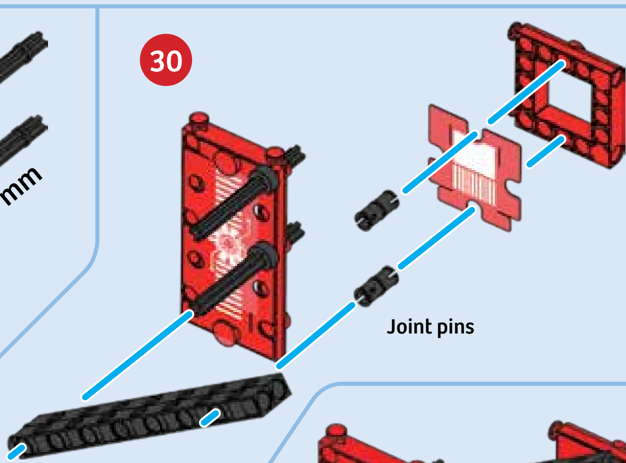


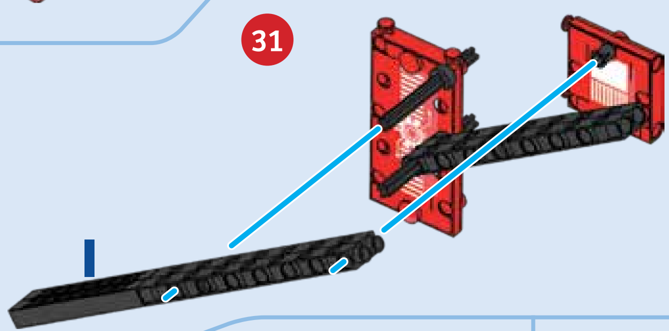


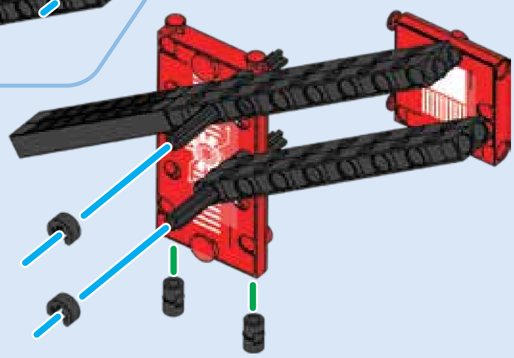


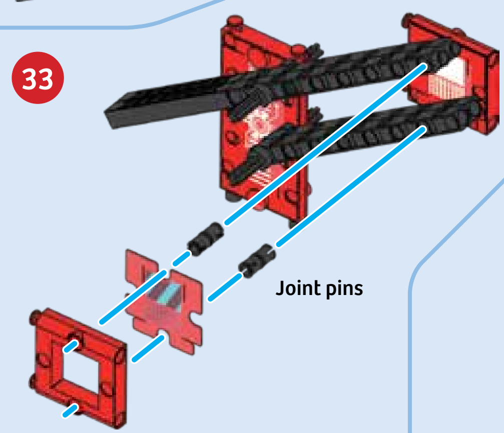


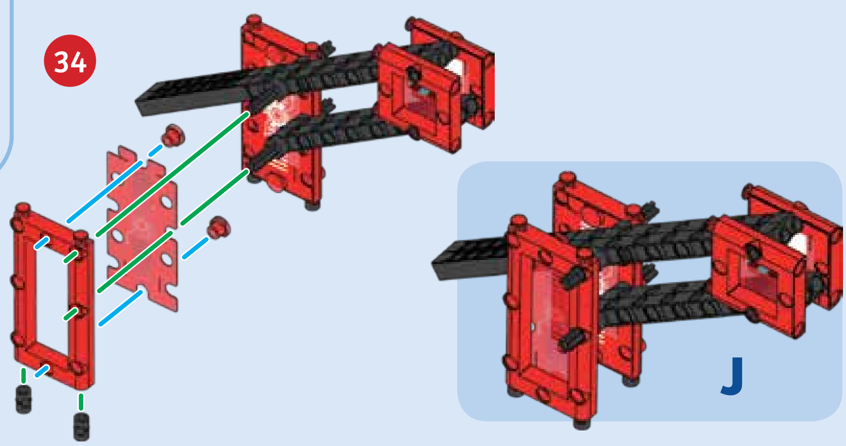




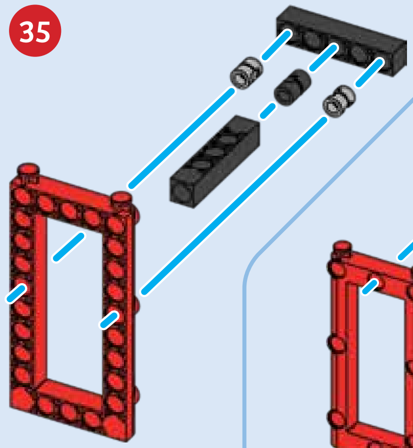




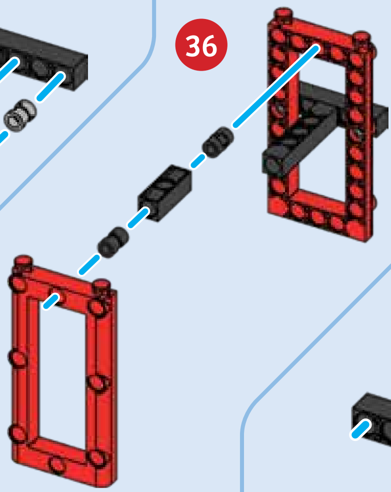




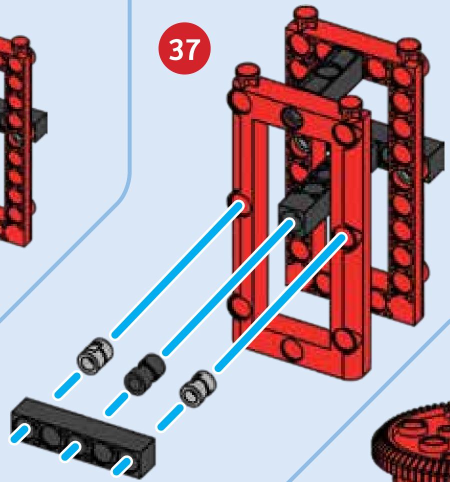
35



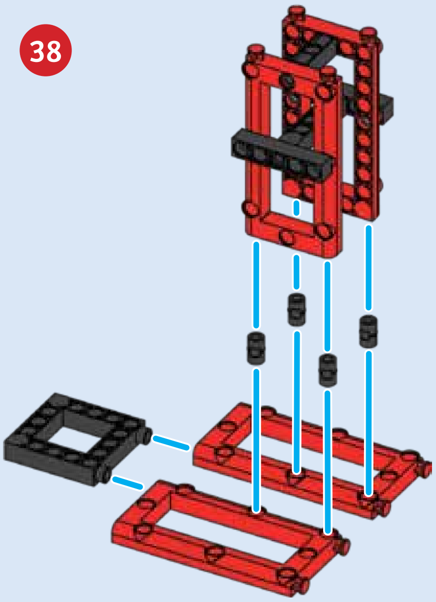
36



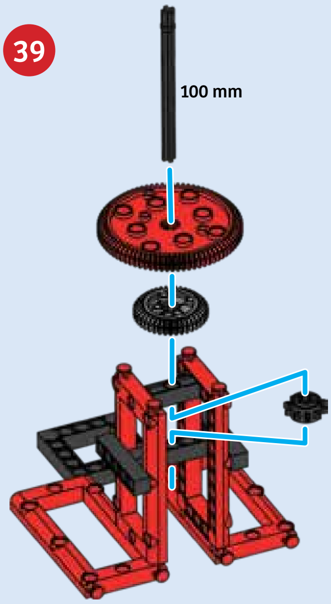
37



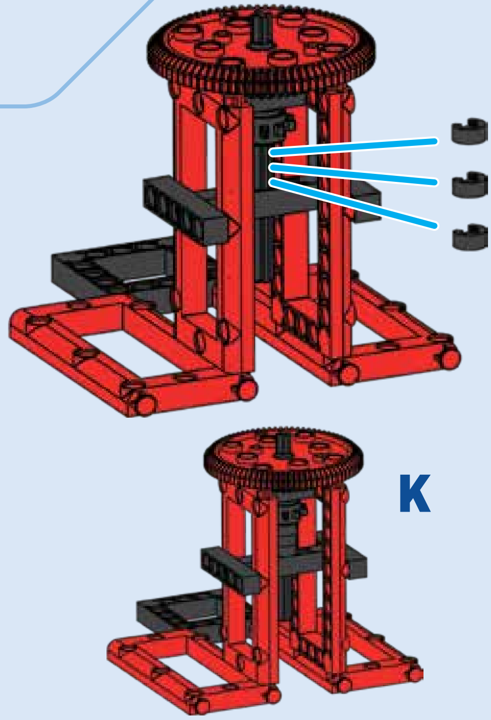
38



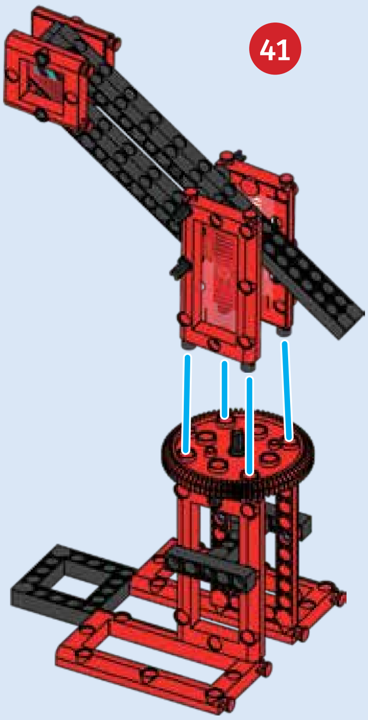
39



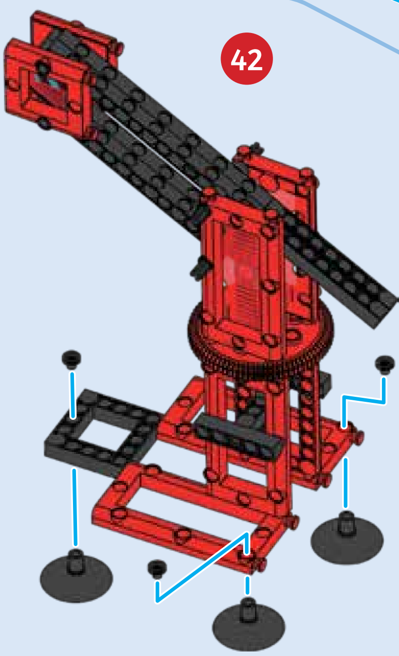
40



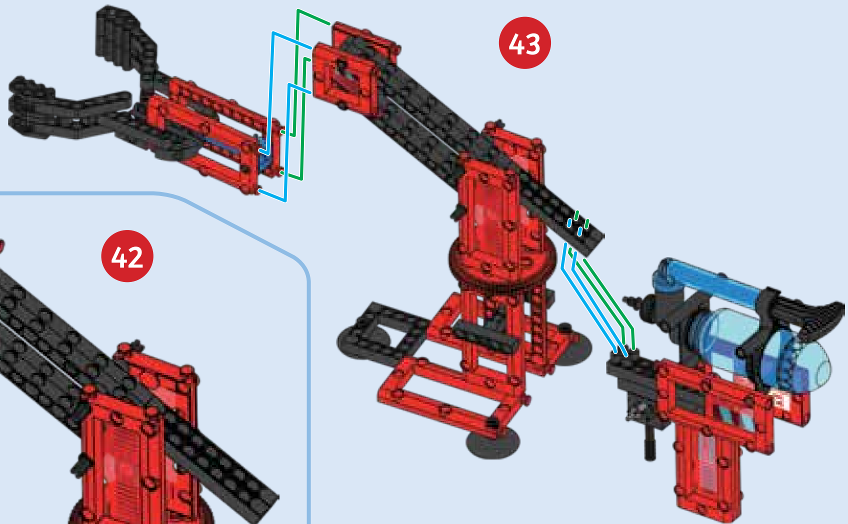
41



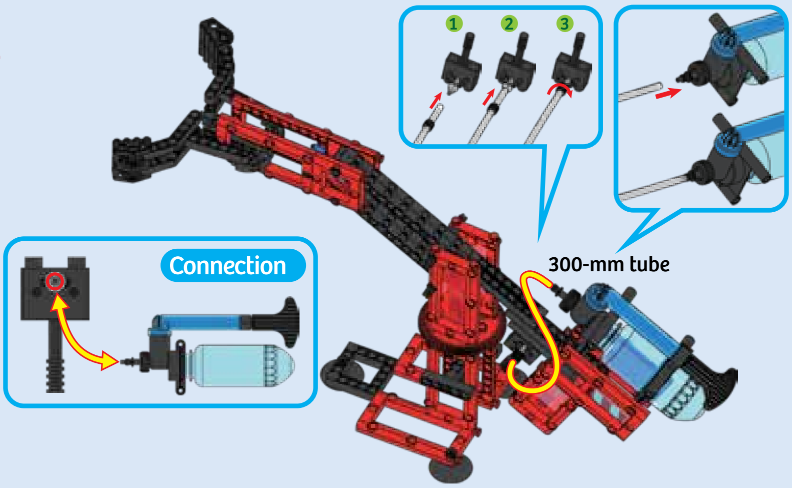
42



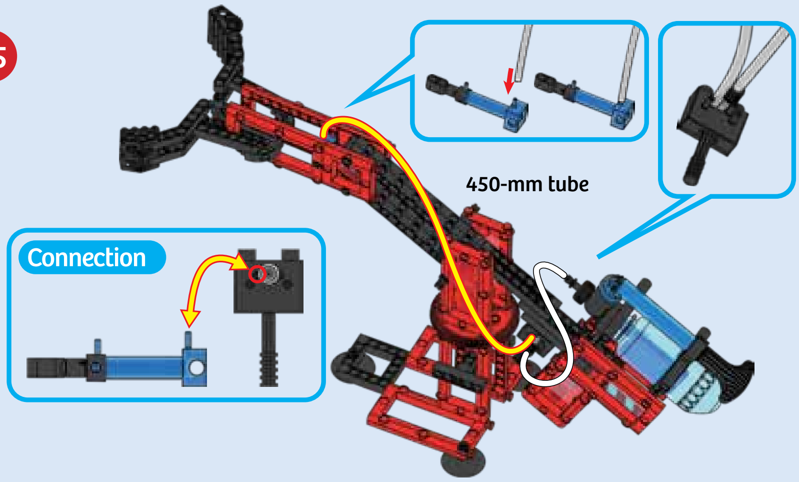
43



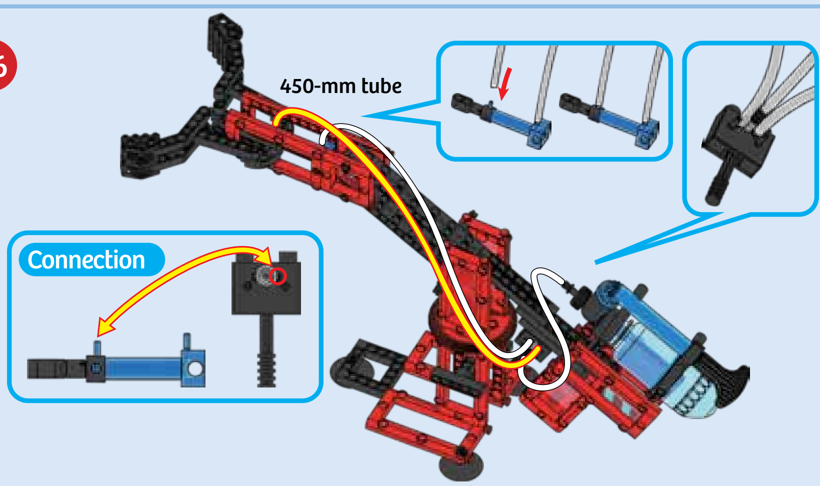
44



45



46



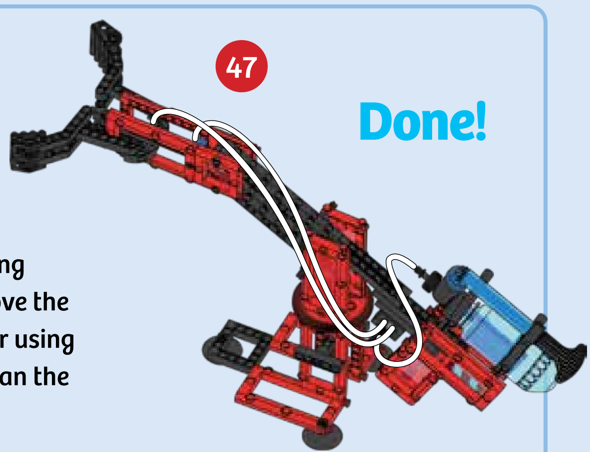
EXPERIMENT 1

Can you move it?

HERE'S HOW

Place a cylinder in front of the pivoting robotic arm. Use the robot arm to move the cylinder from one location to another using two different paths. What positions can the pivoting robotic arm not reach?

47

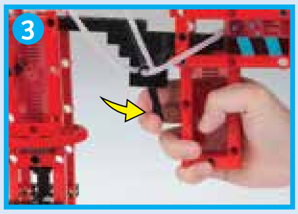


Done!

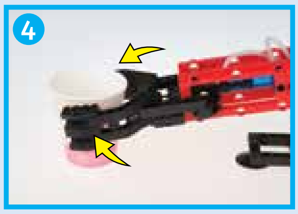
HOW TO USE

1 Put the switch lever in the center position.

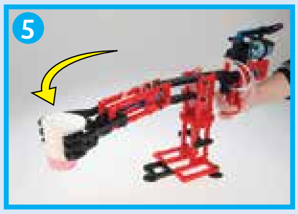
2 Pump about 30 times to fill the air tank.



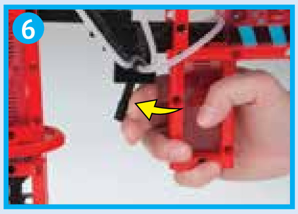
3 The gripper will close when you pull the switch lever.



4



5 Rotate the handle to move the gripper.



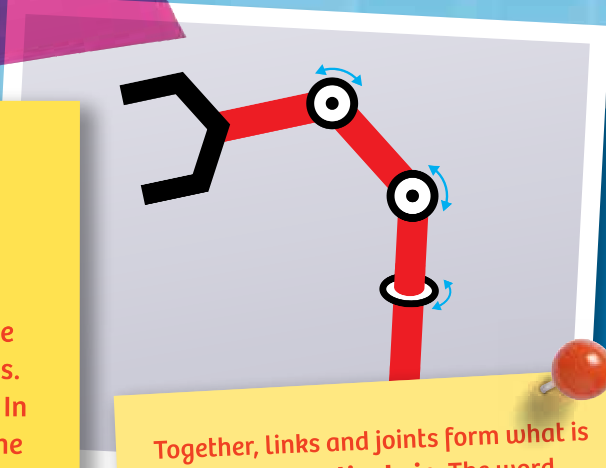
6 The gripper will open when you push the switch lever.

7

CHECK IT OUT

LINKS AND JOINTS

In engineering, it is often necessary to create simplified models of structures or systems in order to better understand their physical characteristics or behaviors. When simplifying a robotic arm to better understand it, the mechanical parts can be thought of as either links or joints. **Links** are the rigid structural elements of the robotic arm. In this kit, this includes the frames and rods. The **joints** are the pieces that allow for movement, such as the joint pins, axles, gears, and pistons in this kit. Joints allow a link to move by either rotation or translation (moving from one point in space to another).



Together, links and joints form what is called a **kinematic chain.** The word "kinematic" refers to how objects move. In a robotic arm, the links in the kinematic chain are constrained by their connection points to the other links — like how your elbow is constrained by the range of motion of your shoulder. To understand how a robotic arm can move as a whole, you can look about how each element in the kinematic chain can move.

Often the end of the robotic arm, called the **end effector,** is designed separately from the rest of the arm. It is designed to interact with objects in its environment, like a human hand, but for specialized tasks such as welding, gripping, spinning, applying materials, and so on.

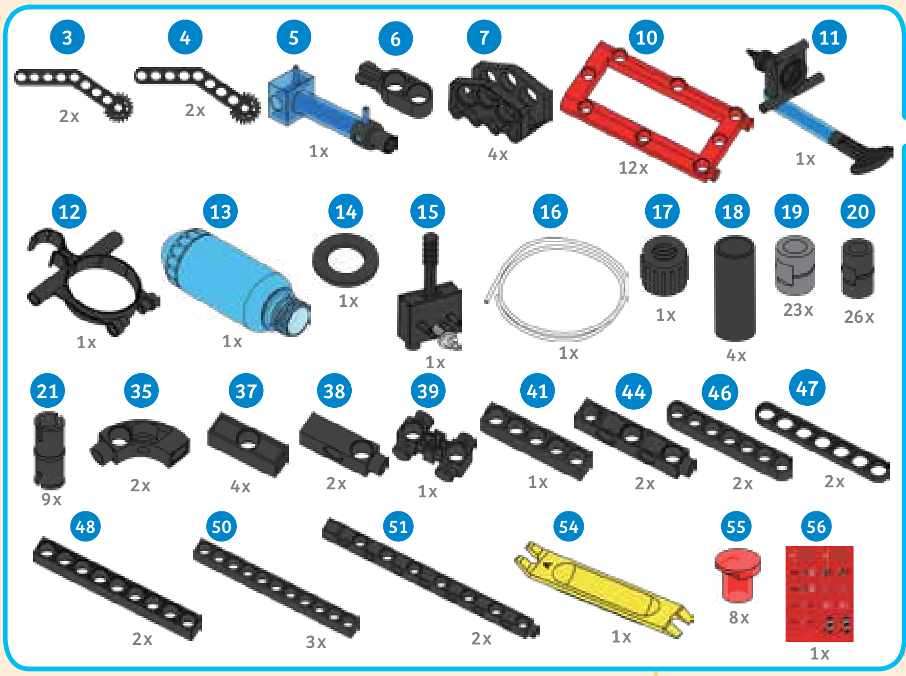
MOVEMENT THROUGH SPACE

Unlike a human arm, a robotic arm can have a lot more freedom to move through space in different ways. The movement of a robotic arm can be described by the term **"degrees of freedom."** The position and orientation of an object in space can be given by three components of movement in the x, y, and z directions, and three components of rotation around those axes. For a single object in space, there are at most six degrees of freedom.

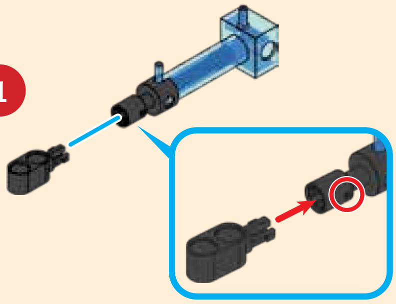
Each joint in a robotic arm has a certain number of degrees of freedom, which might be less than the maximum number of six. For example, not all of the pivoting robotic arm's joints can rotate 360 degrees.

The area defined by all of the positions in space that the end of the robotic arm can reach is known as the **workspace.** If the object that the robotic arm needs to pick up is not in the workspace, the robot cannot pick it up! The workspace depends on the degrees of freedom, limitations of the joints, lengths of the linkages, and the angles at which the object must be picked up.

