EXPERIMENT MANUAL

Catapult Engineering

6-IN-1 MAKER KIT

THAMES & KOSMOS

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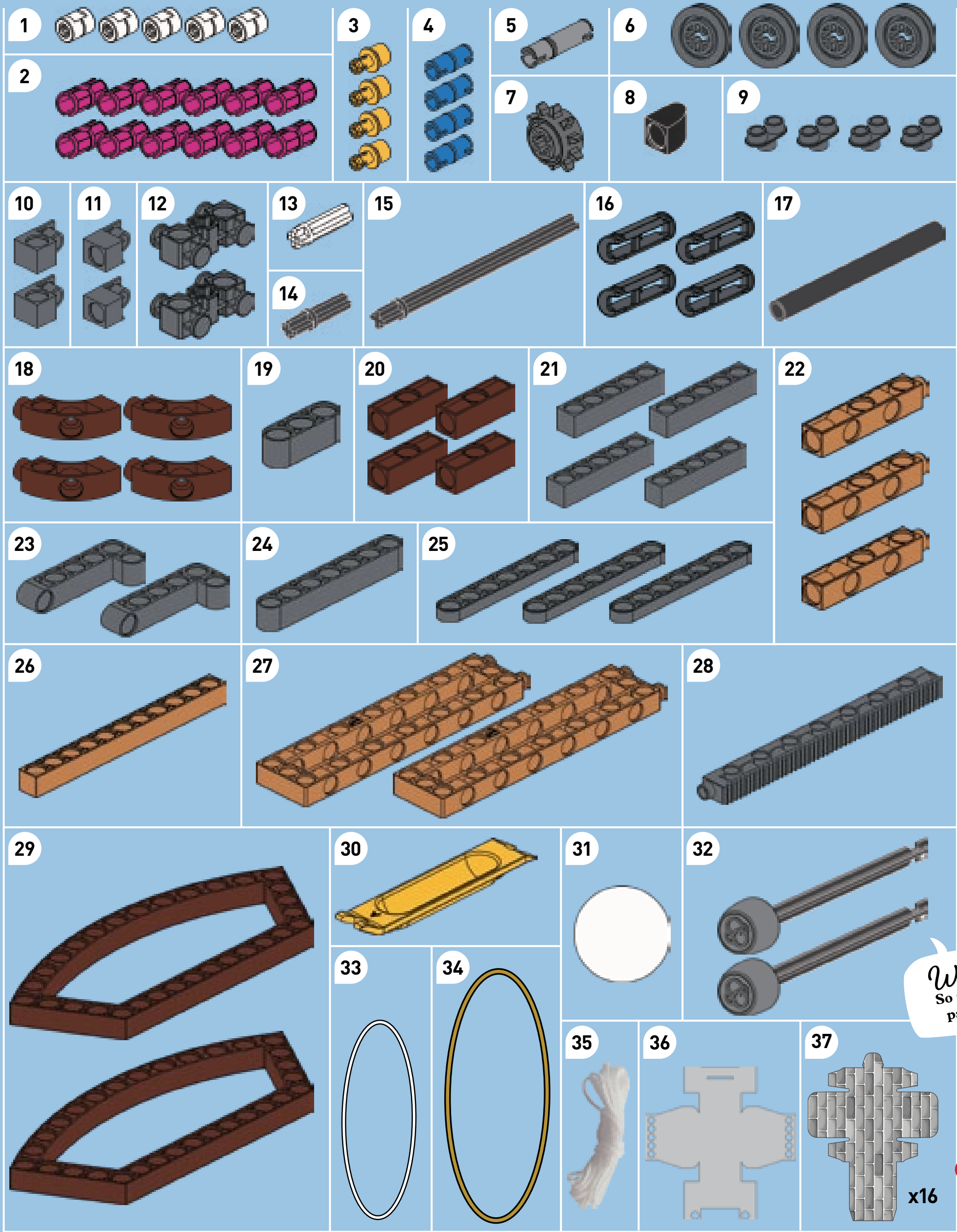
KIT CONTENTS

What's inside your experiment kit:



Wow! So many parts!