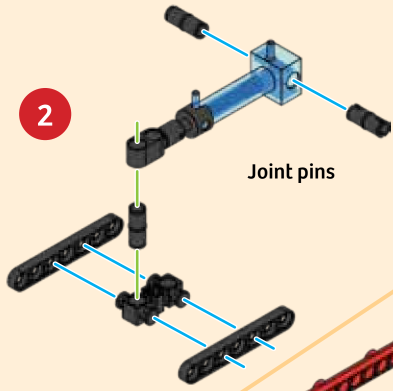
ROBOTIC GRABBER



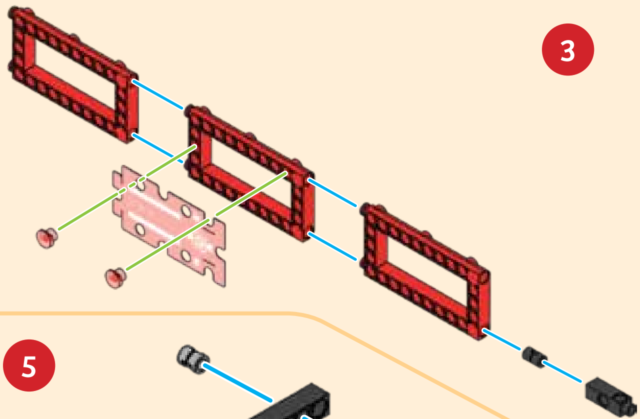
1



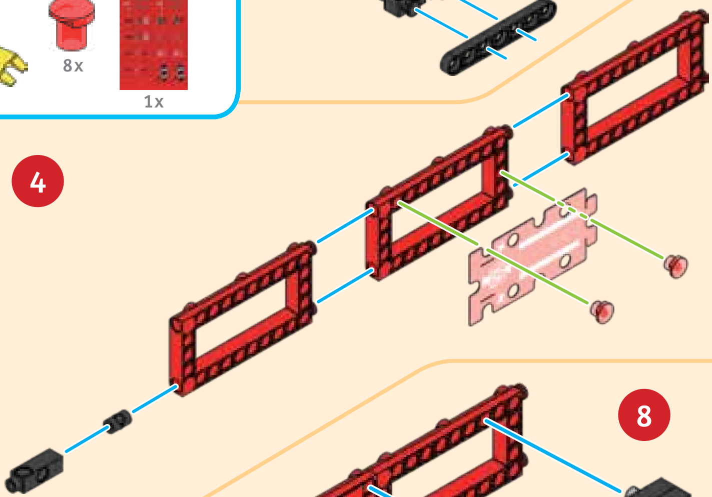
2



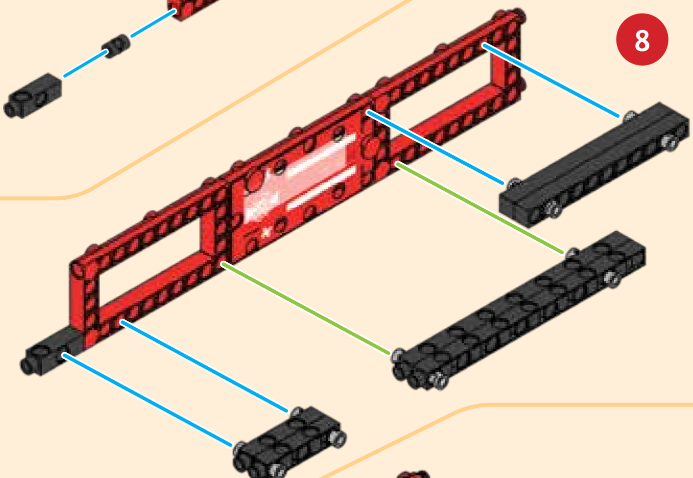
3



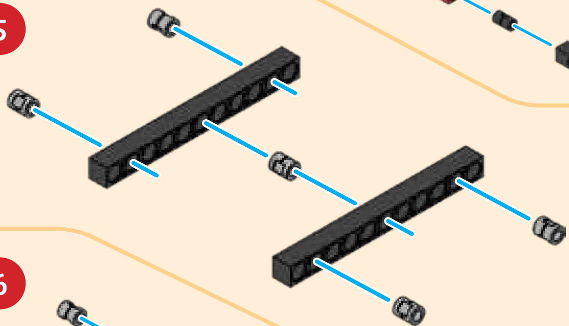
4



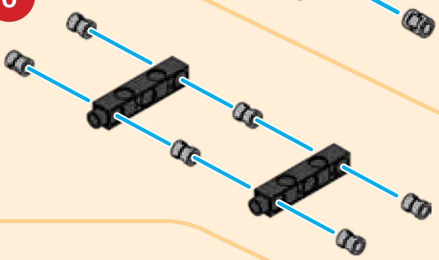
8



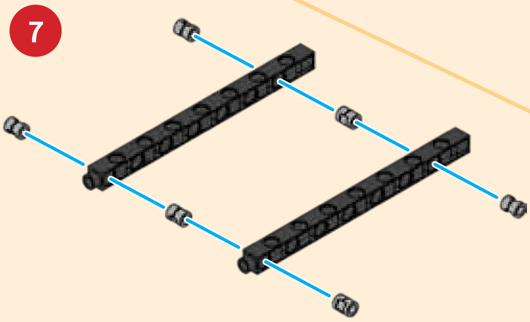
5



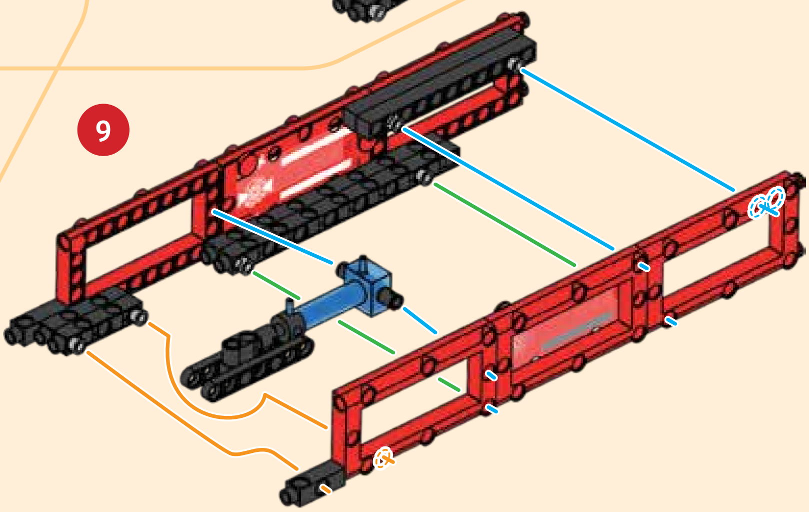
6



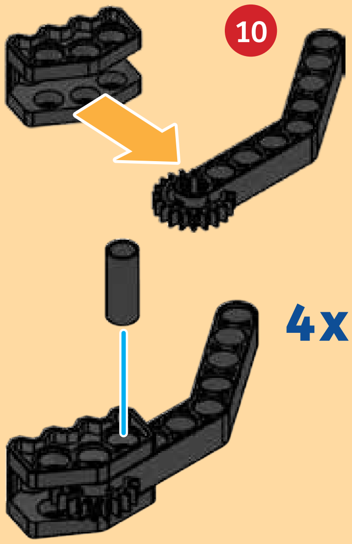
7



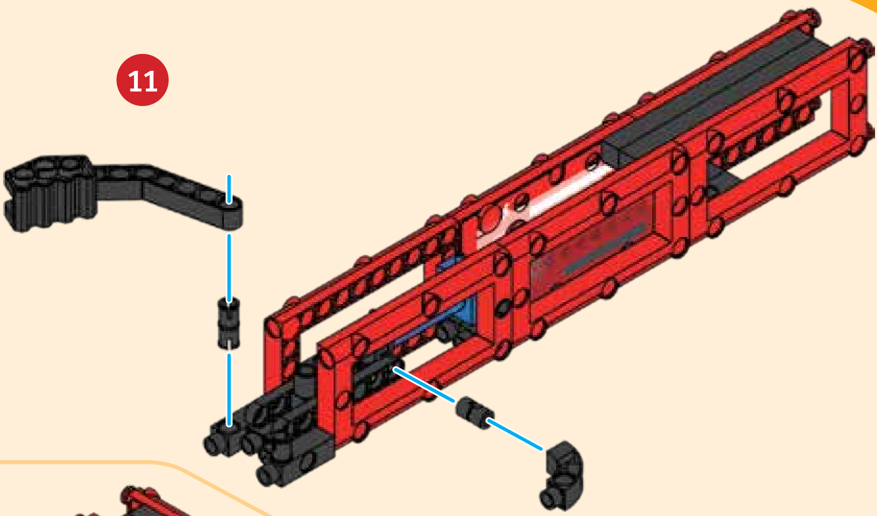
9



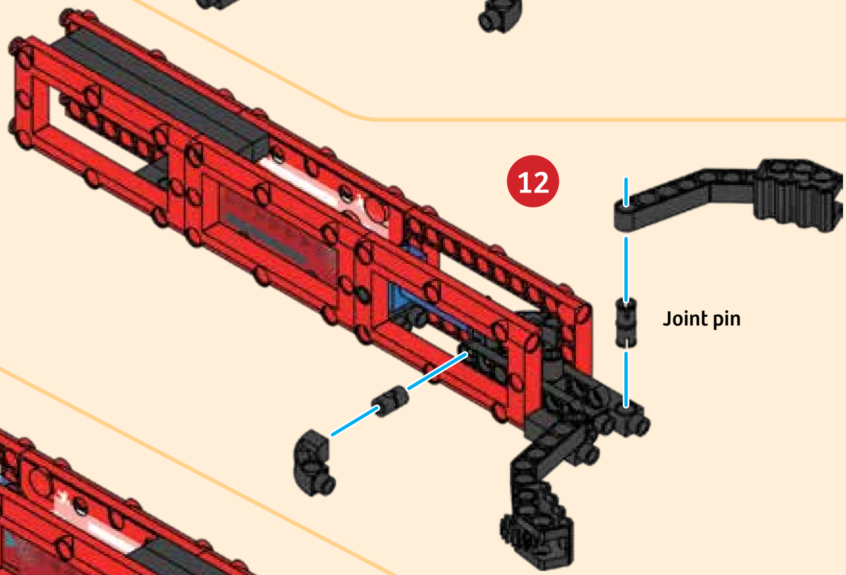
10



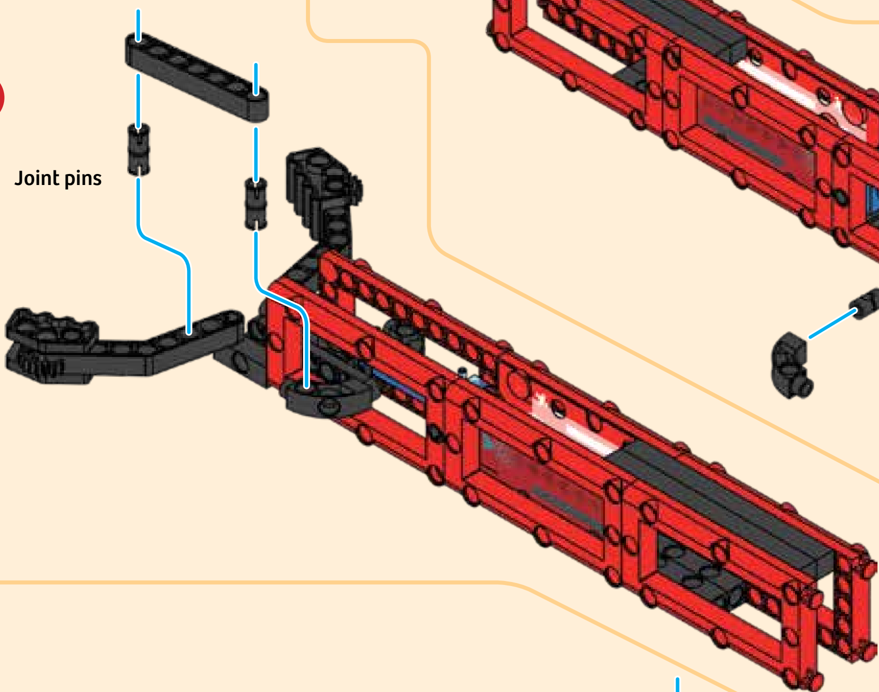
11



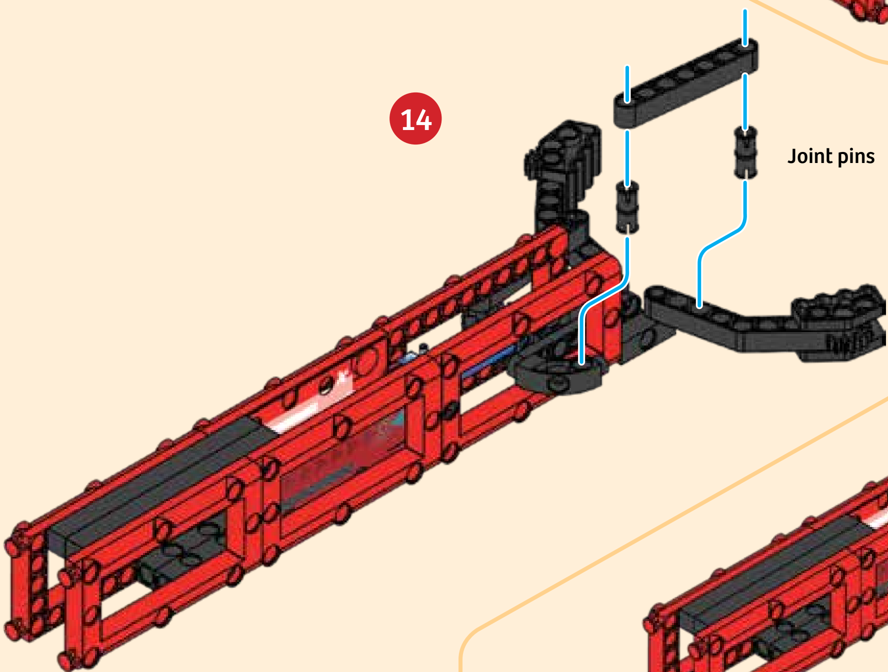
12



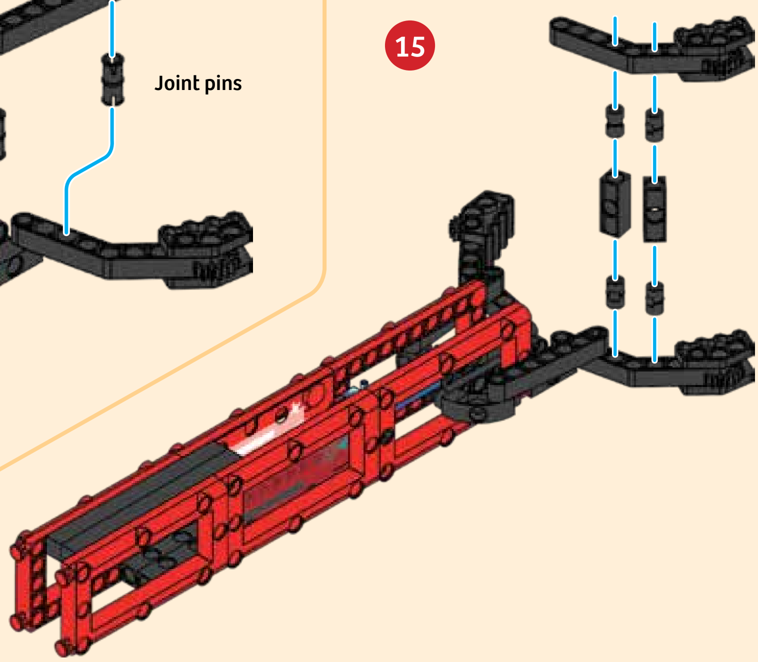
13



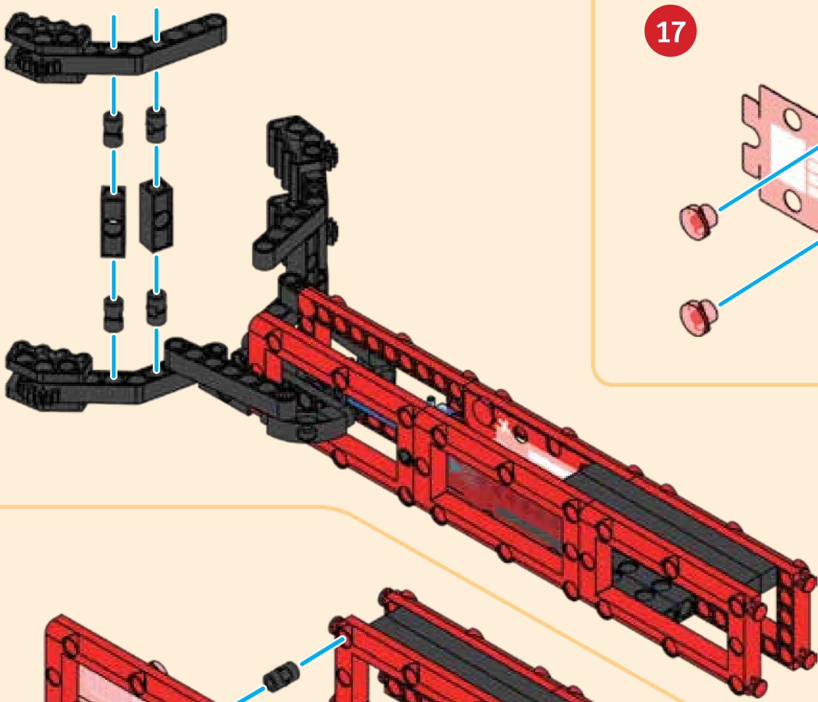
14



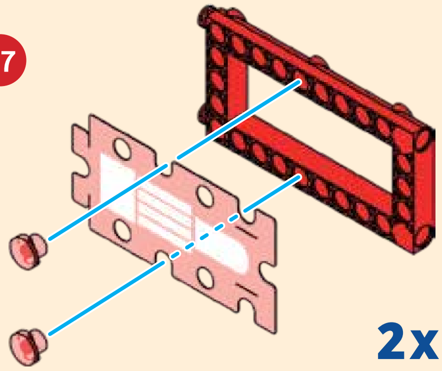
15



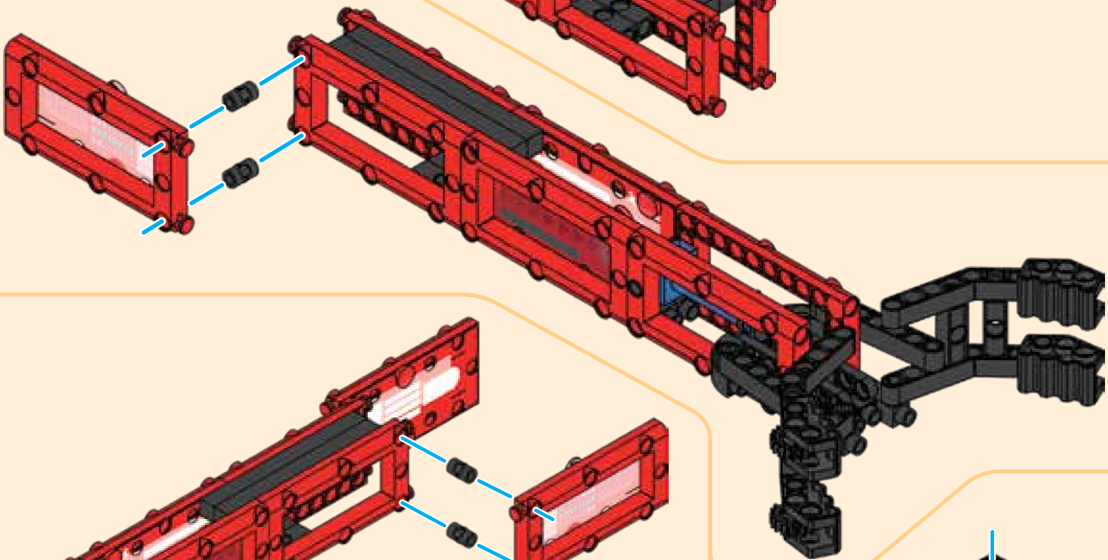
16



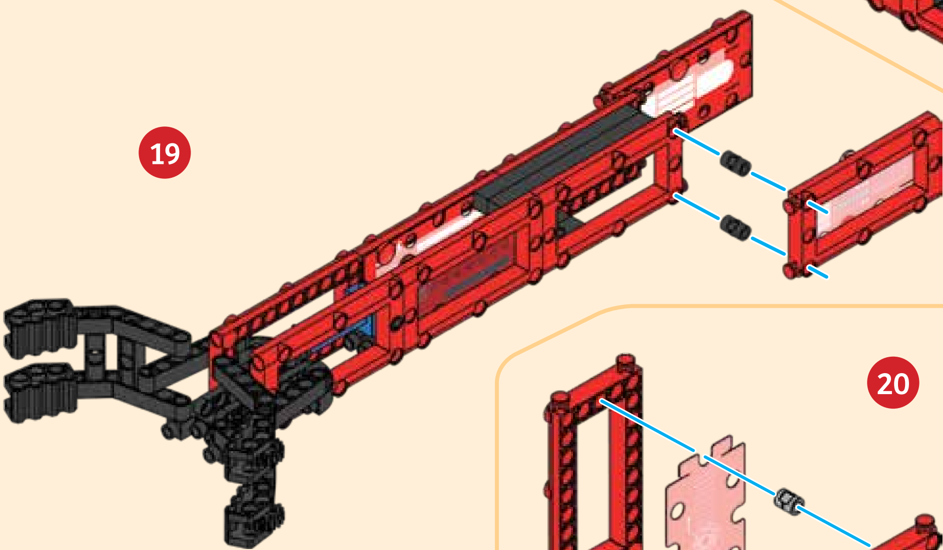
17



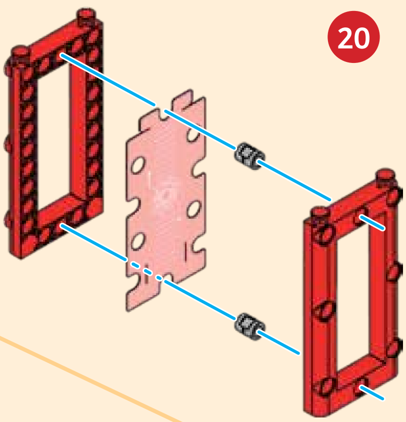
18



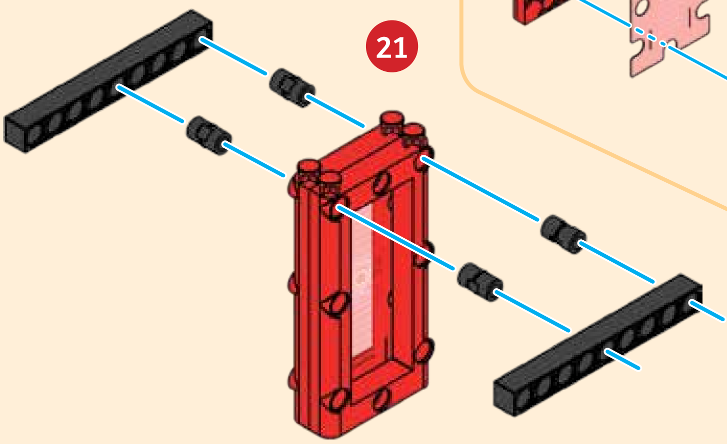
19



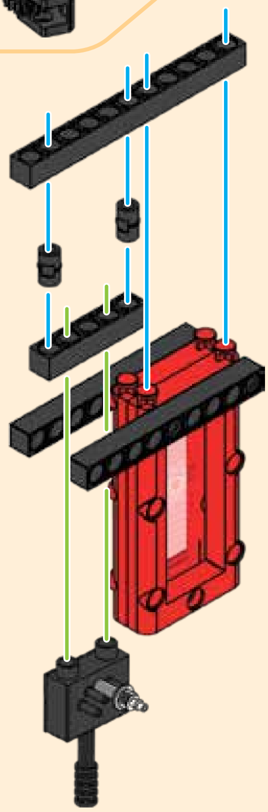
20



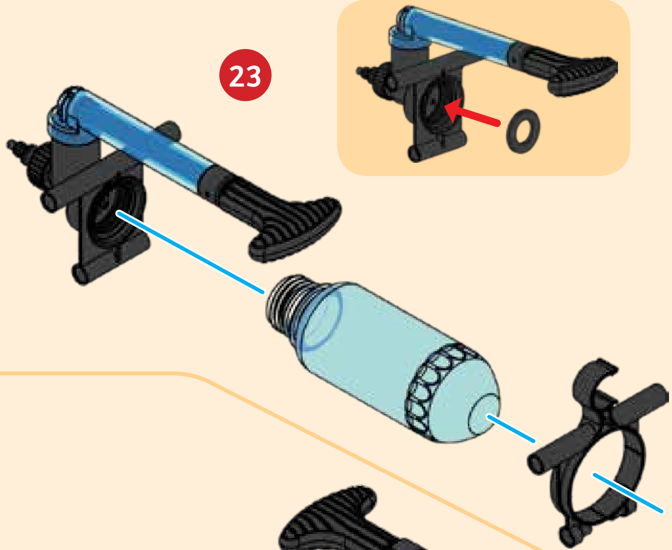
21



22

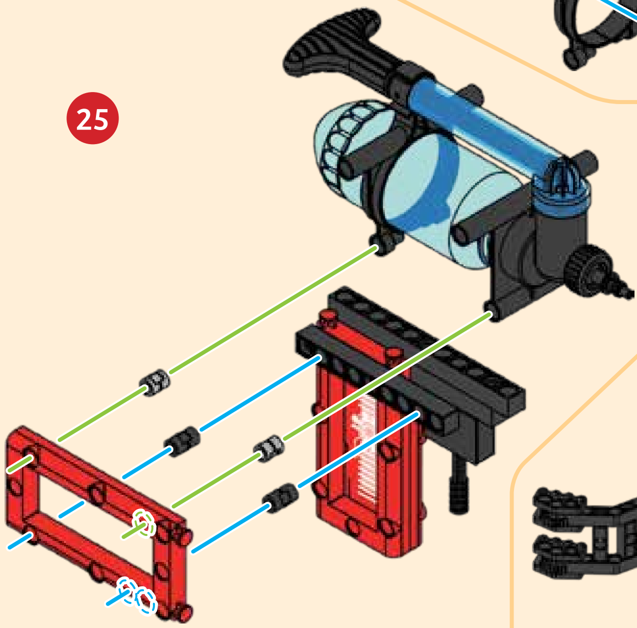


23

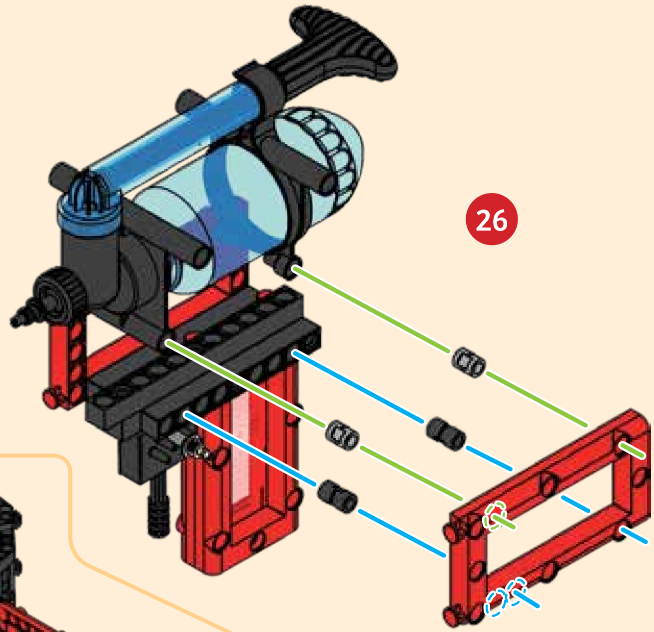


24

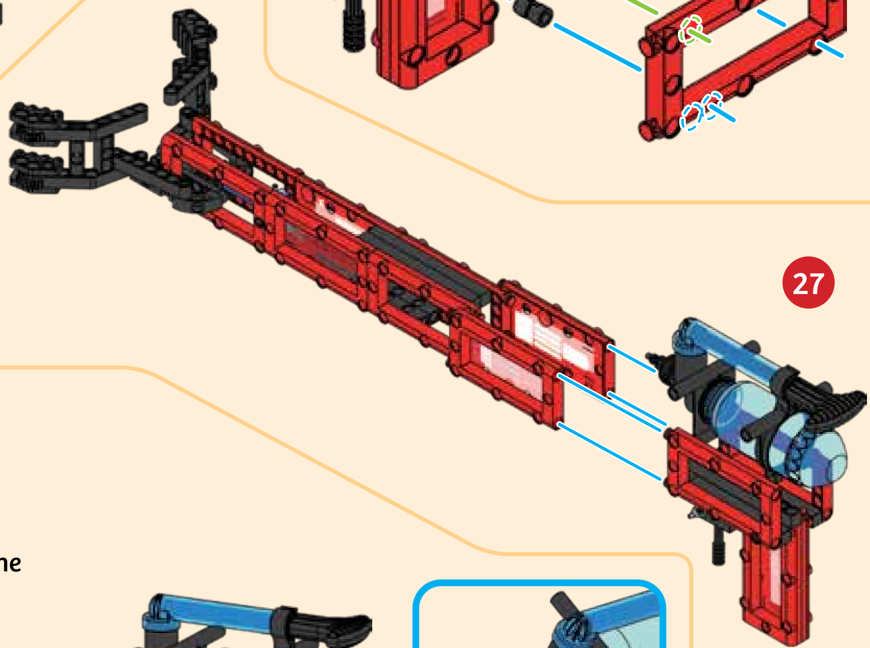
25



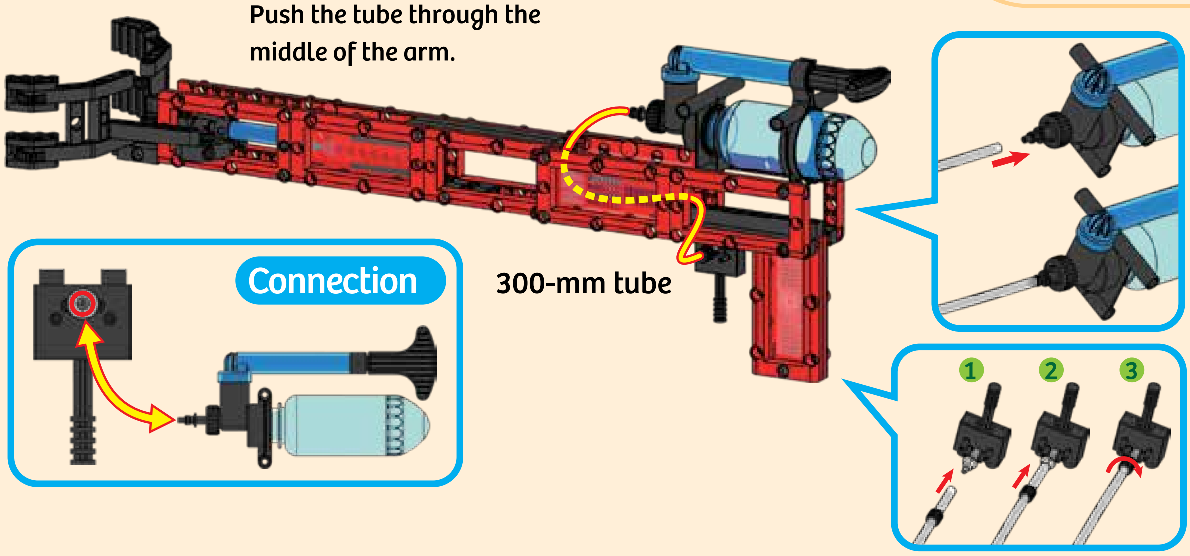
26



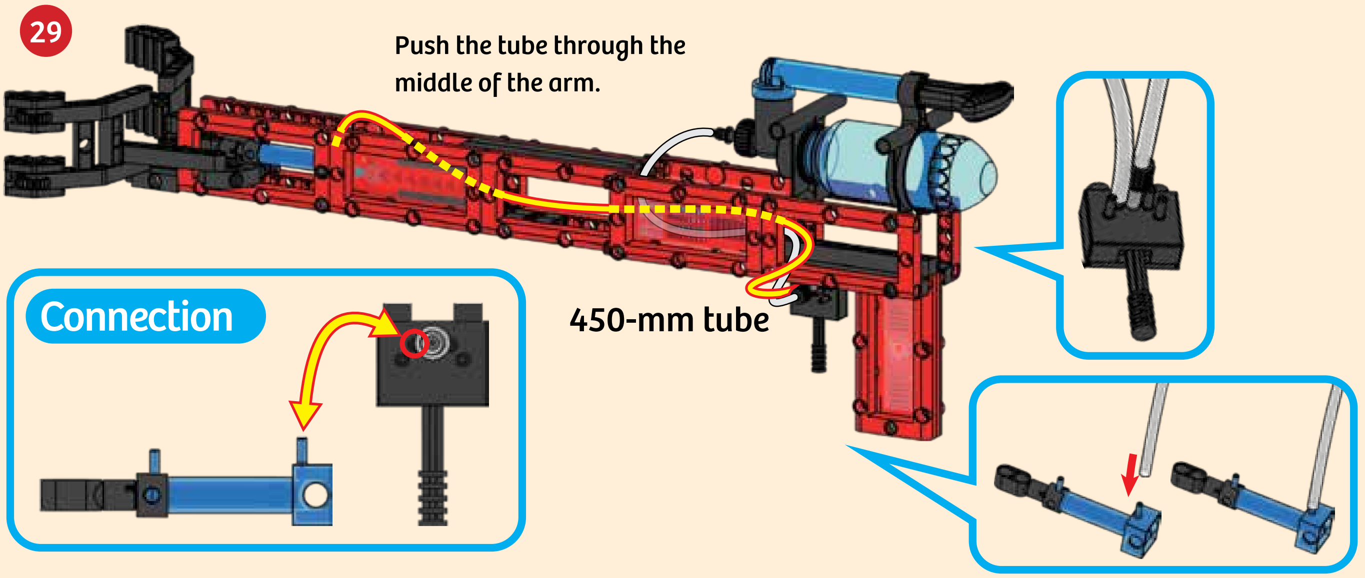
27



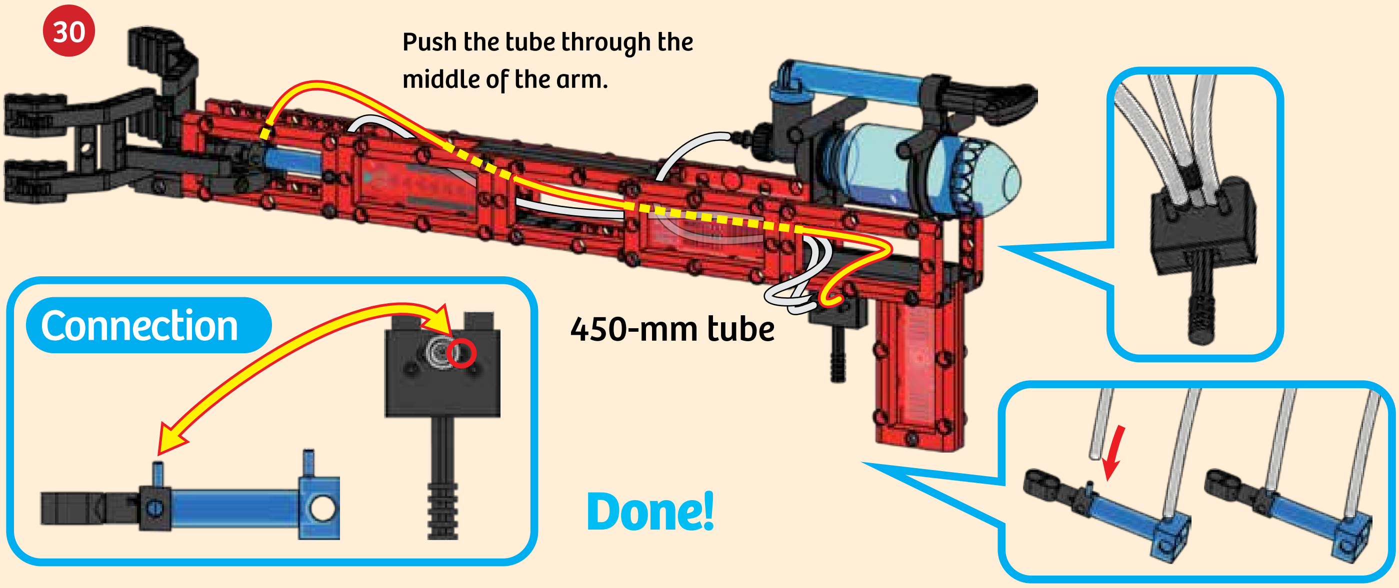
28



29



30



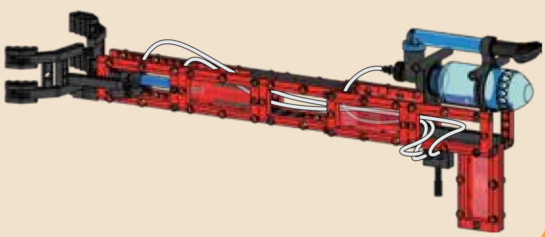
Done!

EXPERIMENT 2

Lifting a bottle

HERE'S HOW

Try to lift a filled water bottle using the robotic grabber with your arms outstretched. Then try to pick up the water bottle with the robotic grabber close to your body. Which way is easier?

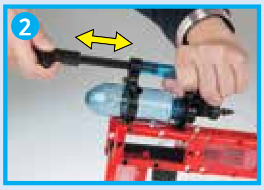


HOW TO USE

1

Put the switch lever in the center position.

2

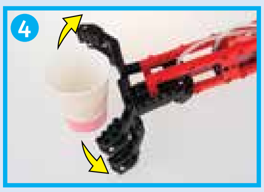


Pump about 30 times.

3

The gripper will open when you push the switch lever.

4



5

The gripper will close when you pull the switch lever.

6

CHECK IT OUT

Forces and Moments

Understanding how **forces** and **moments** influence a robotic arm is critical for its design, because a mistake in these calculations could cause the robotic arm to break.

ACCELERATION

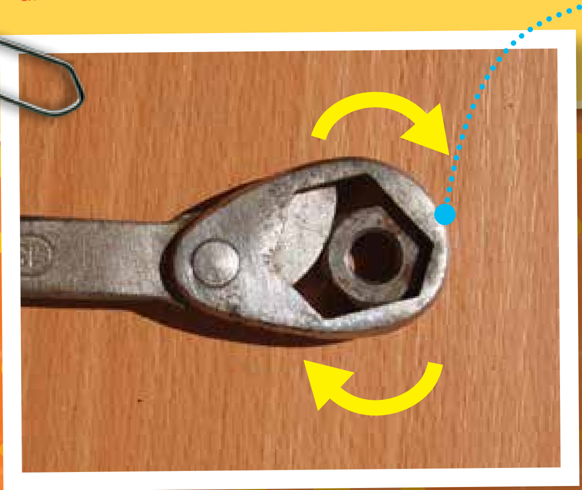
To understand force, you must first understand **acceleration.** Acceleration is a measure of how much the velocity of an object is changing. For example, a car is accelerating when it speeds up, slows down, or changes direction.

MOMENT

A force tends to cause an object to move, but depending on where the force is applied on an object, the force can also cause an object to rotate. For example, if you push on the end of wrench, the force of your push causes it to turn. How much a force causes an object to rotate is measured by its **moment.** A moment depends on how far the force is from the axis of rotation and how big of a force is applied. This can be written as the formula:

$$M = F \times d$$

You can increase the moment by increasing the force or the distance from the axis on which the force is exerted. You felt this in Experiment 2 when you stretched your arm out with the grabber robotic arm.



FORCE

A force can simply be thought of as a push or pull. A force is equal to the mass of the object multiplied by its acceleration. This is summarized by the formula:

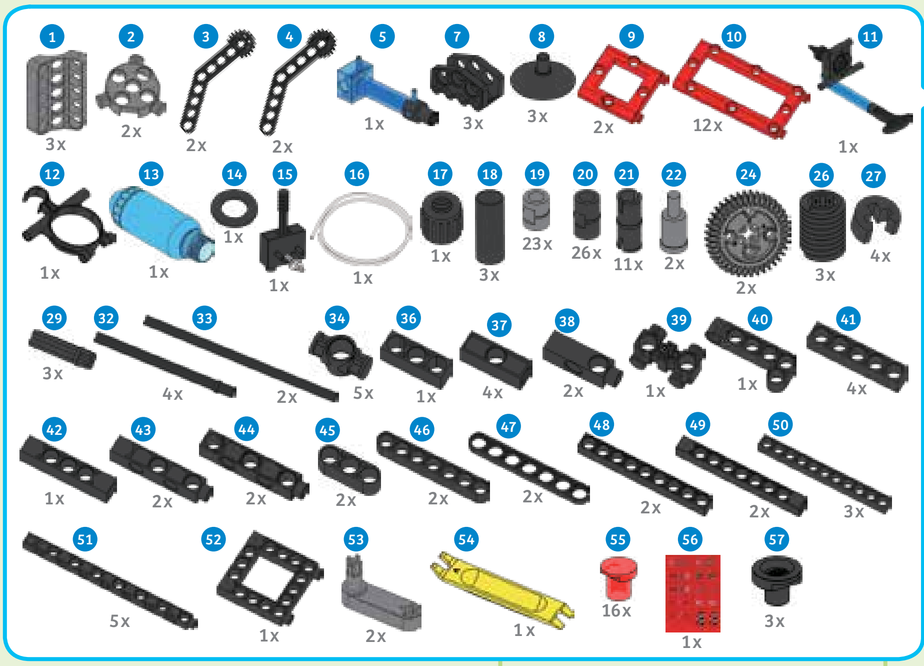
$$F = m \times a.$$

Each linkage and joint in a robotic arm has a weight, which is a force that points downward towards the Earth. A robotic arm must not only be able to support the weight of the arm itself, but also the weight of what the robot arm will carry. The maximum weight that a robot can lift is called the **carrying capacity.**

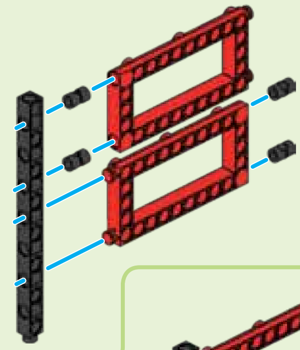
ARM SAGGING

Arm sagging occurs when the robotic arm is too long and heavy, causing it to bend when it is stretched out. This is undesirable. You want your robotic arm to be as rigid and light as possible. This can be overcome partially by positioning the heaviest components as close to the base of the robotic arm as possible.