CONTENTS

TIP

ADDITIONAL EXPERIMENTS CAN BE FOUND AT THE END OF EACH MODEL ON PAGES 9, 15, 19, 24, 27, AND 32.

YOU WILL ALSO NEED:
Metal pie pan or other durable dish, tape, measuring stick or tape measure

Checklist:

✓	No.	Description	Quantity	Part No.
○	1	Short anchor pin	5	7344-W10-C2W
○	2	Connector pin	12	1187-W10-E1K
○	3	Shaft plug	4	7026-W10-H1Y
○	4	Joint pin	4	7413-W10-T1B
○	5	Long joint pin	1	7413-W10-U1S
○	6	Large pulley wheel	4	7344-W10-N3S1
○	7	Small sprocket wheel	1	3569-W10-D2S1
○	8	Nose piece	1	7402-W10-C2D
○	9	Two-to-one converter	4	7061-W10-G1S3
○	10	90-degree converter - X	2	7061-W10-X1S3
○	11	90-degree converter - Y	2	7061-W10-Y1S3
○	12	3-hole bolt rod	2	7406-W10-B1S1
○	13	Motor axle	1	7026-W10-L1W
○	14	Axle, 30-mm	1	7413-W10-N1D
○	15	100-mm axle	1	7413-W10-L2D
○	16	Static connector tube	4	7066-W10-A1S
○	17	Tube, 80 mm	1	7337-W16-A1D
○	18	Curved rod	4	7061-W10-V1T
○	19	3-hole wide rounded rod	1	7404-W10-C1S3
○	20	3-hole cross rod	4	7026-W10-X1T
○	21	5-hole rod	4	7413-W10-K2S2
○	22	5-hole dual rod C	3	7413-W10-X1T
○	23	5-hole L rod	2	7406-W10-B2S1
○	24	7-hole wide rounded rod	1	7404-W10-C2S3
○	25	7-hole flat rounded rod	3	7404-W10-C3S3
○	26	11-hole rod	1	7413-W10-P1T1
○	27	13x3 Frame	2	7406-W10-A1T
○	28	Long rack gear	1	7061-W10-T2S
○	29	Curved frame	2	7392-W10-I1T
○	30	Anchor pin lever	1	7061-W10-B1Y
○	31	Large foam ball	1	K30#7366-2
○	32	Crossbow bolt	2	7406-W85-A-US
○	33	Rubber band, small	1	R10-02
○	34	Rubber band, large	1	R10-28
○	35	500-mm string	1	R39#7063
○	36	Die-cut counterweight	1	K16#7086
○	37	Die-cut knockdown block	16	K16#7086-1

Ready? Let's get building!

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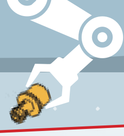


SAFETY INFORMATION

WARNING!

Not suitable for children under 3 years. Choking hazard — small parts and small balls may be swallowed or inhaled. Strangulation hazard — long string and long rubber bands may become wrapped around the neck. Keep the packaging and instructions as they contain important information.

WARNING! Do not aim at eyes or face.
Do not aim the projectiles (crossbow bolts and foam balls) toward other people or animals. Make sure people and animals are well out of the potential path of the projectiles.

WARNING! Do not discharge an object other than the projectiles included with this kit.

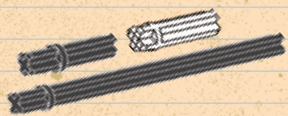
TIPS

Dear Explorers,

Please read these notes carefully. This information will help you avoid possible risks and get the most out of this experiment kit.

ANCHOR PINS AND CONNECTORS

TAKE A CAREFUL LOOK AT THE DIFFERENT ASSEMBLY COMPONENTS. WHITE ANCHOR PINS, PINK CONNECTOR PINS, YELLOW SHAFT PLUGS, AND BLUE JOINT PINS ALL LOOK PRETTY SIMILAR AT FIRST GLANCE. WHEN YOU ASSEMBLE THE MODELS, IT'S IMPORTANT TO USE THE RIGHT ONES.