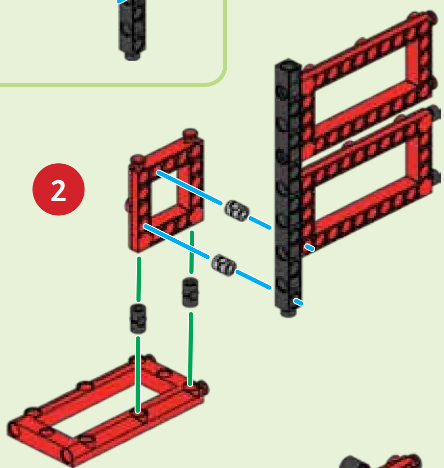
ROBOTIC CLAW



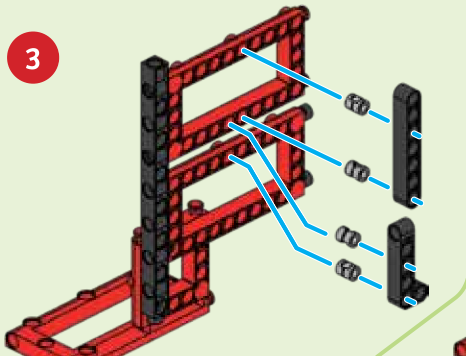
1



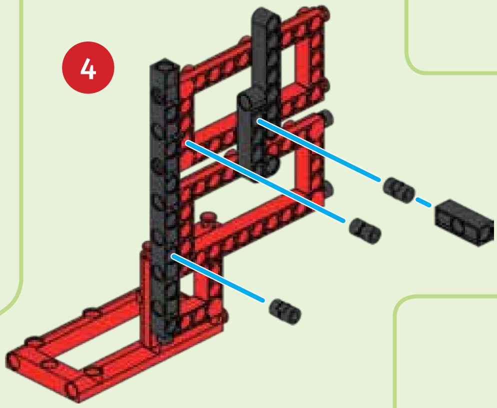
2



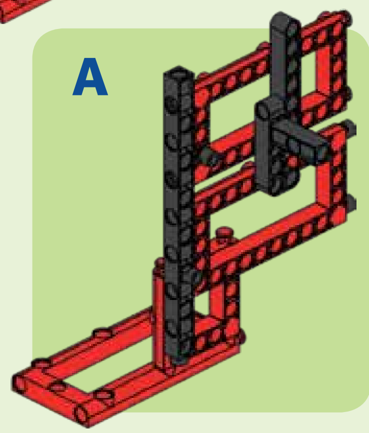
3



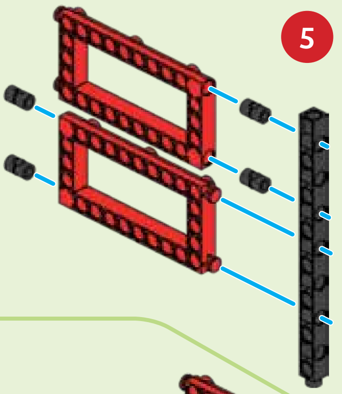
4



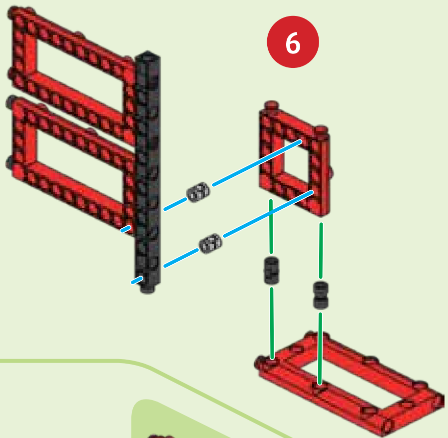
A



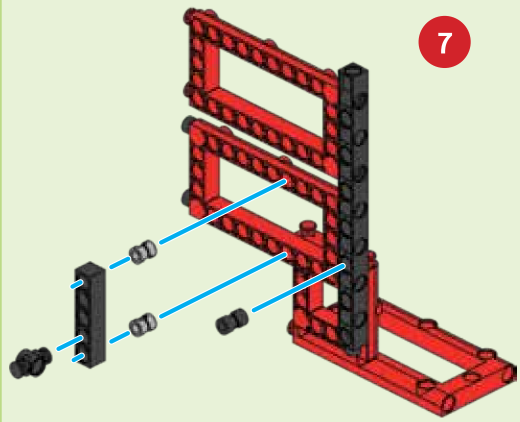
5



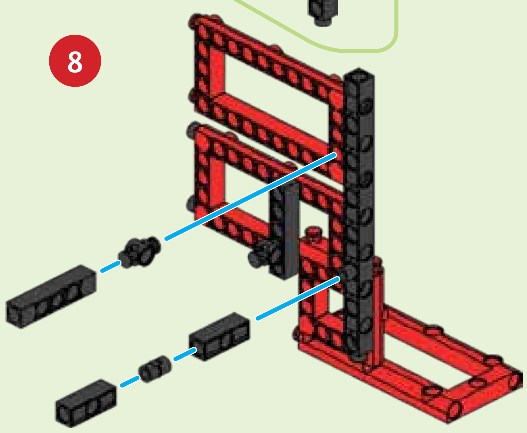
6



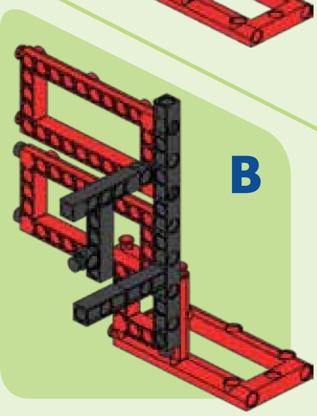
7



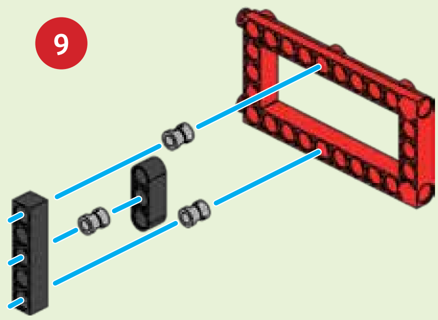
8



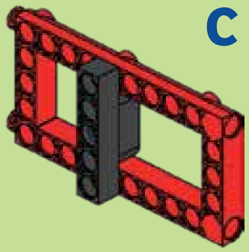
B



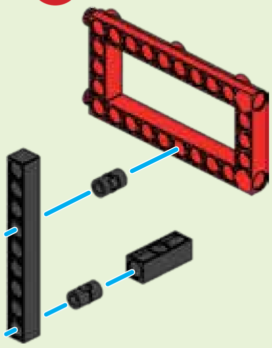
9



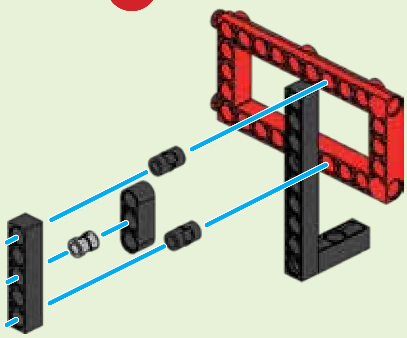
C



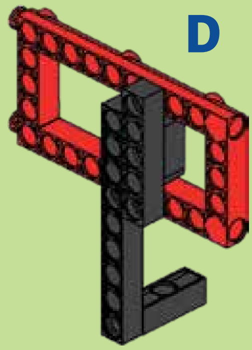
10



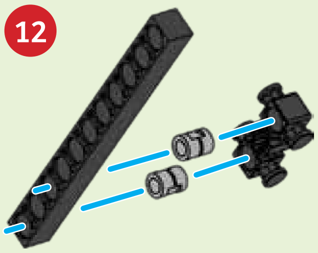
11



D

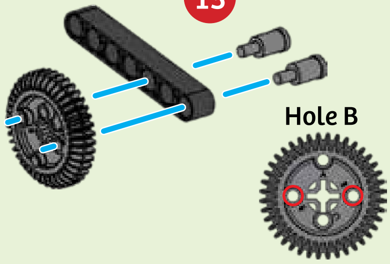


12

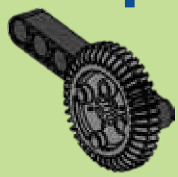


E

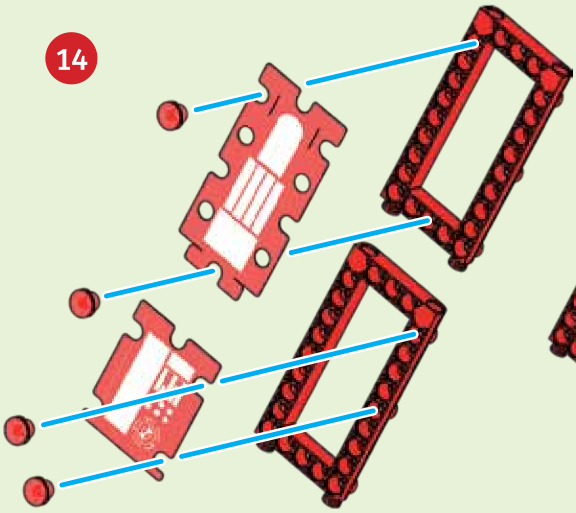
13



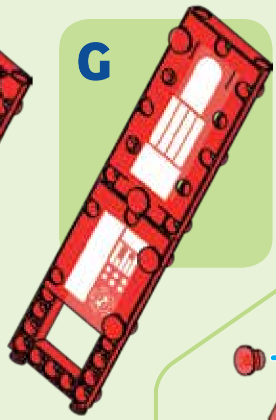
F



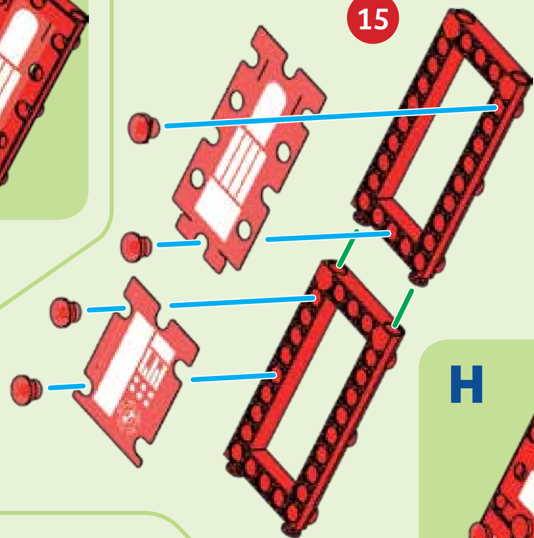
14



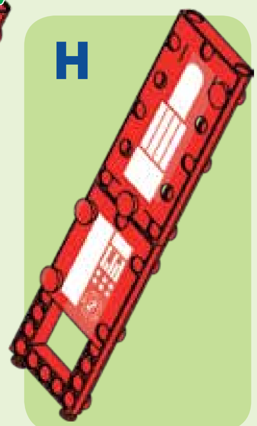
G



15



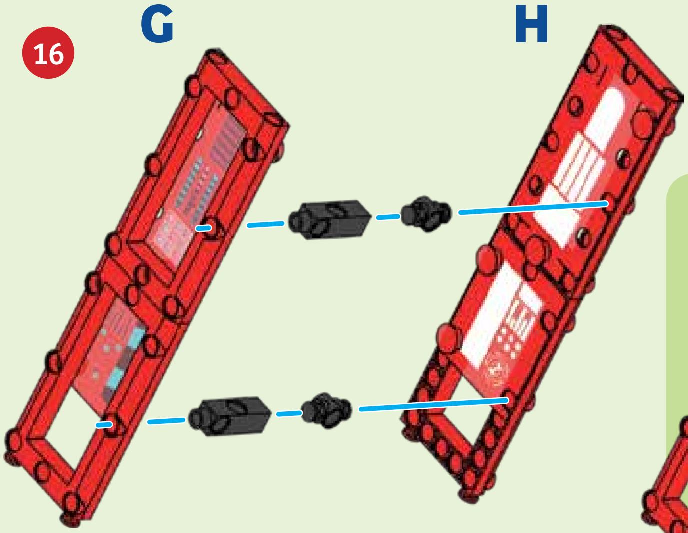
H



16

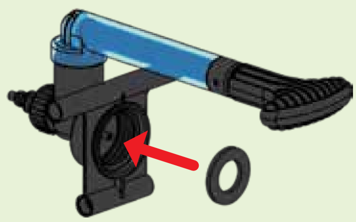
G

H

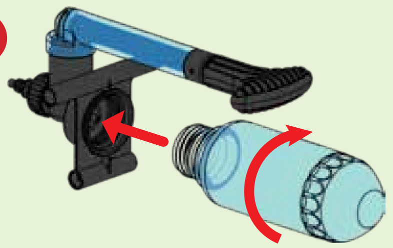


I

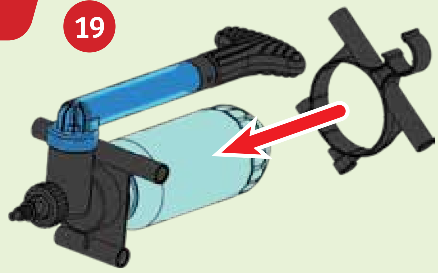
17



18

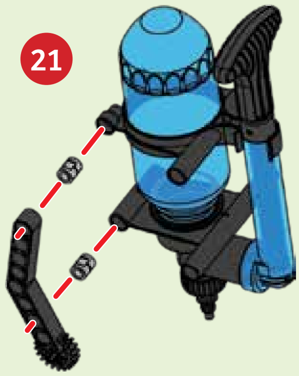


19

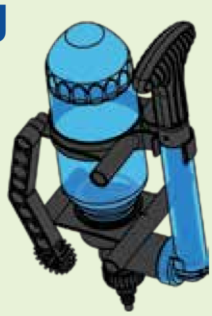


20

21

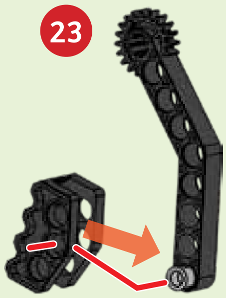


J

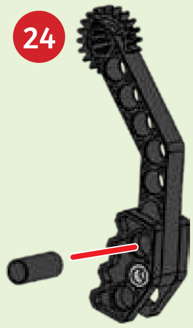


22

23

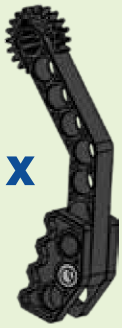


24

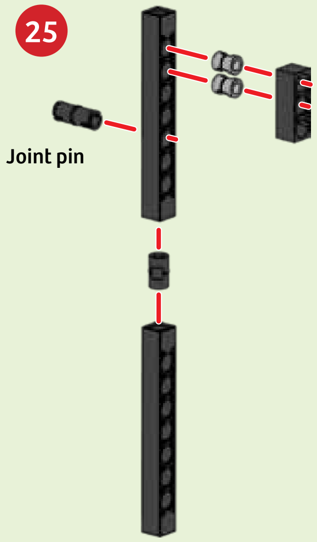


J

3x

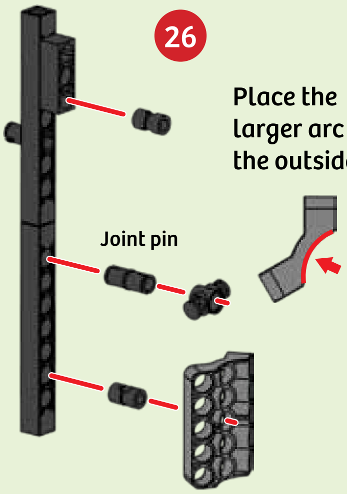


25

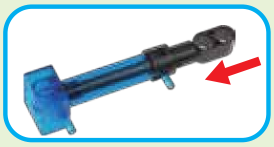


26

Place the larger arc on the outside.



How to remove the pneumatic piston handle:



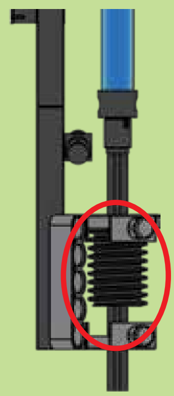
1. Push the handle back into the piston cylinder.

2. Slide the anchor pin lever around the neck of the handle.

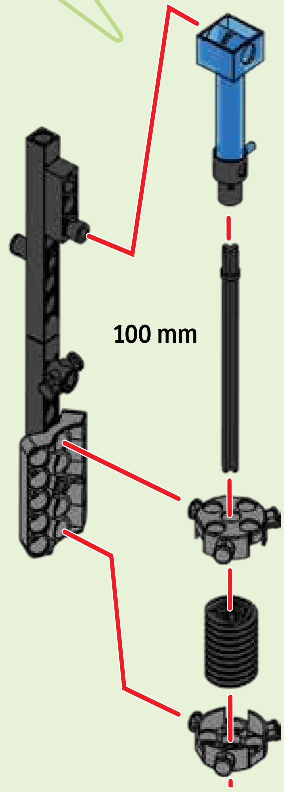
3. Gently use the anchor pin lever to pry the handle from the piston.

4. Pull the piston handle out of the piston.

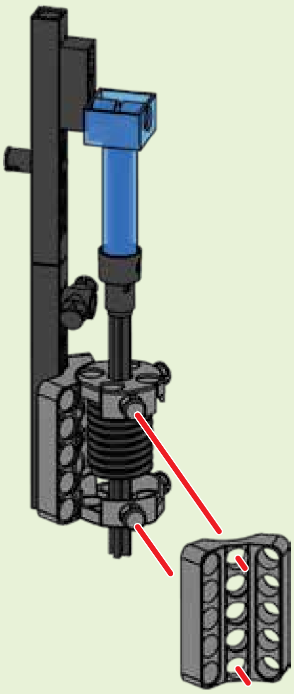
27



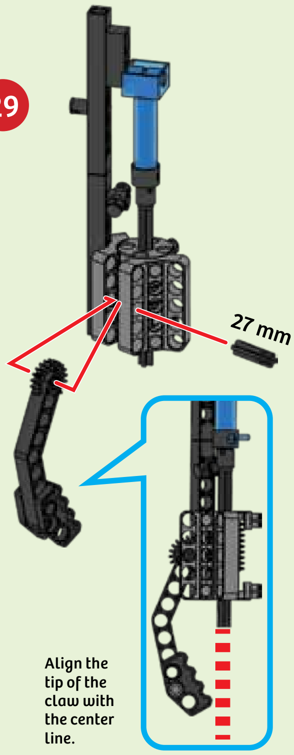
Keep the worm toward the top.



28

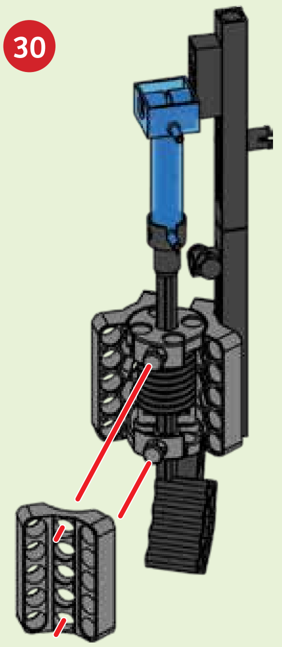


29

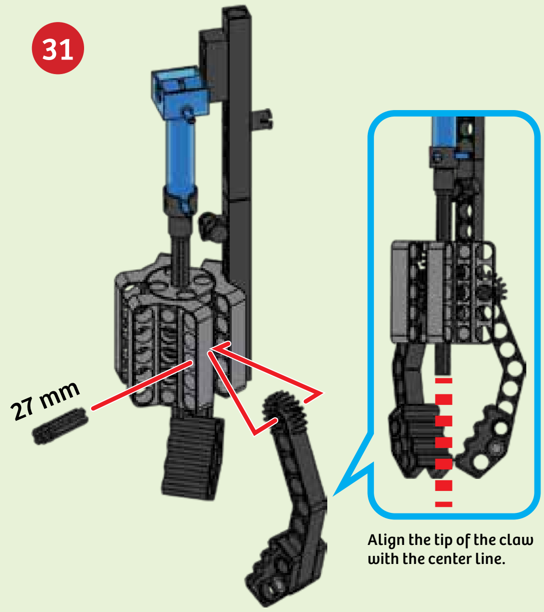


Align the tip of the claw with the center line.

30

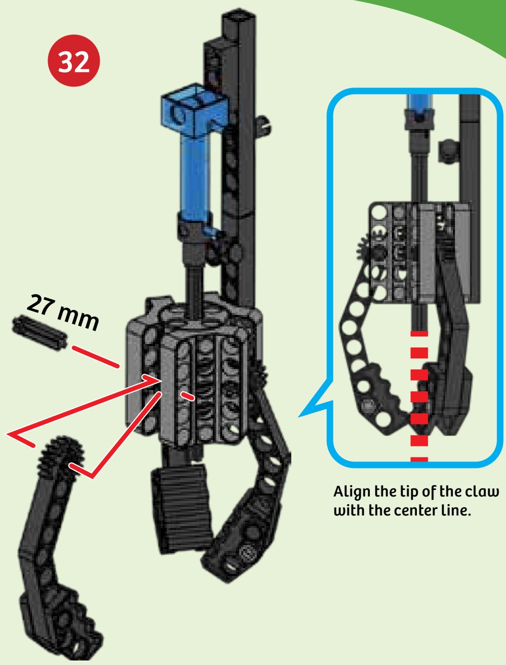


31



Align the tip of the claw with the center line.

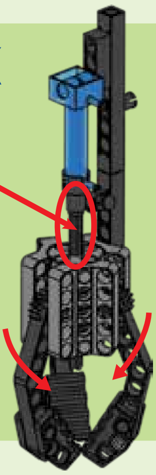
32



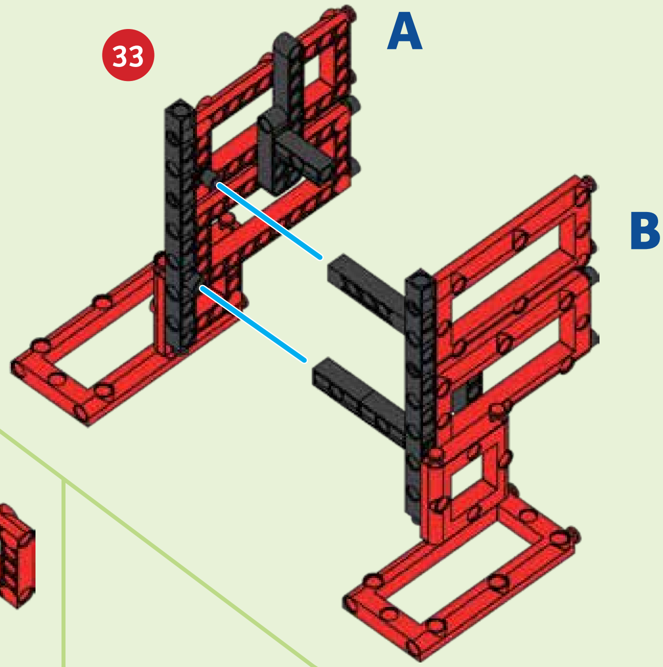
Align the tip of the claw with the center line.

TIP!
Rotate the axle to adjust the claws up or down.

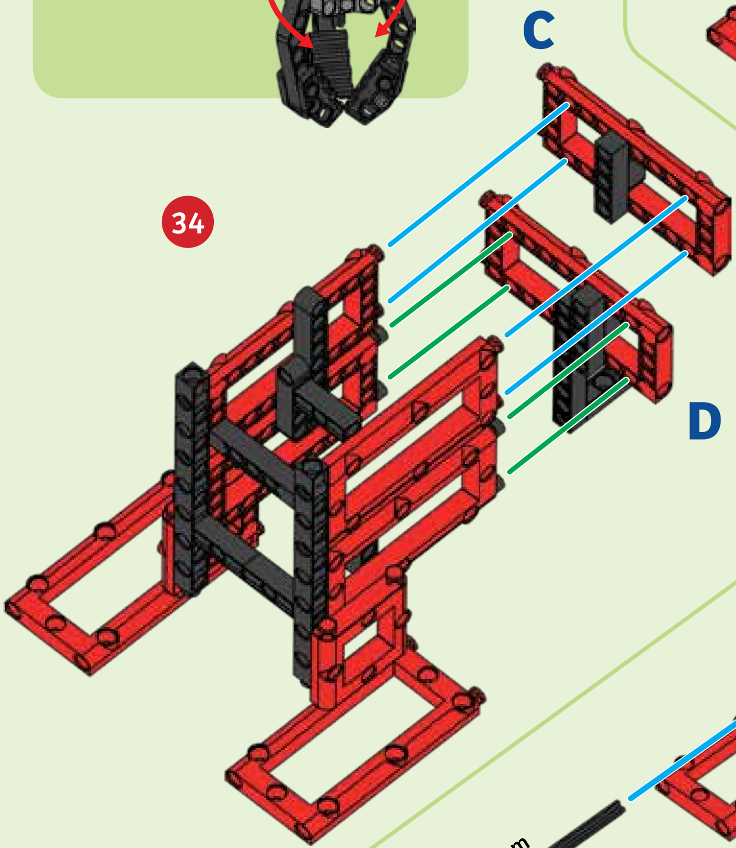
K



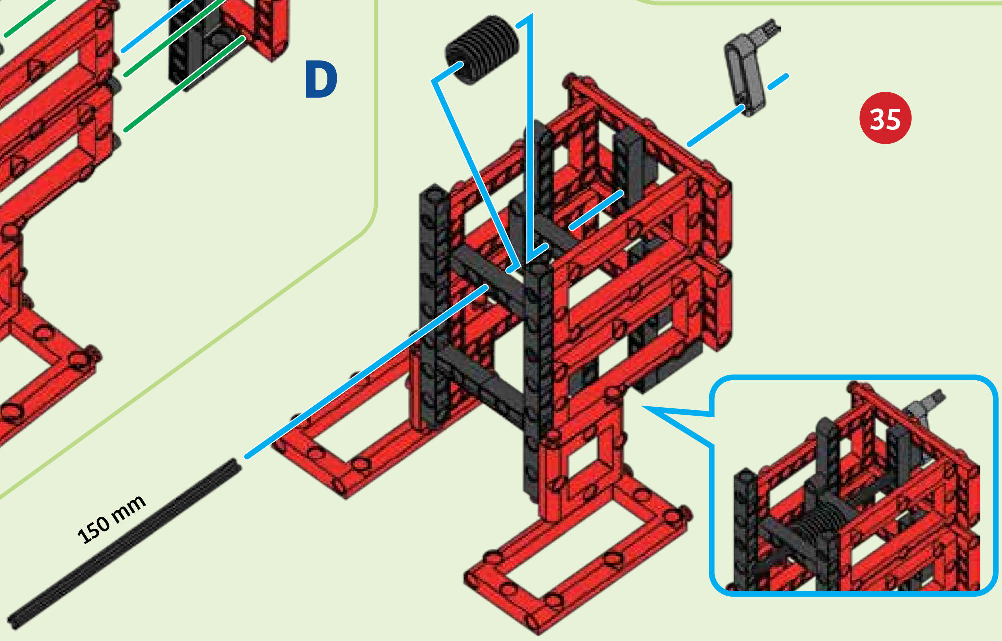
33



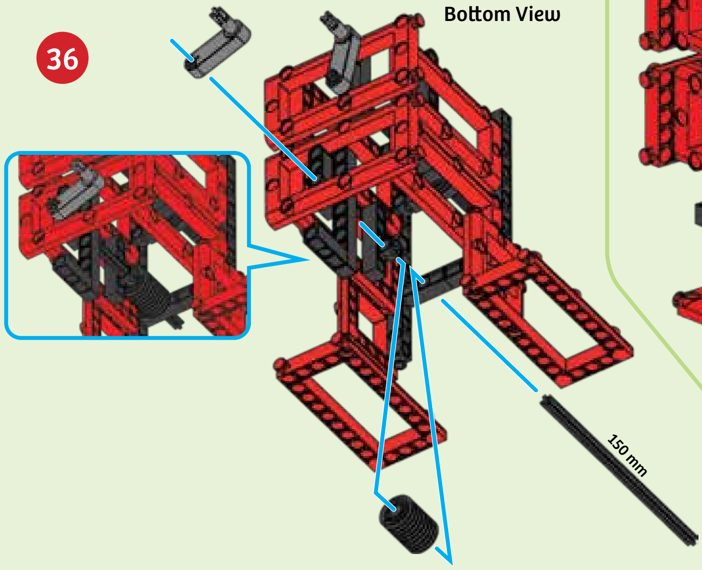
34



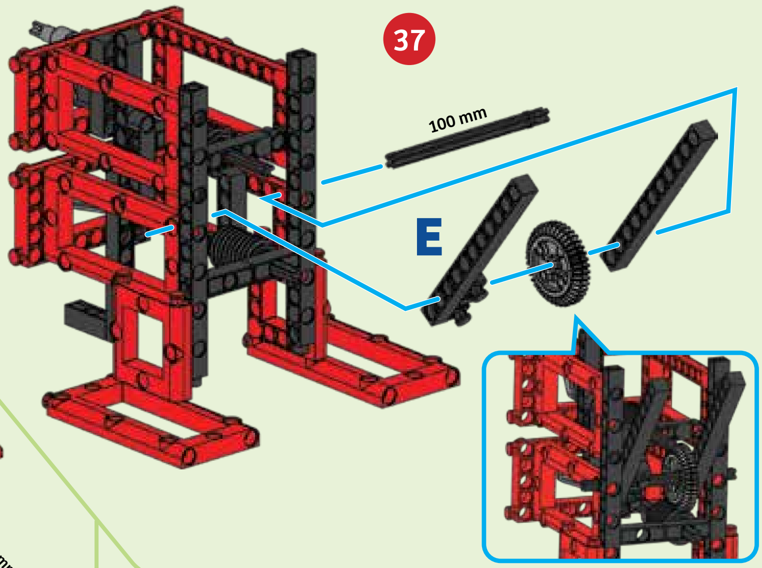
35



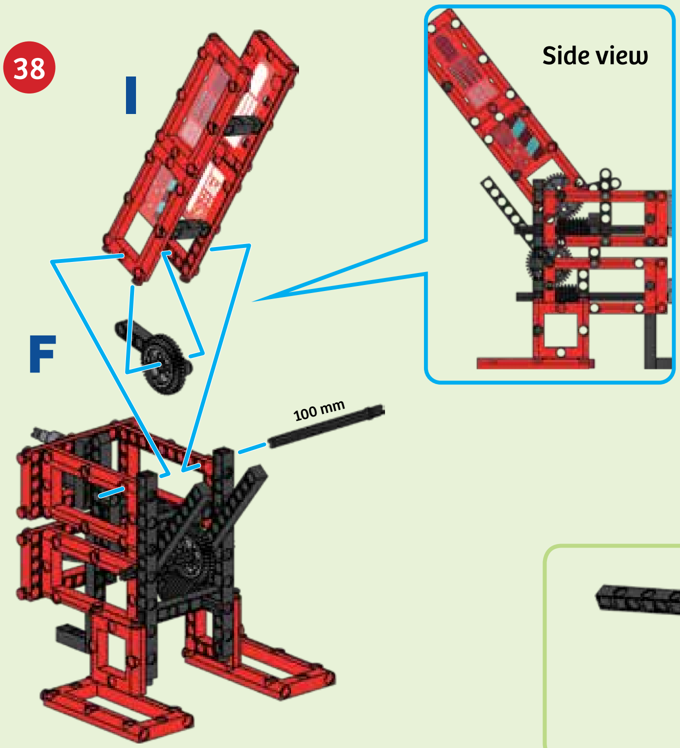
36



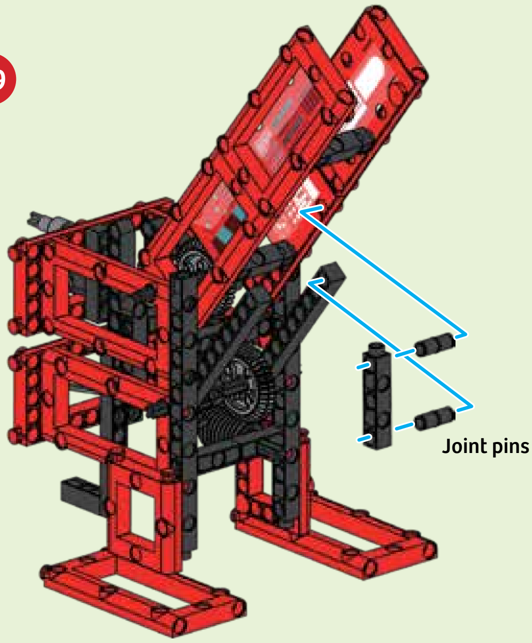
37



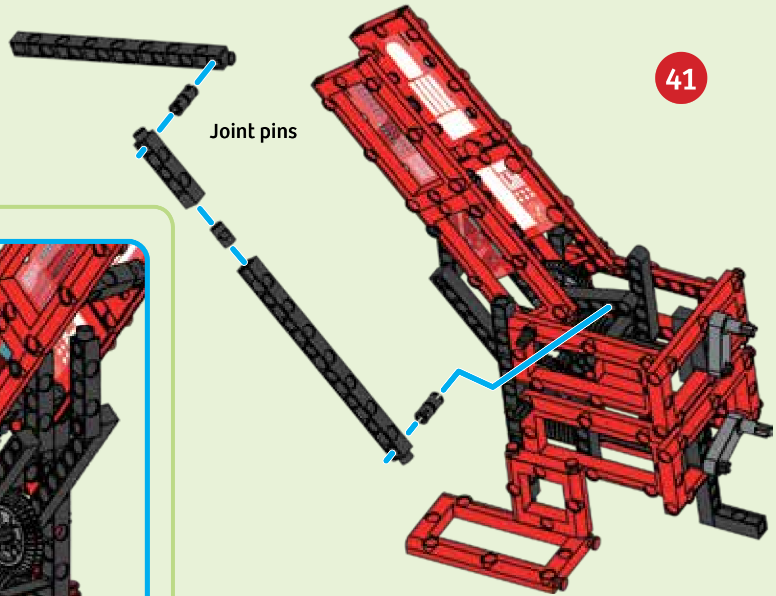
38



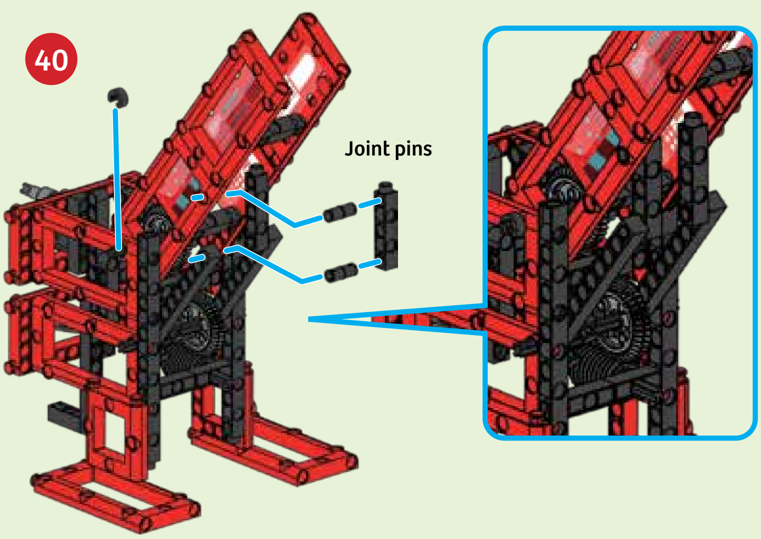
39



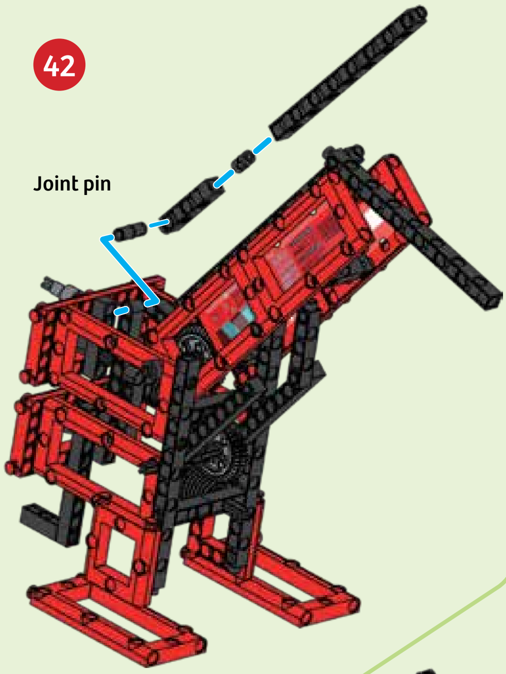
41



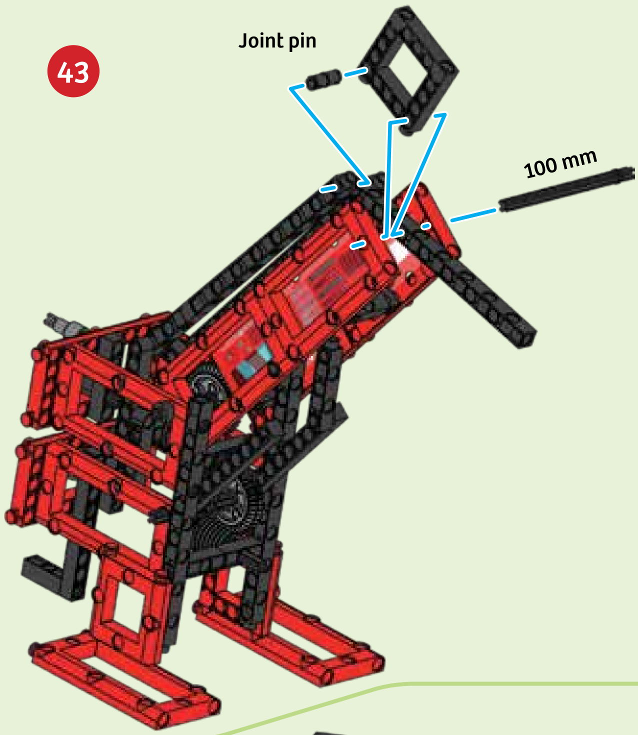
40



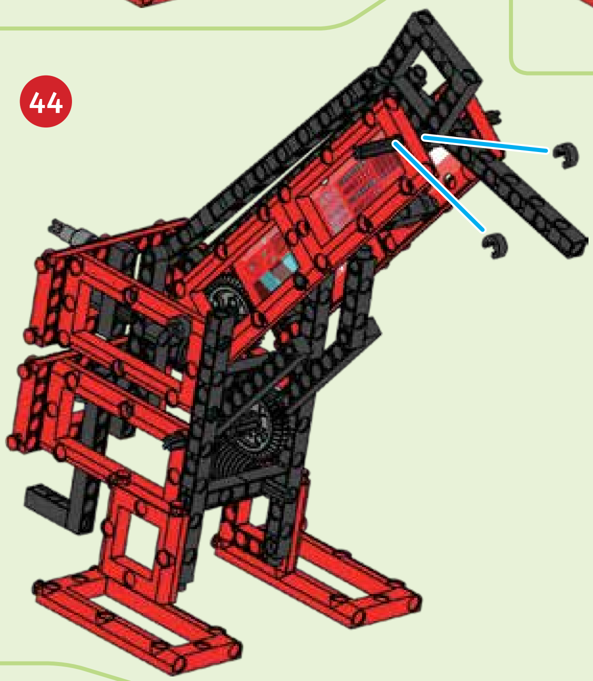
42



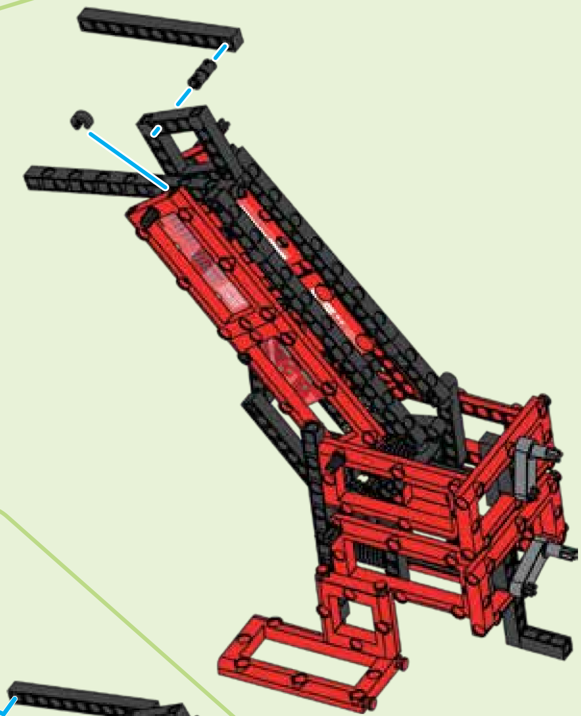
43



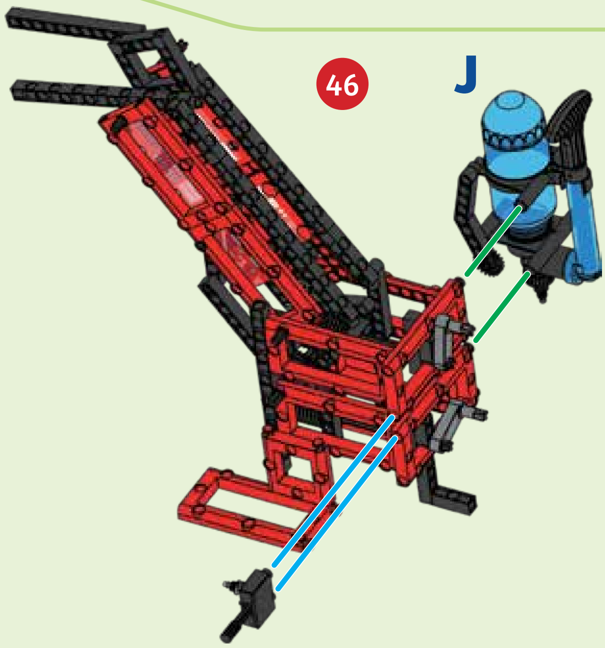
44



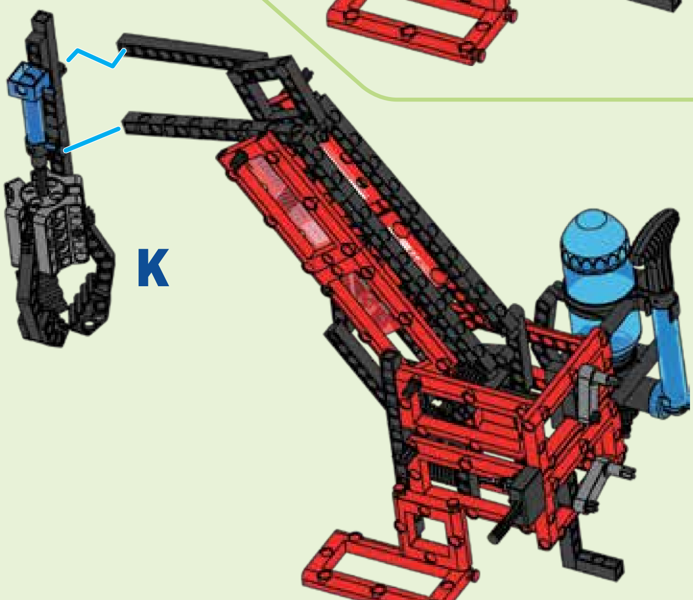
45

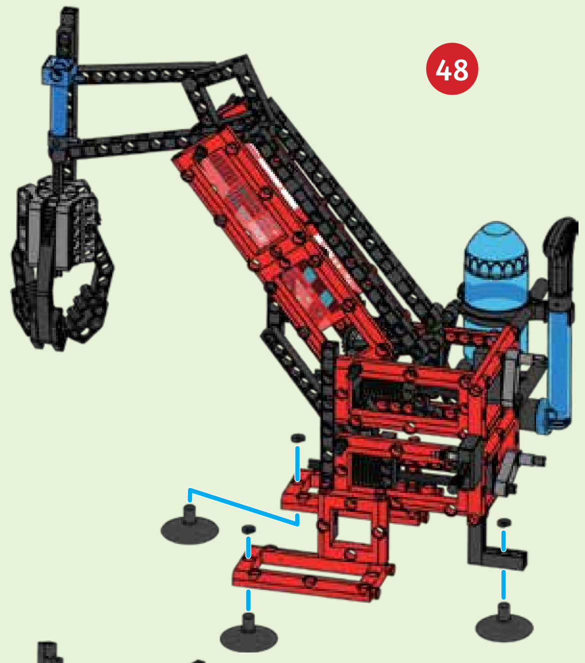


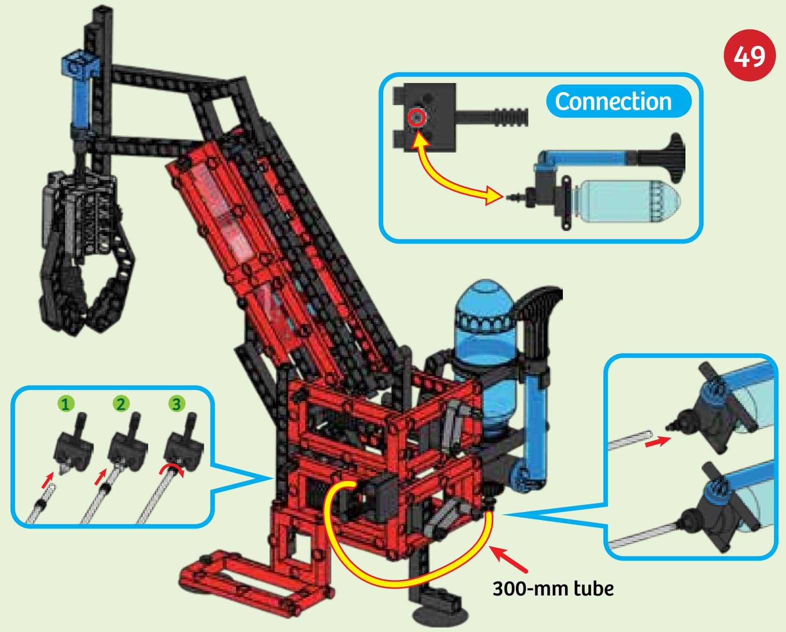
46

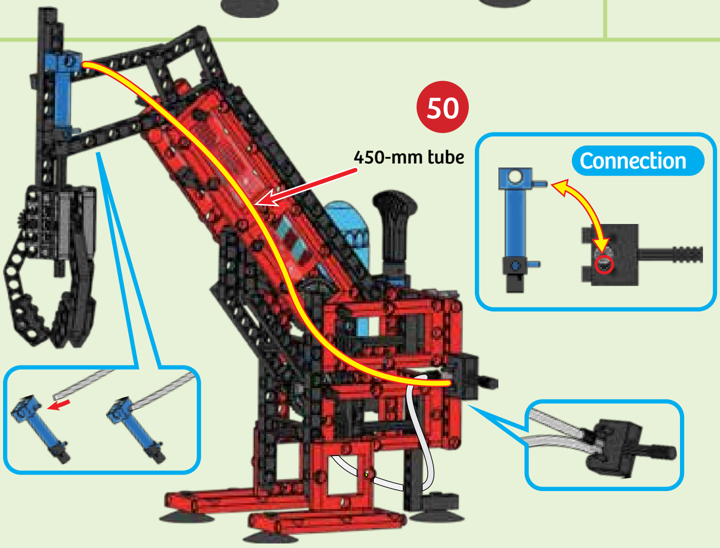


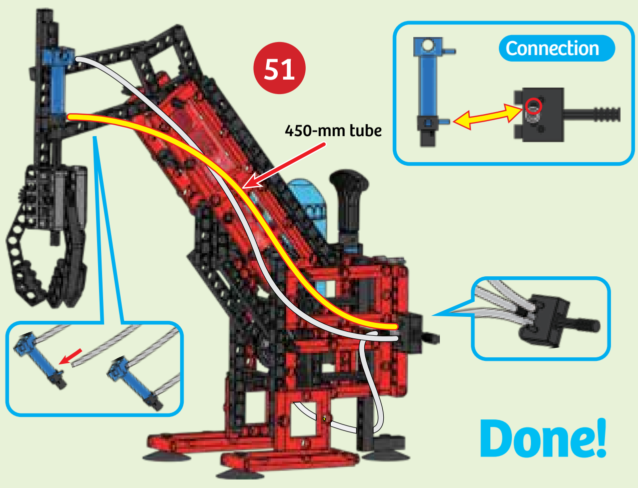
47









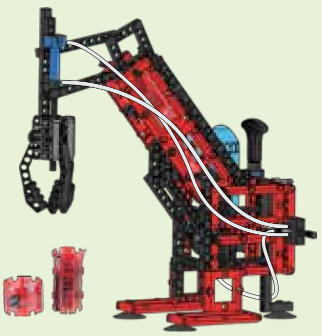


EXPERIMENT 3

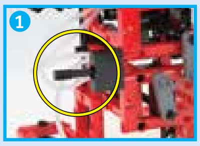
Pneumatic strength

HERE'S HOW

Instead of the normal 30 pumps to fill the air tank, use only 15 pumps. Then try to pick up one of the cylinders. Repeat this experiment using 30 pumps and then 40 pumps. Compare the speed and strength of the grabber each time.

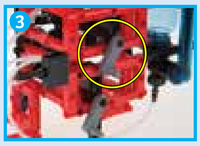


HOW TO USE

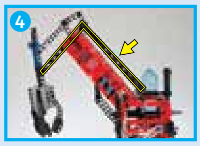


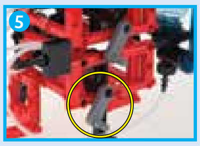
Put the switch lever in the center position.

Pump about 30 times.

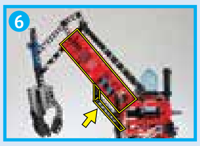


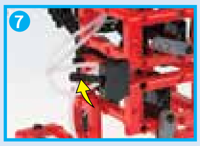
The upper handle controls the upper linkage.



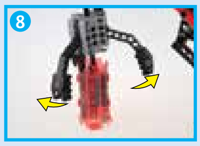


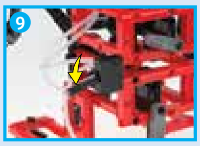
The lower handle controls the lower linkage.



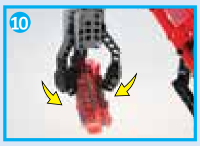


The gripper will open when the switch lever is up.





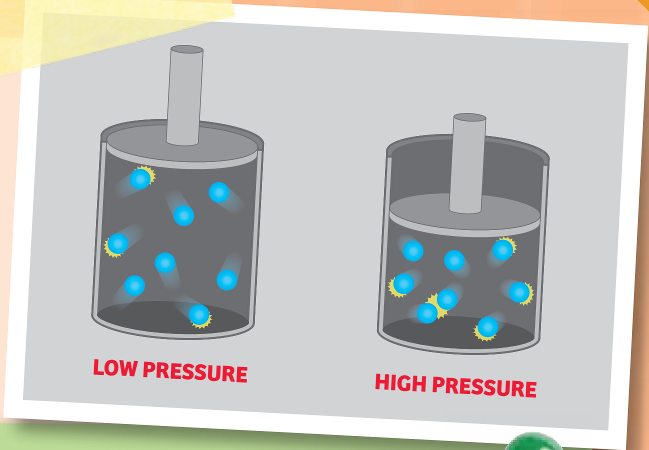
The gripper will close when the switch lever is down.



CHECK IT OUT

Pneumatics

In a machine, the parts that are responsible for moving or controlling a mechanism are called **actuators.** The robotic arms in this kit use mechanical parts (gears and axles) to move the robotic arm and a piston to open and close the gripper. The tubes, piston, pump, and air tank together are known as a **pneumatic system.**



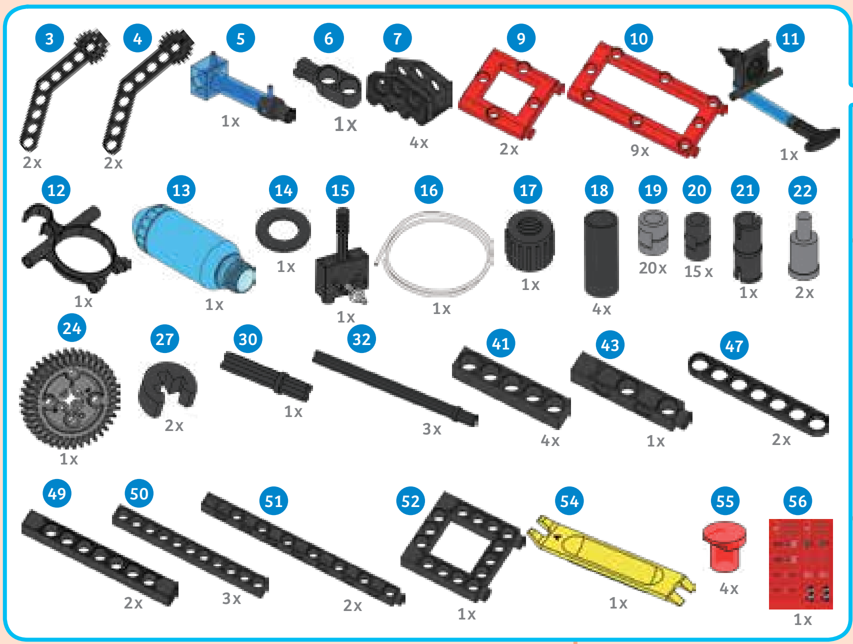
WHAT IS PRESSURE?

Air is a gas consisting of many very small molecules that are constantly moving in all directions. When these molecules bump against an object they push against it. **Pressure** is a measure of how hard and how often these gas molecules are pushing on an area. In physics, pressure is a force over an area and has units of pounds per square inch (psi), Pascal, or Bar.

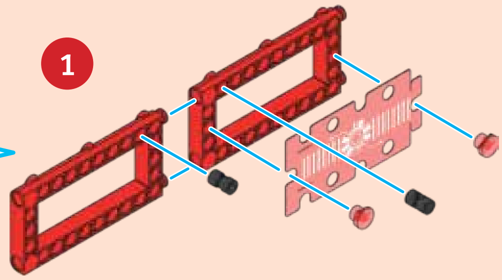
1. When you pump the pump handle, you are pushing air from the atmosphere into the air tank. Because there are now more air molecules bouncing around inside the air tank, the pressure inside the air tank has increased.
2. When the switch is opened, it releases the pressurized air from the tank. The pressurized air travels through the tube into the piston. The pressure in the piston then increases, pushing the piston rod outward.
3. When the switch is pushed to the third position, the air is released from the piston, pulling the piston rod inward.

Most industrial robotic arms use electric motors because they are usually cheaper than pneumatic systems and provide faster and more precise control over movement. However, pneumatic actuators are stronger and advantageous in applications where an electrical spark could start a fire.