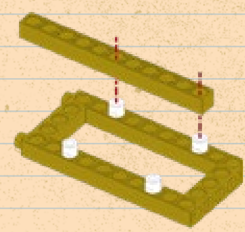


AXLES

THE BUILDING SYSTEM CONTAINS AXLES (ALSO CALLED SHAFTS) OF VARIOUS LENGTHS. WHEN ASSEMBLING THE MODEL, ALWAYS BE SURE THAT YOU'RE USING THE RIGHT ONE.

PULLEYS AND RATCHETS

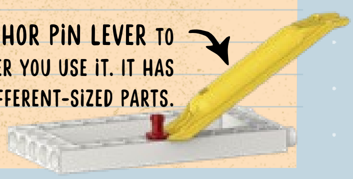
IF PULLEYS OR RATCHETS ARE MOUNTED TOO TIGHTLY AGAINST OTHER COMPONENTS, THEY CAN BE HARD TO TURN. IF YOU LEAVE A GAP OF ABOUT 1 MM BETWEEN THE RATCHET OR PULLEY AND AN ADJACENT COMPONENT, IT WILL TURN EASILY.



CONNECTING FRAMES AND RODS

USE THE ANCHOR PINS TO CONNECT FRAMES AND RODS.

YOU WILL USE **THE ANCHOR PIN LEVER** TO DISASSEMBLE EACH MODEL AFTER YOU USE IT. IT HAS **TWO DIFFERENT ENDS** FOR DIFFERENT-SIZED PARTS.



IMPORTANT INFORMATION

Dear parents and adults,

Children want to explore, understand, and create new things. They want to try new things and they want to do this on their own. They want to gain knowledge! They can do all of this with Thames & Kosmos experiment kits. With every single experiment, they grow smarter and more knowledgeable.

— Physics is an exciting and varied science that is not hard to understand, especially when you use fun models to demonstrate physics principles in action. It can be a lot of fun to figure out the astonishing physical phenomena that we encounter every day and to put this understanding to use.

— This experiment kit and the working models you can build with it introduce your child to physics concepts including energy, motion, and forces. With its wealth of simple examples, your child will gain basic insights into the world of physical units and laws — which will help them to understand and engage more deeply in the lessons taught in school.

— The individual experimental models are assembled step by step using an adjustable building system. It will require a little practice and patience at first. And your child will be particularly happy to have your help with the models that they find more difficult.

— Some of the experiments will require common items from your household, including a dish, tape, measuring stick, coins, tissue, paper clips, and a stopwatch. Help your child select these items.

We hope you and your child have a lot of fun with Catapult Engineering!

Have fun!

You will need

Metal pie pan or other durable dish, tape, measuring stick or tape measure

Here's how

1. Place a metal pie pan upside down on the floor. This is your bull's eye target.
2. Place a piece of tape 10 or so feet away from the pie pan. This is where you will stand when testing out your catapults and crossbows.

Low accuracy and low precision

Low accuracy and high precision

High accuracy and low precision

High accuracy and high precision

WHAT'S HAPPENING?

When you do the experiments with your catapults, you should think about the accuracy and precision of where the projectiles land. **Accuracy** is how close your results (or shots) are to your target value — in this case, the center of the target. **Precision** is how often you are able to get the same value, or have your projectile land in the same place. Look at the pictures to the right to see how accuracy and precision are related. Accuracy and precision are both critical concepts in the scientific world.

As you perform the experiments for each model, think about how the changes affect your precision and accuracy. Keep a record of your results for the different experiments.