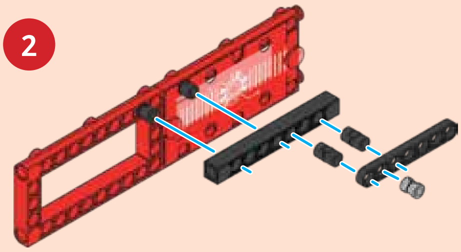
ROBOTIC HAND



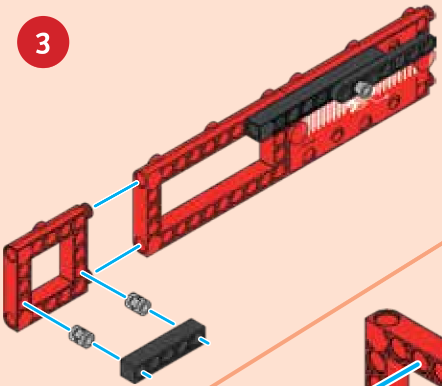
1



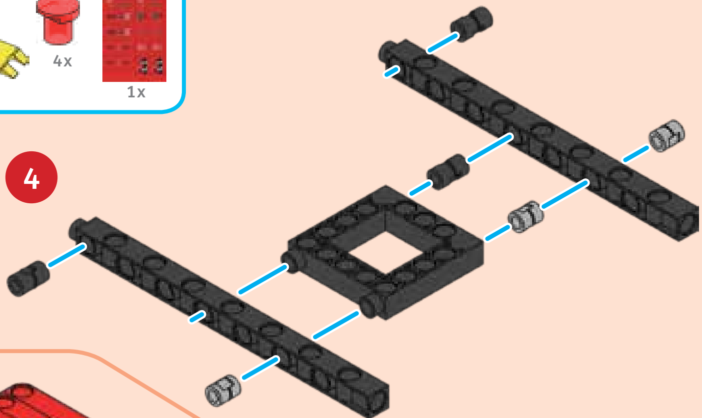
2



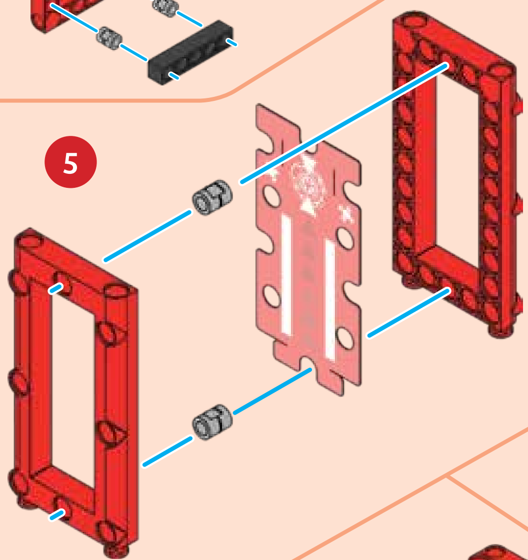
3



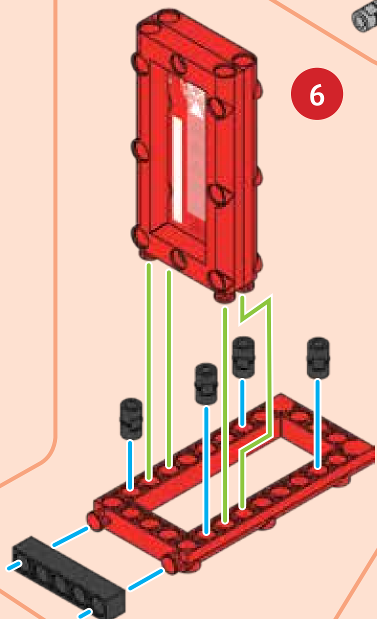
4



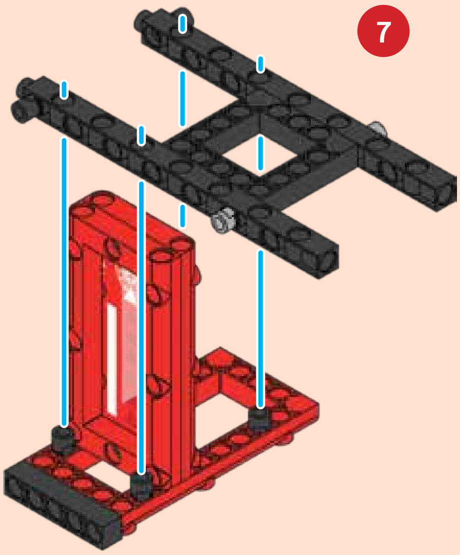
5



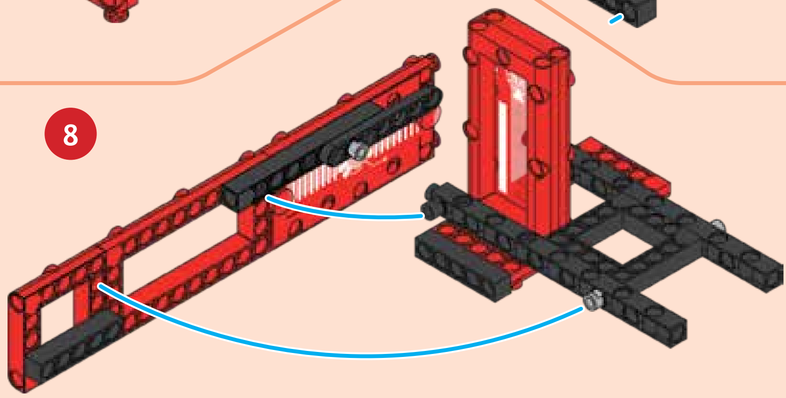
6



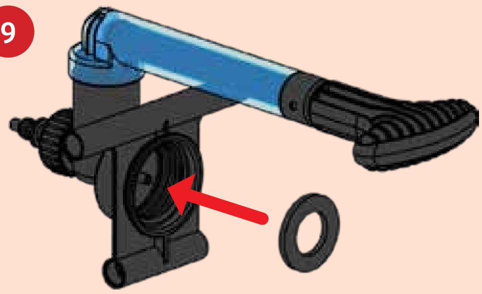
7

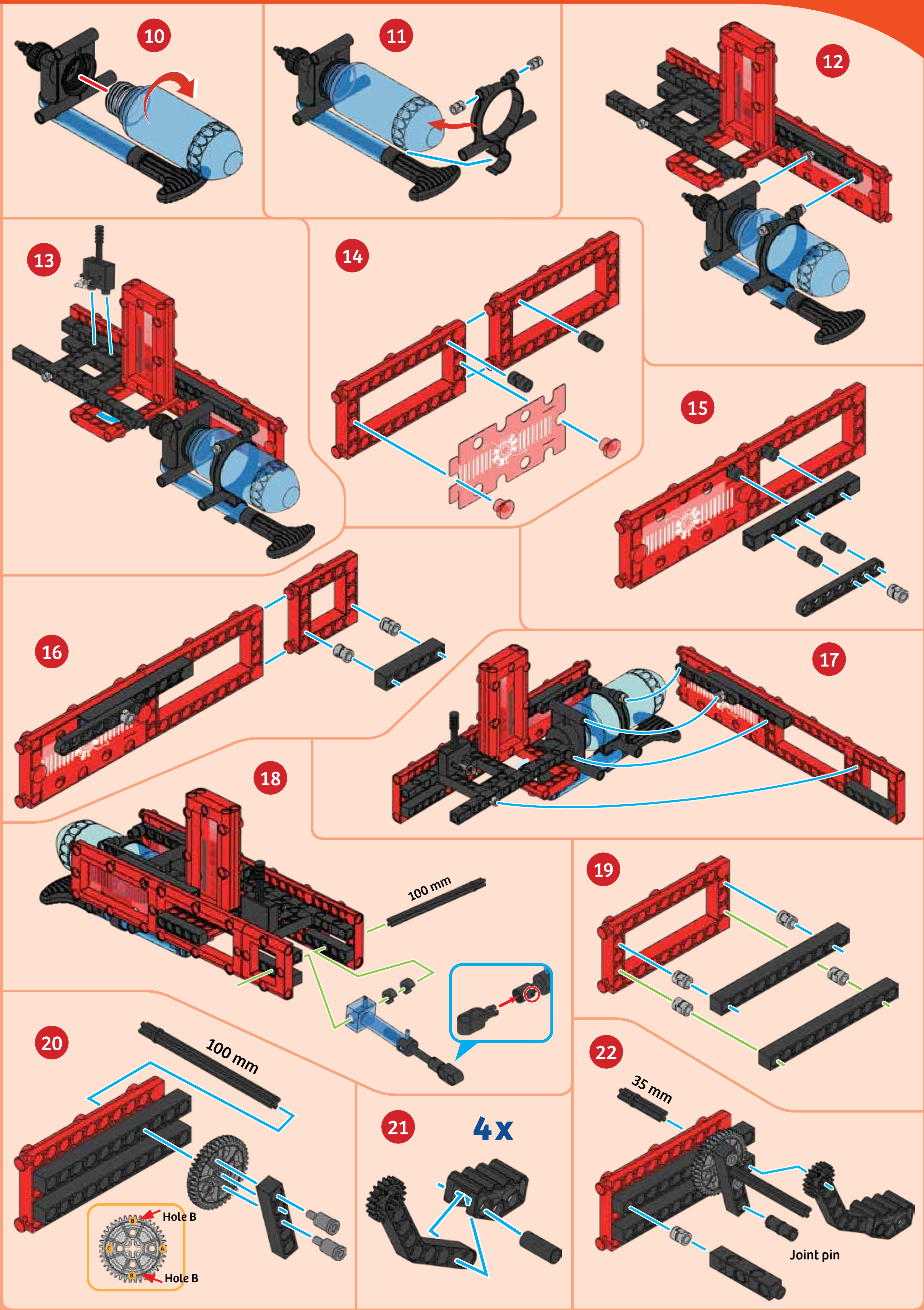


8

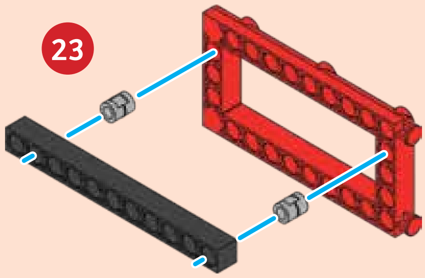


9

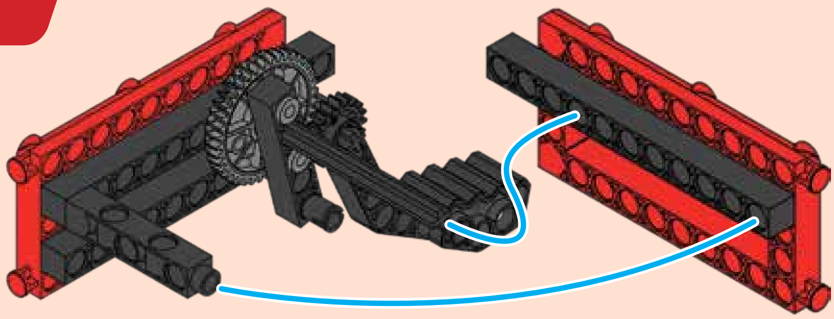



10
11
12
13
14
15
16
17
18
100 mm
19
20
100 mm
Hole B
Hole B
21
4x
22
35 mm
Joint pin

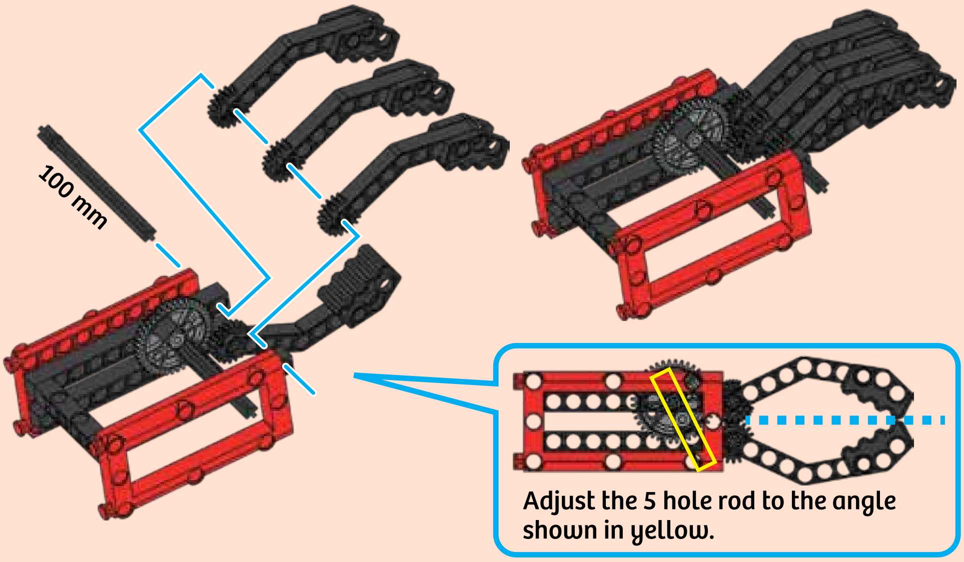
23



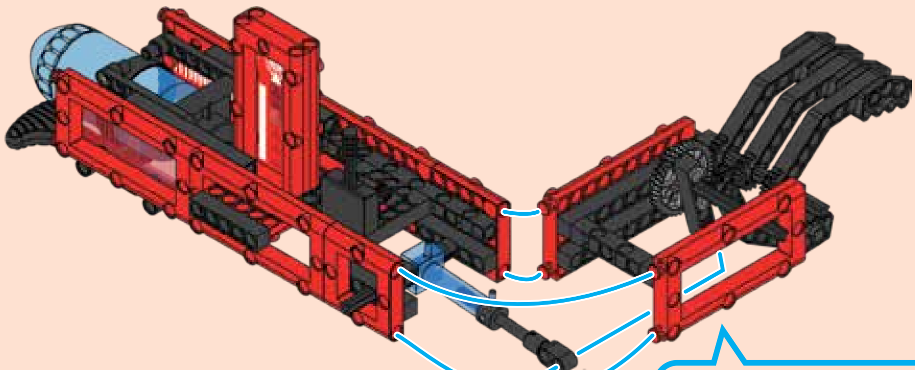
24

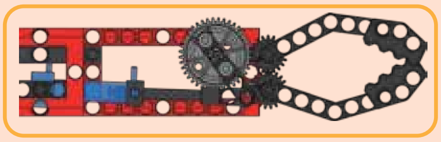


25

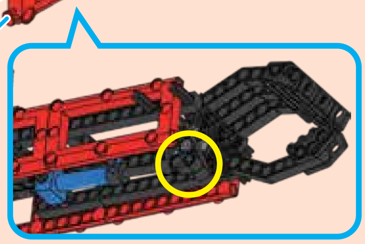


26



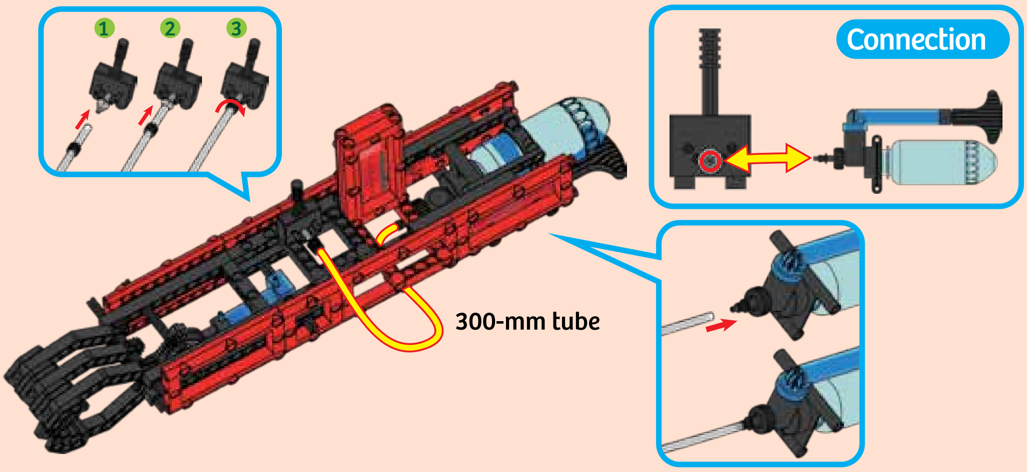


When the cylinder is pulled all the way out, the two grippers should be closed.

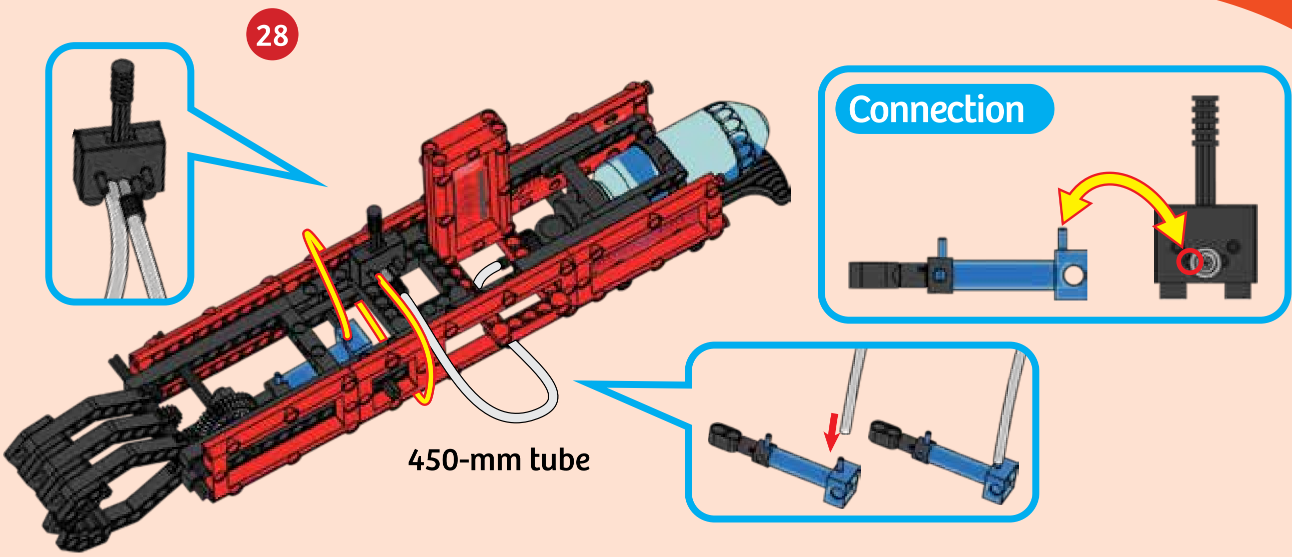


Connect the cylinder to the 5-hole rod.

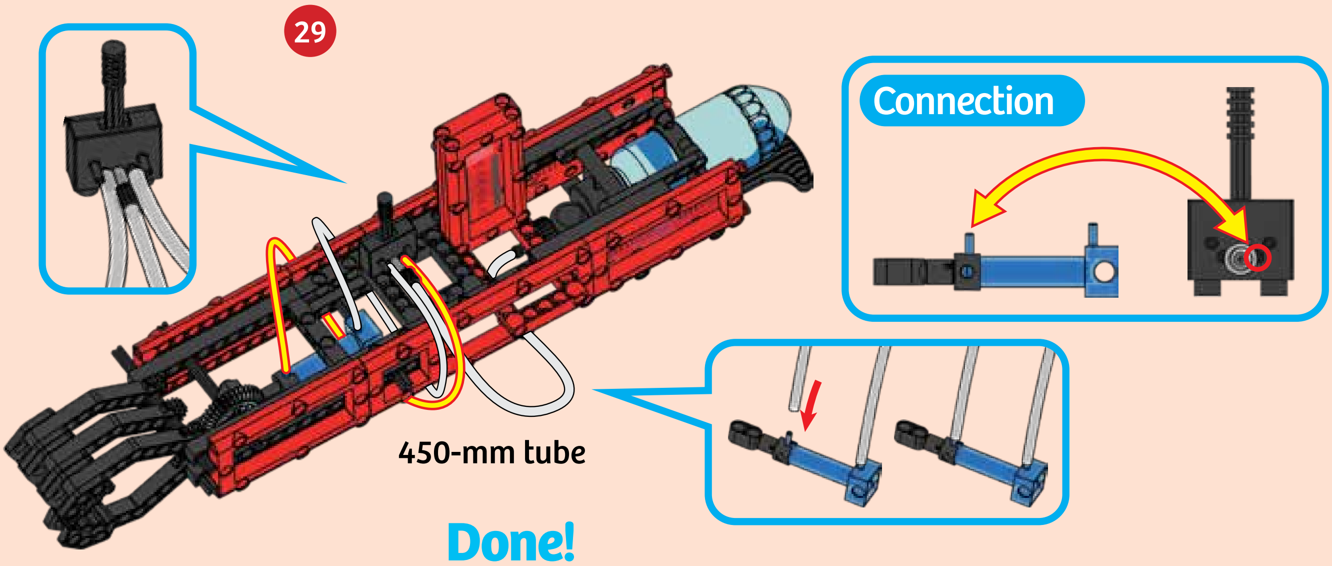
27



28



29



Done!

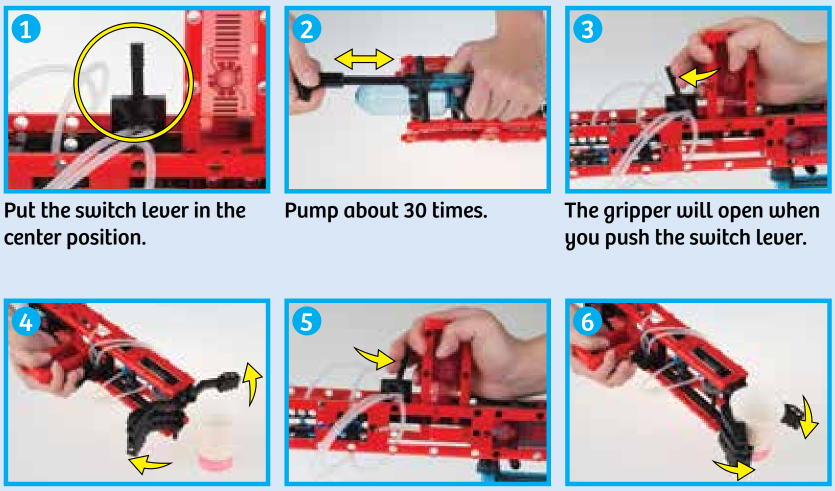
EXPERIMENT 4

Coming in handy

HERE'S HOW

If you wear an oversized sweater or sweatshirt with large sleeves, you can slide the robotic hand up your sleeve so that only the hand is outside the sleeve. Operate the trigger inside the sleeve. Now try to pick up various objects. Can you pick up some items and not others?

HOW TO USE



1. Put the switch lever in the center position.
2. Pump about 30 times.
3. The gripper will open when you push the switch lever.
4.
5. The gripper will close when you pull the switch lever.
6.

CHECK IT OUT

Robotic Exoskeletons

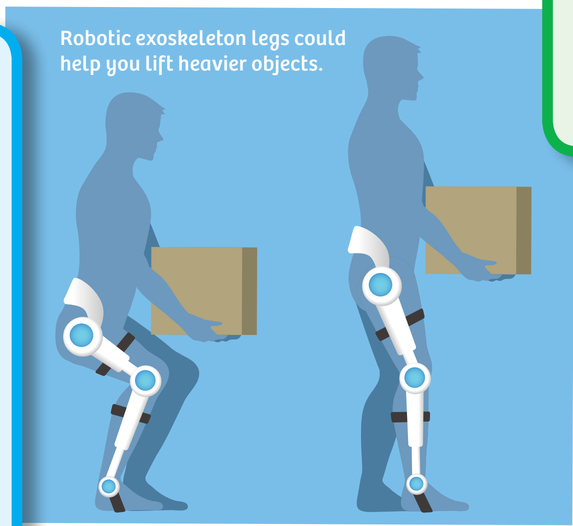
What you have learned about robotic arms can also be applied to the design of robotic exoskeletons. An exoskeleton is a wearable mobile machine that is used to increase limb strength and endurance. Exoskeletons could be used in the medical field to improve people's quality of life or to make tasks easier and safer. They could also be used in industrial or commercial applications — wherever increased strength would come in handy. However, currently there are several challenges to creating viable exoskeletons.

MATERIALS

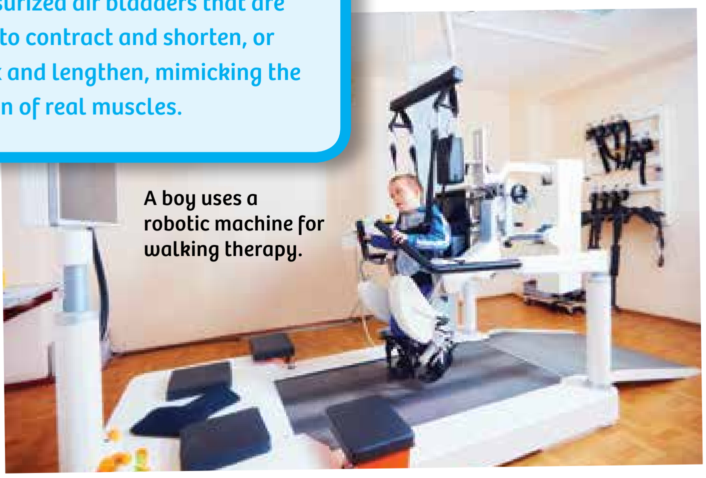
The materials needed to build an exoskeleton require trade-offs between strength, weight, and cost. The materials used must be strong enough so that they do not fail or break easily but also need to light to reduce the power needed to move the exoskeleton. However, the use of lighter and stronger materials, such as titanium or carbon-fiber, can be more expensive and require more complex construction and manufacturing methods.

ACTUATORS

Just as is true of the materials needed to build an exoskeleton, the actuators that are needed must be lightweight and powerful, but they must also be precise in their movements. You have seen from the robotic arm models how you are not able to easily control the degree with which the grabber closes. One possibility to overcome this is through the use of pneumatic artificial muscles. Pneumatic artificial muscles are pressurized air bladders that are able to contract and shorten, or relax and lengthen, mimicking the action of real muscles.


Robotic exoskeleton legs could help you lift heavier objects.

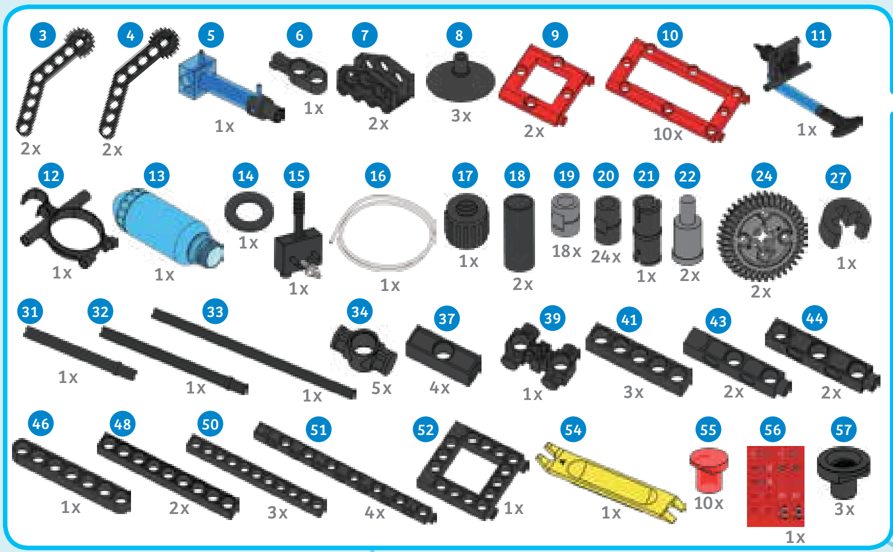

This robotic exoskeleton helps the woman move her legs.


A boy uses a robotic machine for walking therapy.

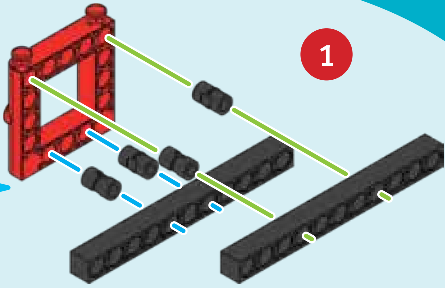
POWER

Another challenge is that there are currently few power sources that have enough energy to power an exoskeleton for more than a few hours. Non-rechargeable batteries have more energy but require transporting, storing, and replacement. On the other hand, rechargeable batteries require a system to recharge the battery. Most current prototype exoskeletons are tethered to a separate power source, which may be sufficient if the exoskeleton is used in a limited range, such as a home or factory. However, this would not work if the exoskeleton is required to go to locations that do not have access to a power source.

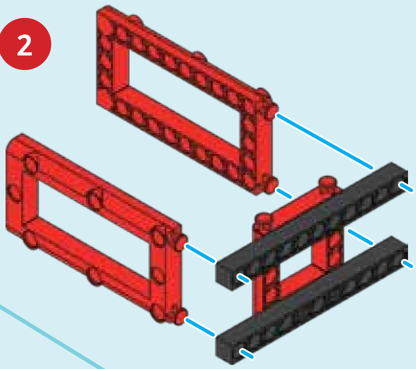
EXOSKELETON ARMS



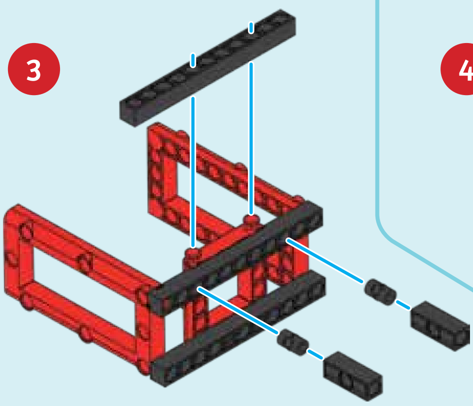
1



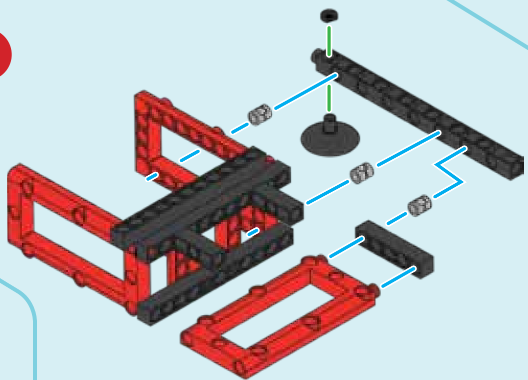
2



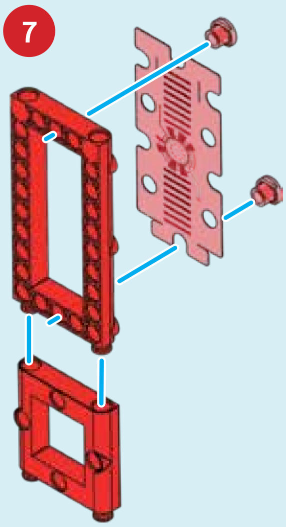
3



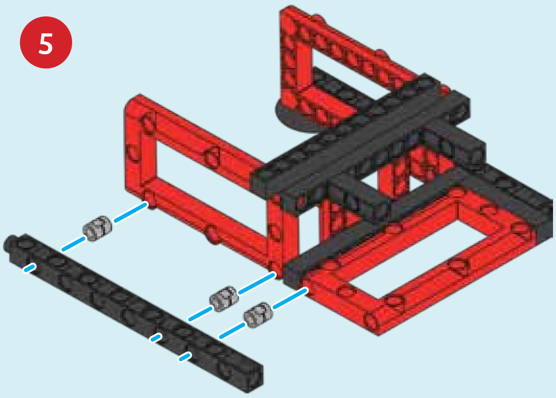
4



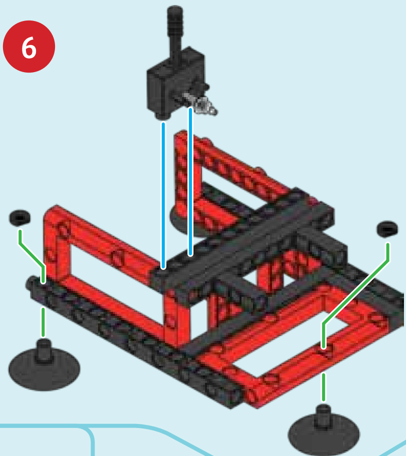
7



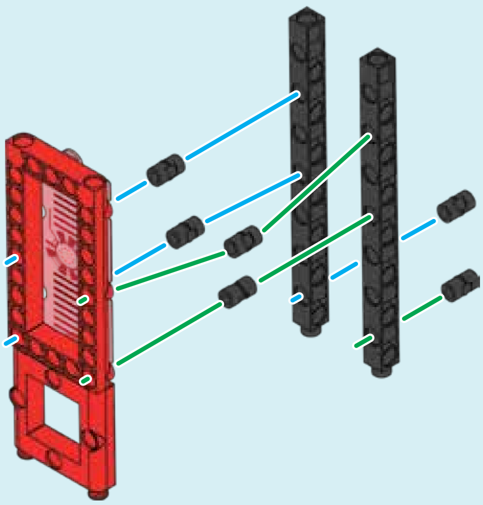
5



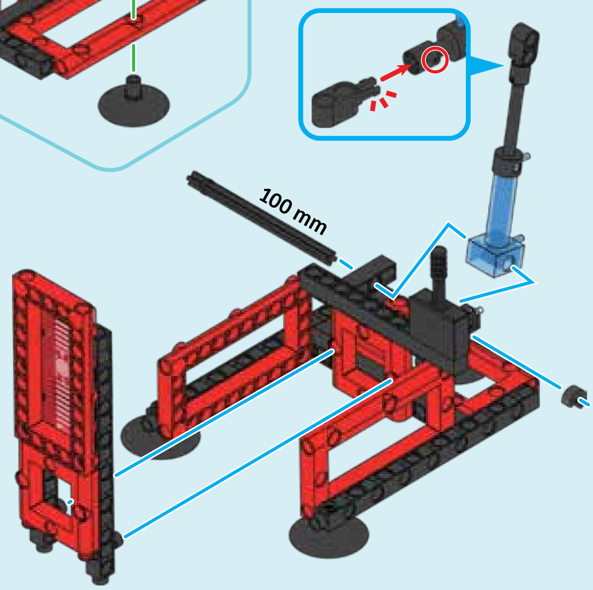
6



8

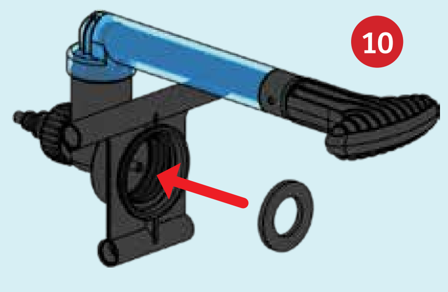


9

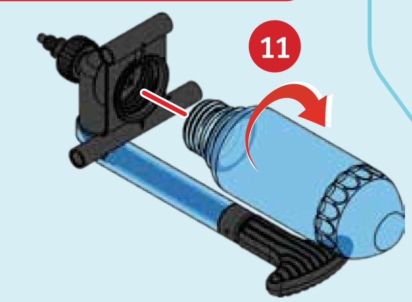


EXOSKELETON ARMS

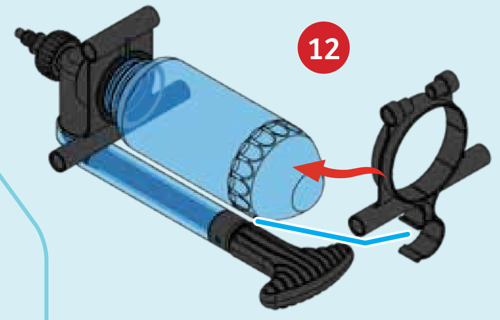
10



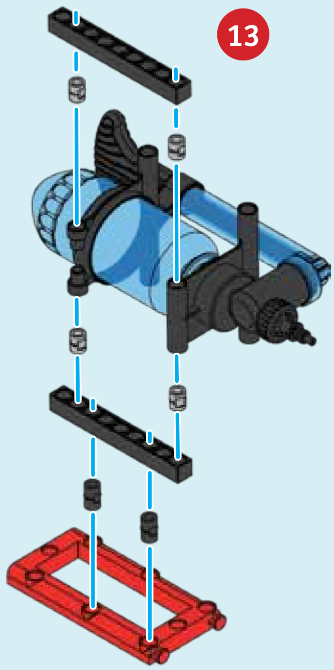
11



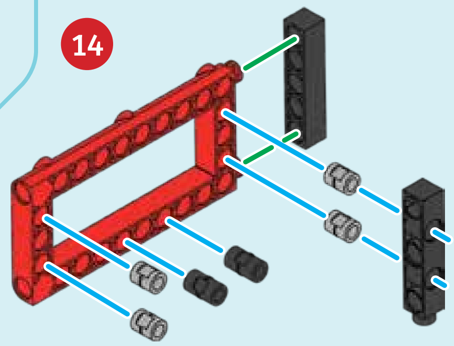
12



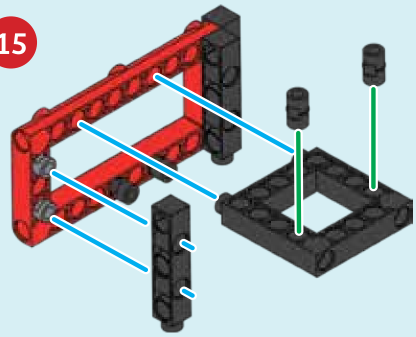
13



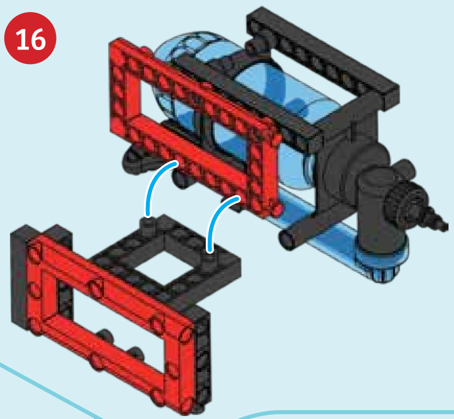
14



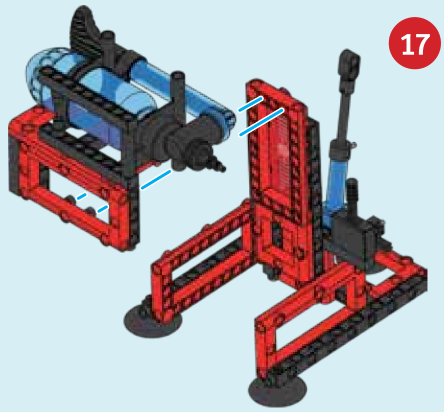
15



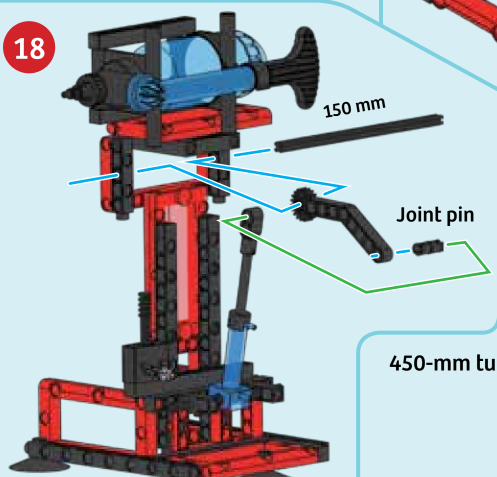
16



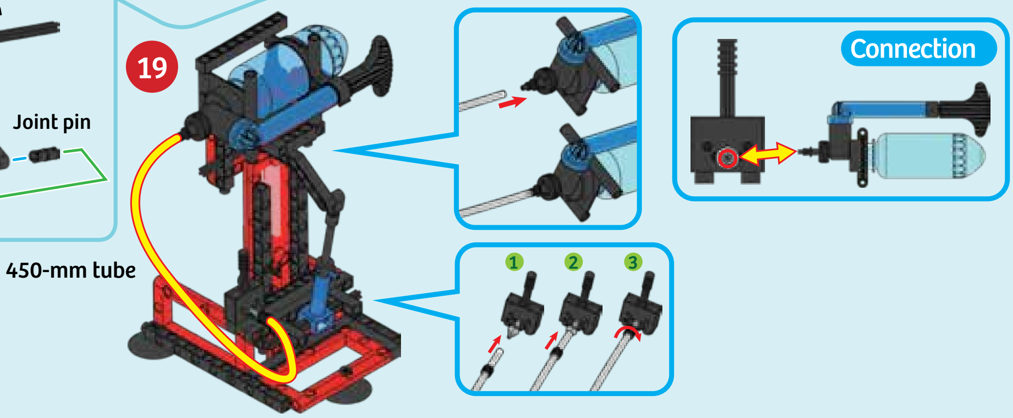
17



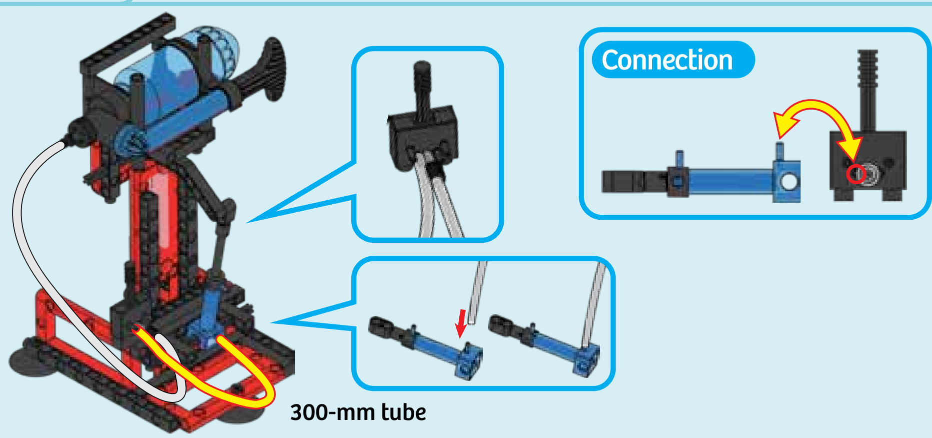
18



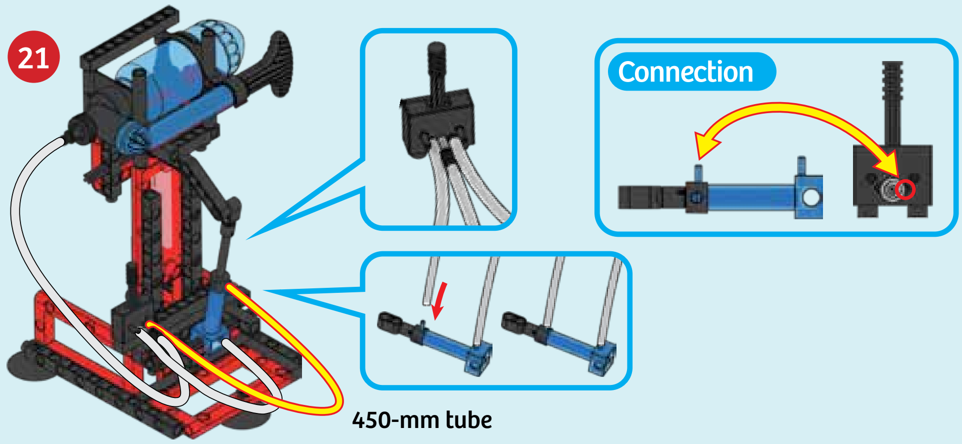
19



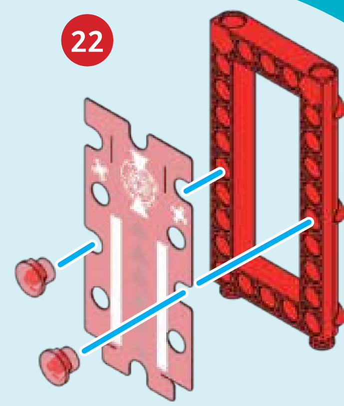
20



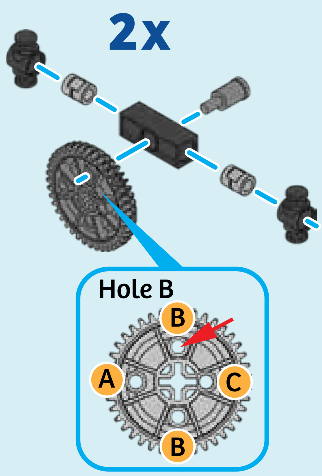
21



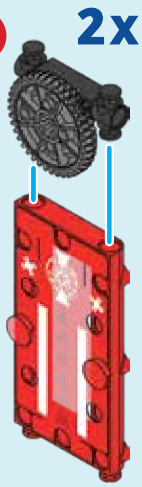
22



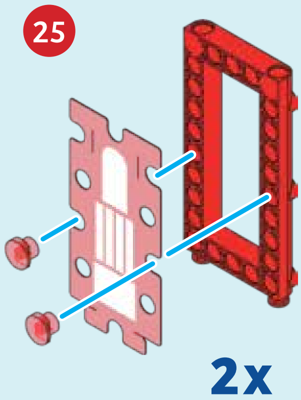
23



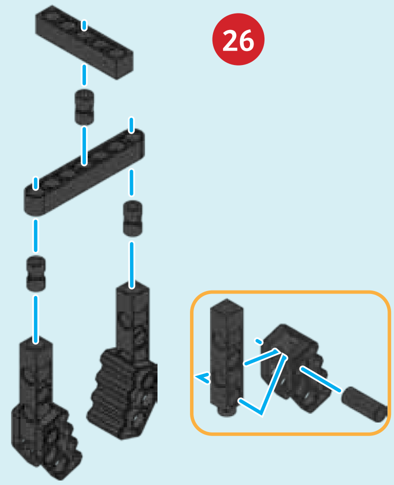
24



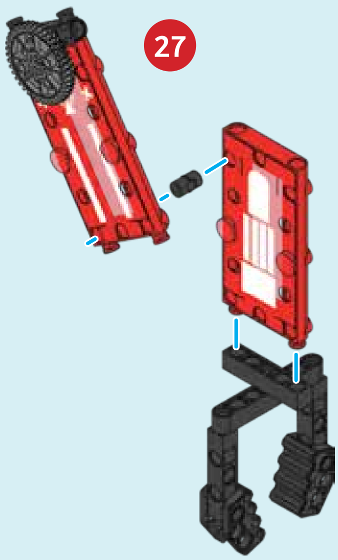
25



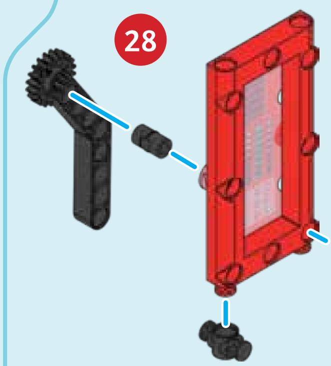
26



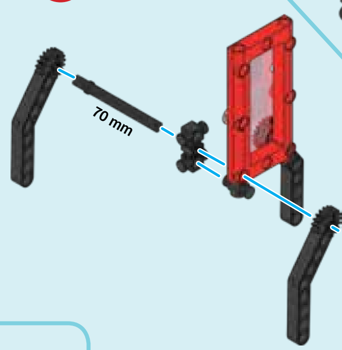
27



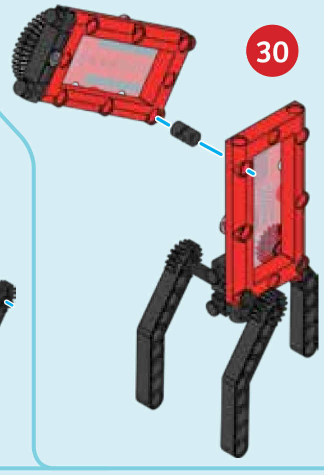
28



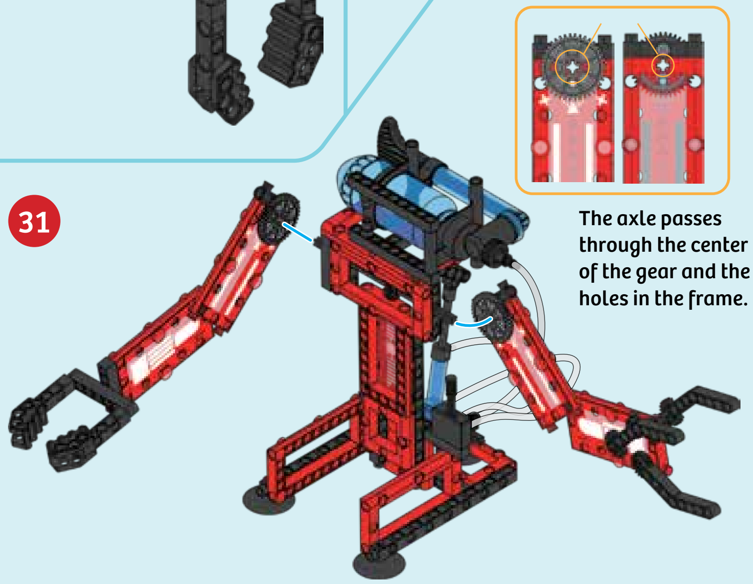
29



30

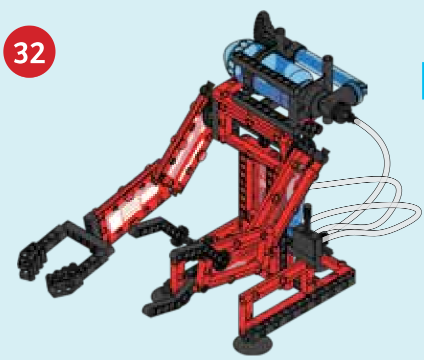


31



The axle passes through the center of the gear and the holes in the frame.

32

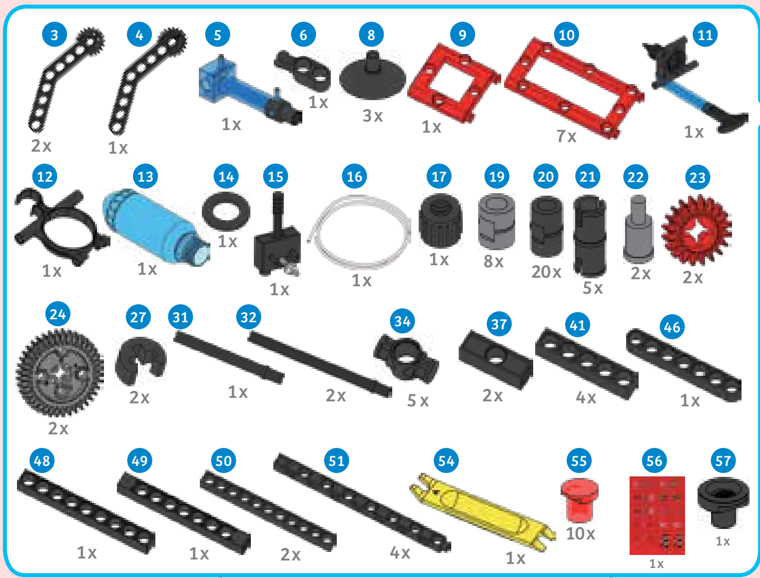


Done!

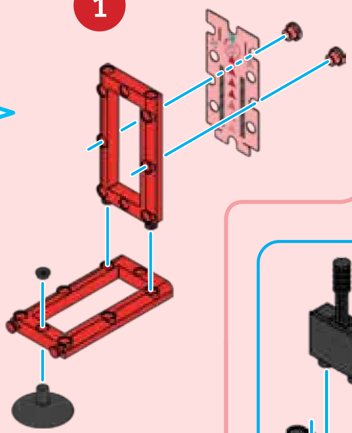
How to use:

1. Put the switch lever in the center position.
2. Pump about 30 times.
3. The arms will move when you move the switch left and right.