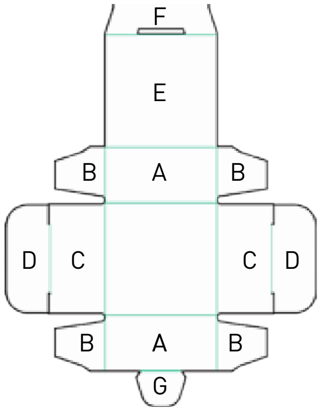
KNOCKDOWN BLOCKS & CASTLE WALLS

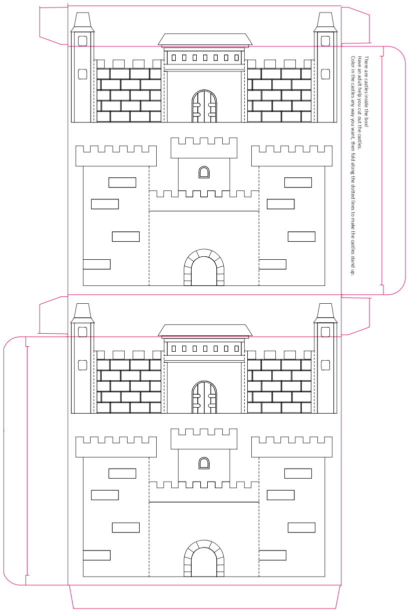
Knockdown Blocks

Your kit includes 16 knockdown blocks for you to build, stack, and knock over with the included projectiles.

Here's how

1. Turn over the die-cut sheet so you see the white side. Fold the two A flaps upward toward the middle.
2. Fold all four B flaps inward.
3. Fold the two C flaps upward.
4. Fold down the two D flaps 90 degrees so they are perpendicular to the C flaps.
5. Fold down F and then fold over E so that E covers the box and F tucks inside.
6. Push tab G into the slit.





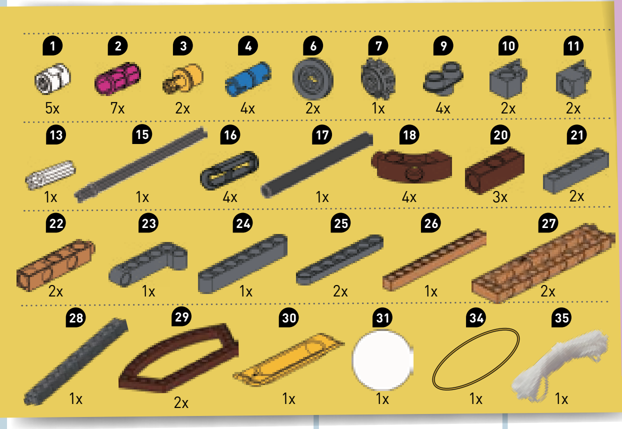
Castle Walls

There are illustrations of castle walls on the inside of the Catapult Engineering box. You can use these as targets for the included projectiles.

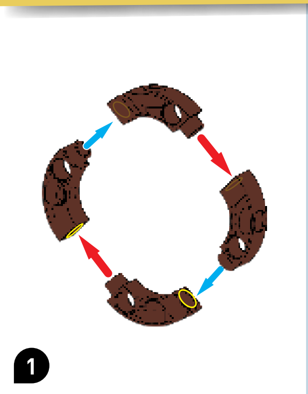
Here's how

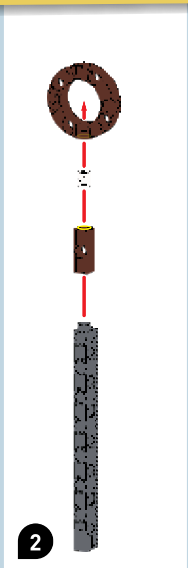
1. Open up the box along the vertical seam.
2. Have an adult carefully cut out the castle walls.
3. Personalize the castle walls by coloring them in or adding other decorations.
4. Fold the castles along the dotted lines so they stand up.