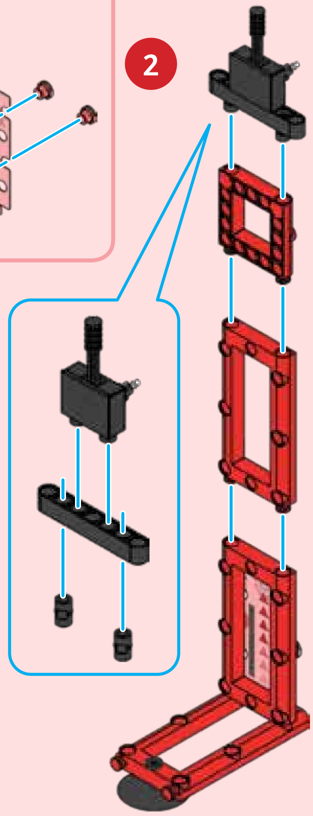
EXOSKELETON LEGS



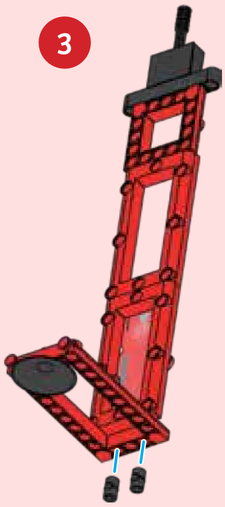
1



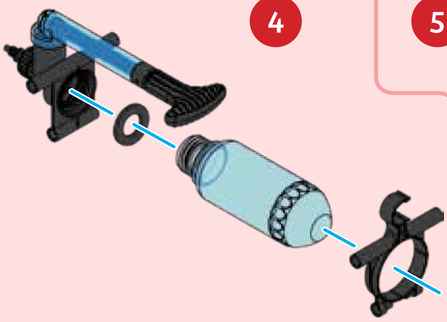
2



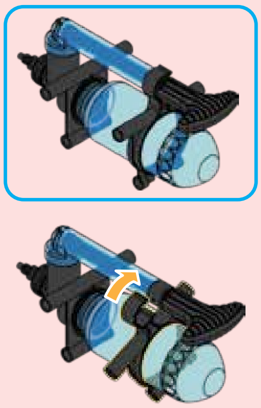
3



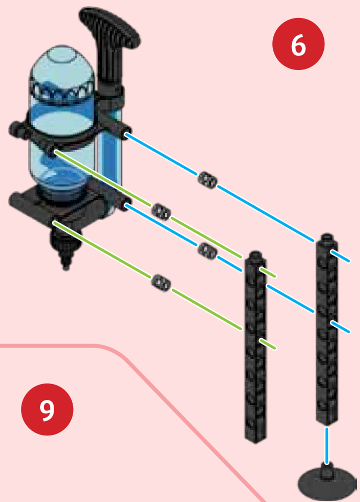
4



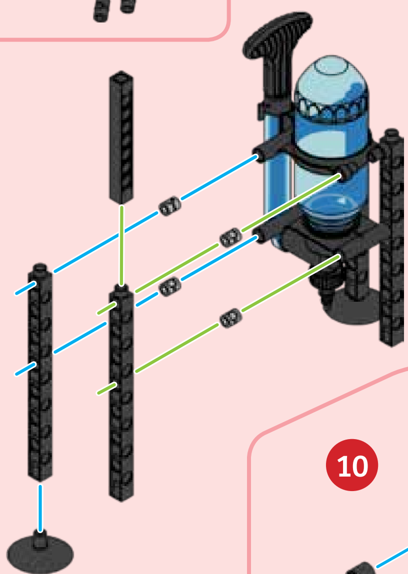
5



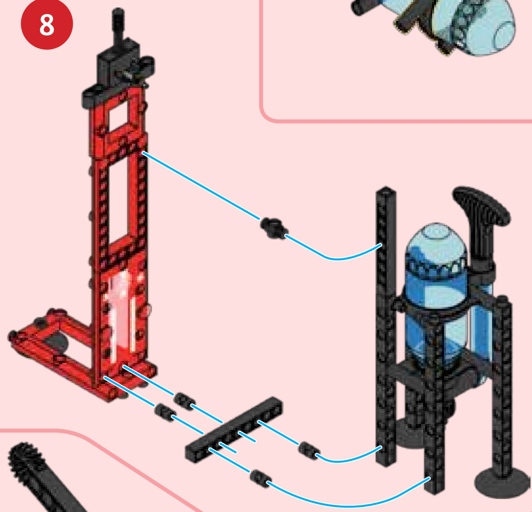
6



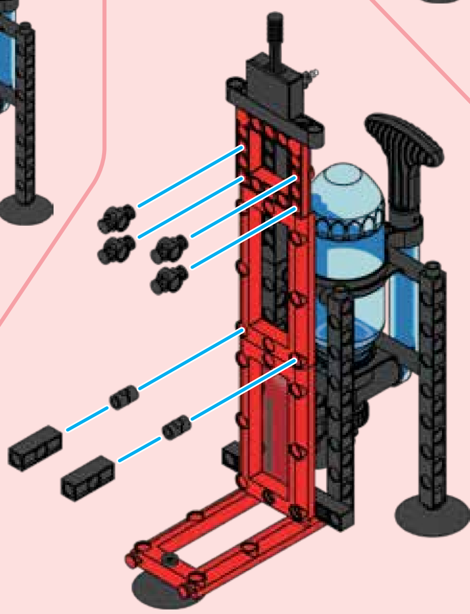
7



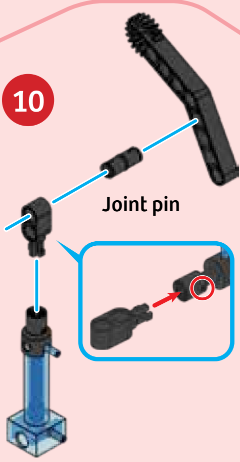
8



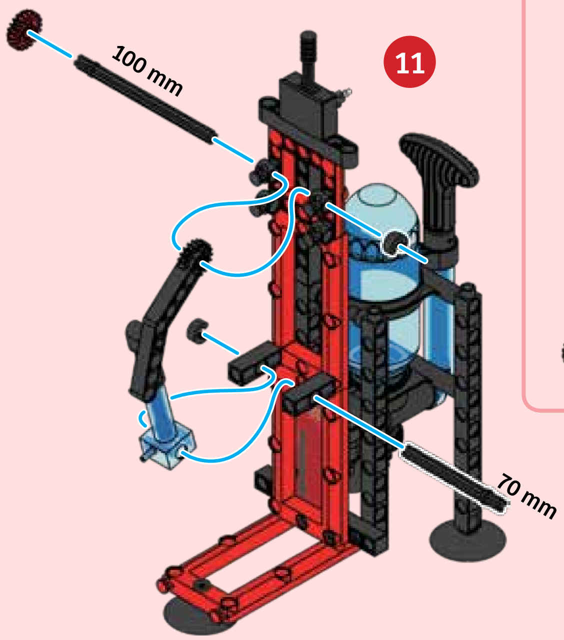
9



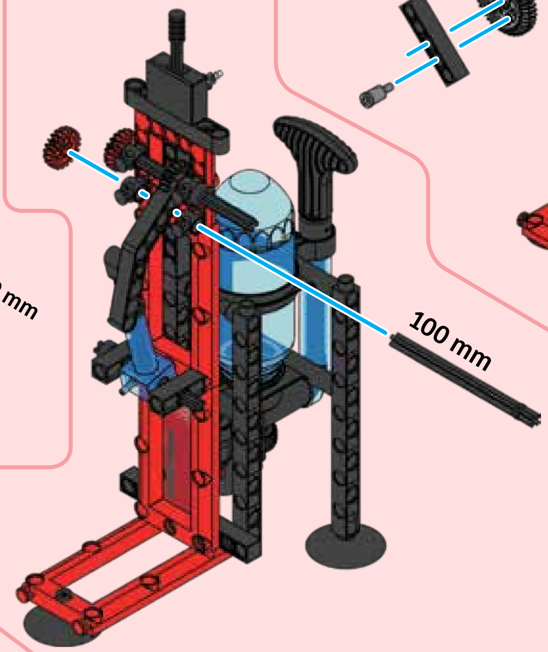
10



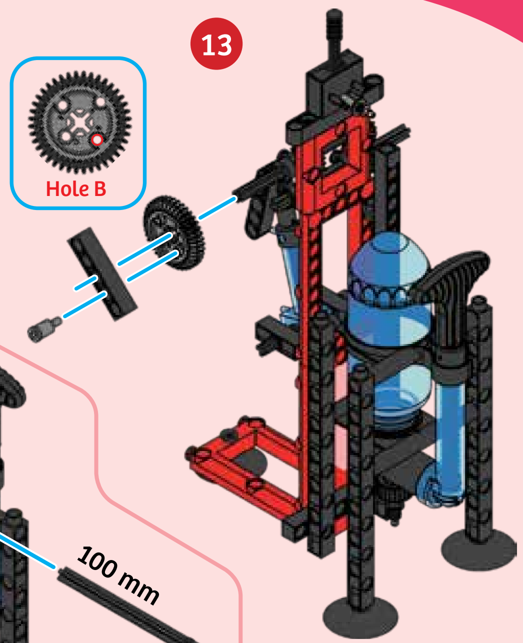
11



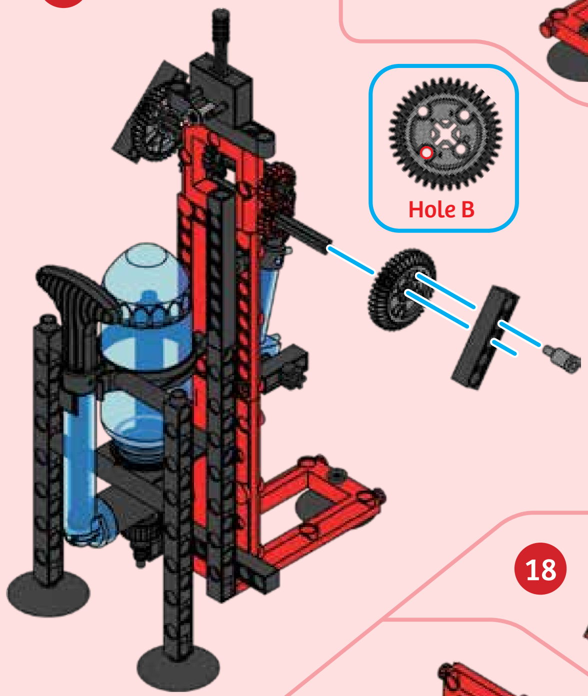
12



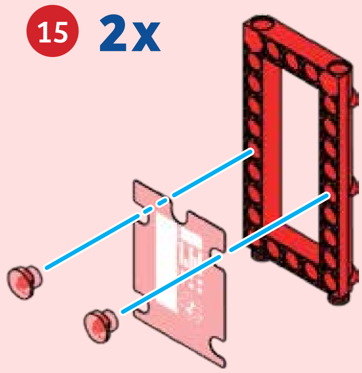
13



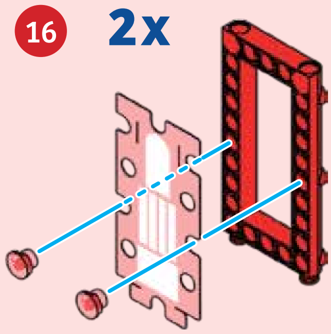
14



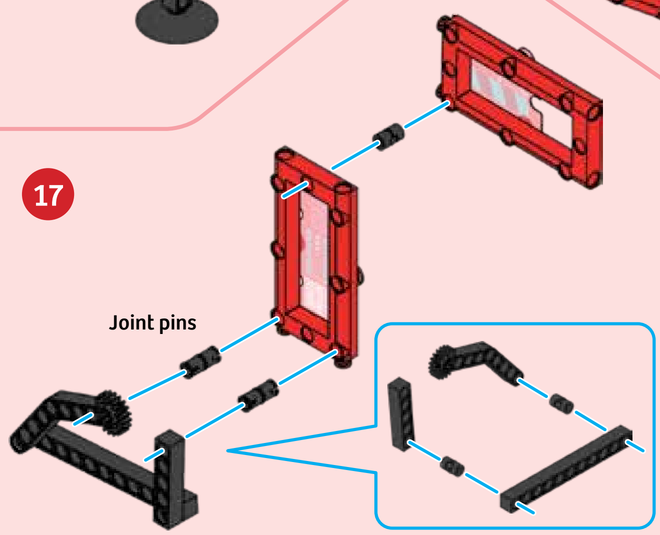
15 2x



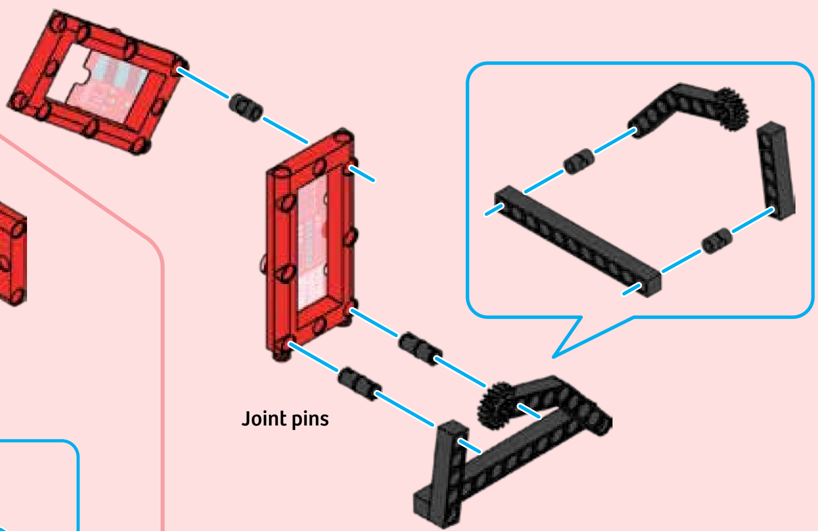
16 2x



17

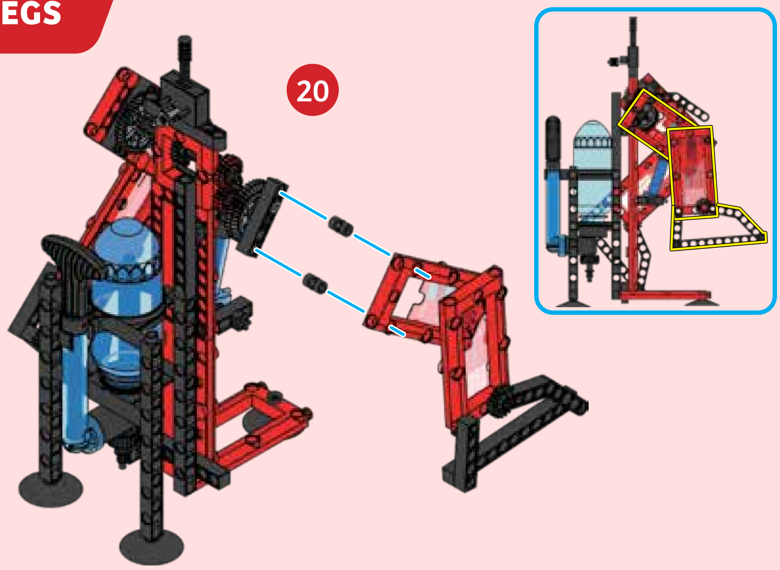


18

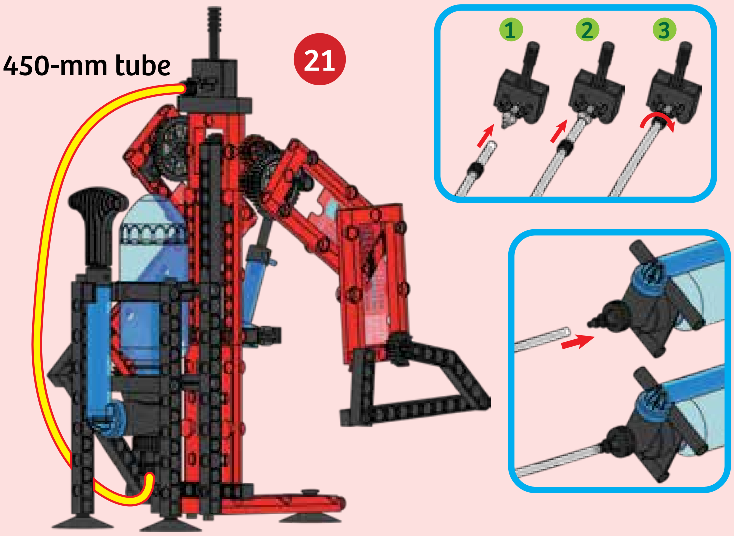


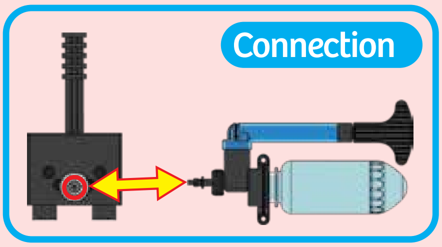
19

20

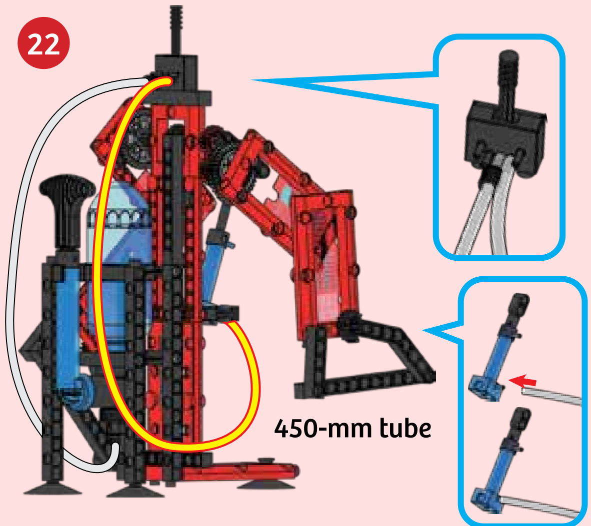


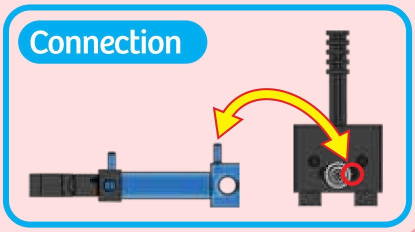
21



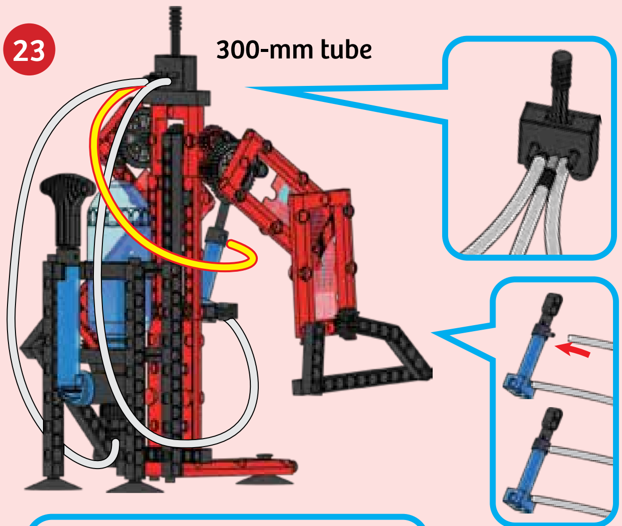


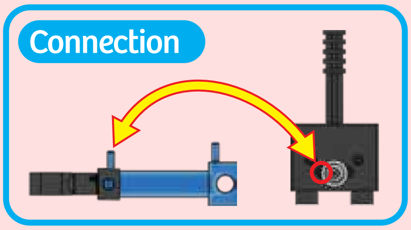
22





23

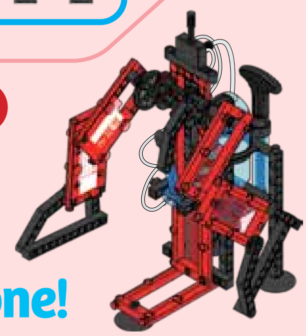




How to use:

1. Put the switch lever in the center position.
2. Pump about 30 times.
3. The arms will move when you move the switch left and right.

24



Done!

Kosmos Quality and Safety

More than one hundred years of expertise in publishing science experiment kits stand behind every product that bears the Kosmos name. Kosmos experiment kits are designed by an experienced team of specialists and tested with the utmost care during development and production. With regard to product safety, these experiment kits follow European and US safety standards, as well as our own refined proprietary safety guidelines. By working closely with our manufacturing partners and safety testing labs, we are able to control all stages of production. While the majority of our products are made in Germany, all of our products, regardless of origin, follow the same rigid quality standards.

Technical product development: Genius Toy Taiwan Co., Ltd., Taichung, Taiwan, R.O.C.
Author: Camille Duhamel
Manual Layout: Ashley Greenleaf
Editing: Ted McGuire
Additional Graphics: Ashley Greenleaf, Ted McGuire, Dan Freitas
Packaging: Dan Freitas

Manual design concept: Atelier Bea Klenk, Berlin
Manual illustrations: Genius Toy Taiwan Co., Ltd., Taichung, Taiwan, R.O.C., and Thames & Kosmos

Manual photos: askaja (all paper clips); Jamie Duplass (all tape strips); picsfive (all push pins); (all previous © fotolia.com); p. 2 (upper left) and p. 11 (lower right) (robotic arm over chassis) wellphoto, p. 5 (center left) (robotic arms welding) Tum2282, p. 5 (center right) (robotic arms on assembly line) Sasint, p. 17 (upper right) (robotic arm moving) xiaoliangge, p. 17 (upper left) (robotic Arm lifting car door) Nataliya Hora, p. 25 (lower right) (pneumatic cylinder) Tonhorm_2, p. 30 (boy in walking therapy) Olesia Bilkei, p. 30 (robotic leg illustration) chombosan, (all previous ©Adobe Stock); p. 2 (lower left) and p. 11 (upper right) (glass suction cup robotic arm) Oliver Sved, (all previous ©fotolia.com); p. 30 (woman in robotic exoskeleton) andresr, (all previous ©istock.com); p. 17 (lower left) (wrench turning) François GOGLINS (CC BY-SA 4.0);
All remaining images: Thames & Kosmos, Franckh-Kosmos Verlags-GmbH & Co. KG, and Genius Toy Taiwan Co., Ltd.

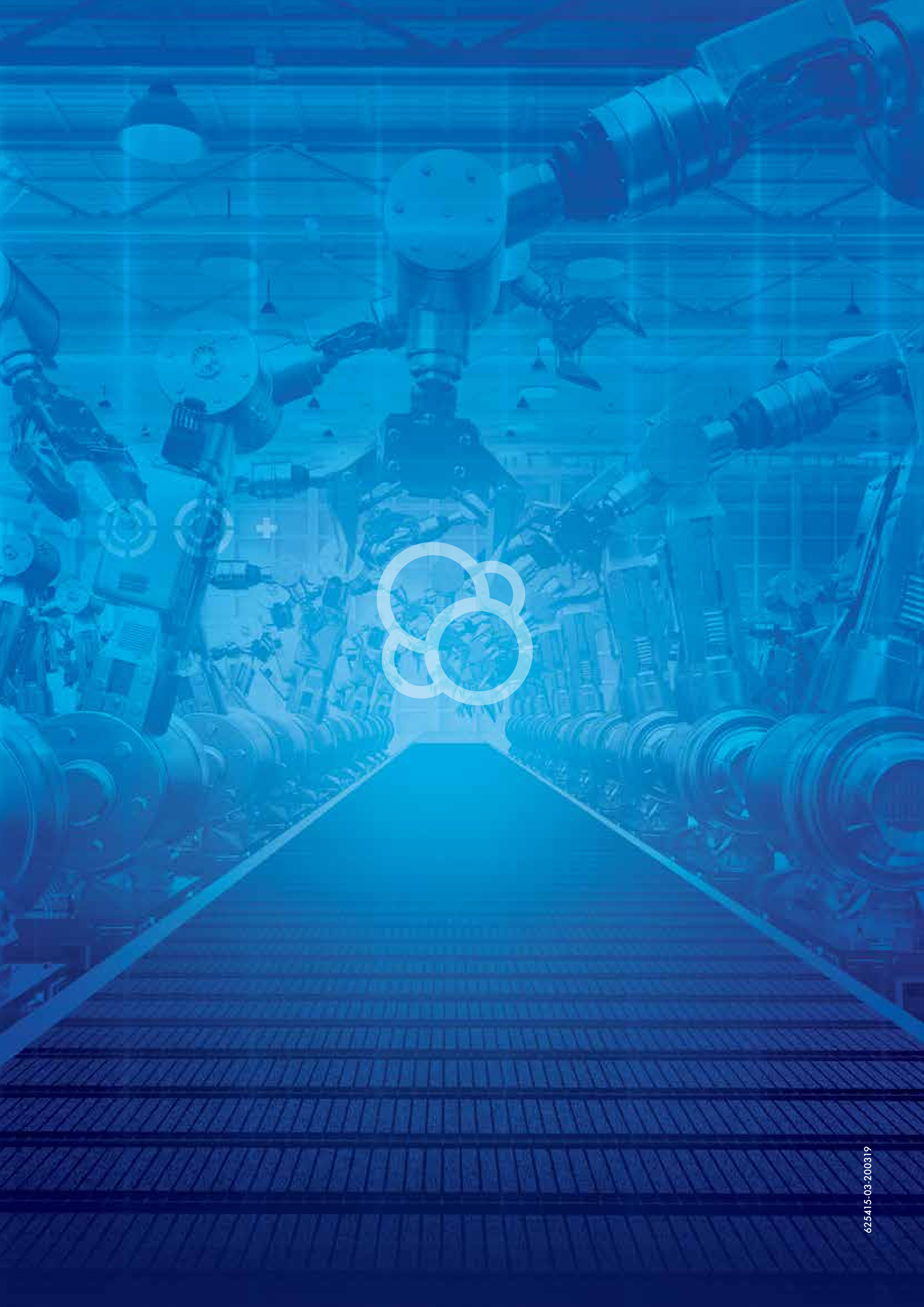
The publisher has made every effort to locate the holders of image rights for all of the photos used. If in any individual cases any holders of image rights have not been acknowledged, they are asked to provide evidence to the publisher of their image rights so that they may be paid an image fee in line with the industry standard.

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

Distributed in United Kingdom by Thames & Kosmos UK LP. Cranbrook, Kent TN17 3HE
Phone: 01580 713000; Web: www.thamesandkosmos.co.uk

We reserve the right to make technical changes.

Printed in Taiwan / Imprimé en Taiwan



625415-03-200319