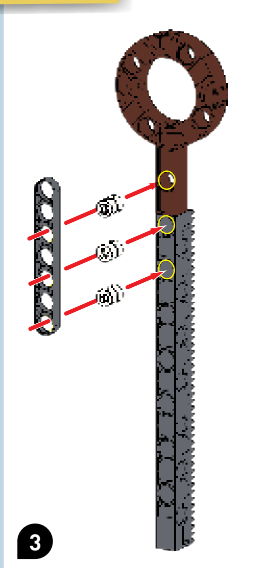
MODEL 1: CATAPULT

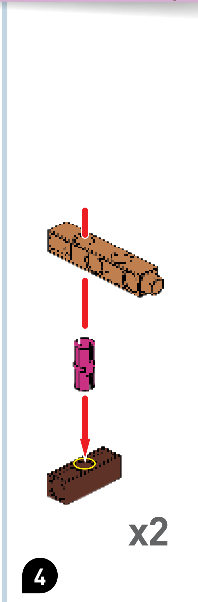


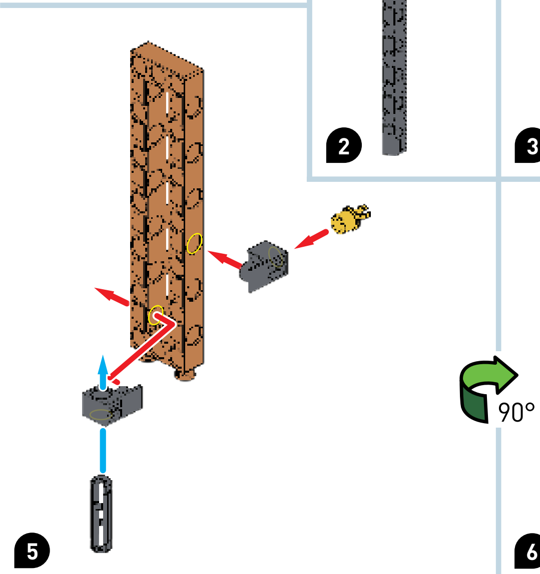
The term catapult comes from the Ancient Greek word Katapeltes. The Ancient Greek Dionysius the Elder of Syracuse invented the catapult around 400 BCE. Early catapults were larger versions of crossbows.

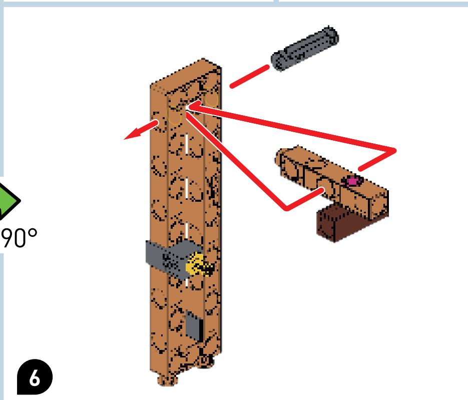


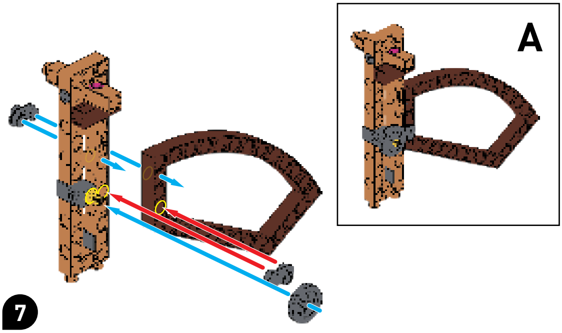












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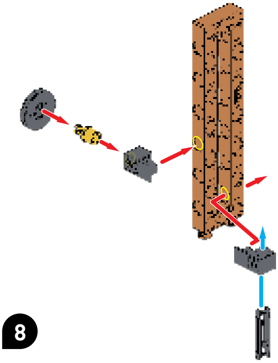

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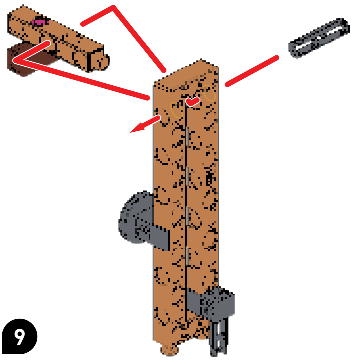

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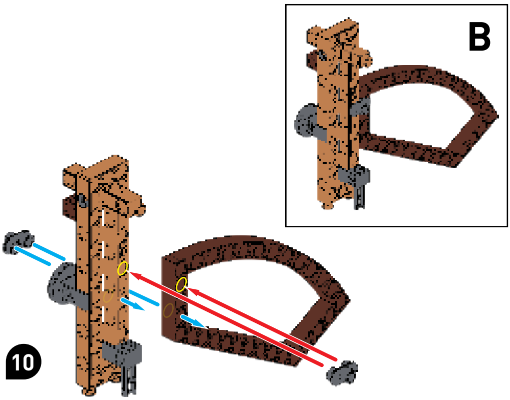

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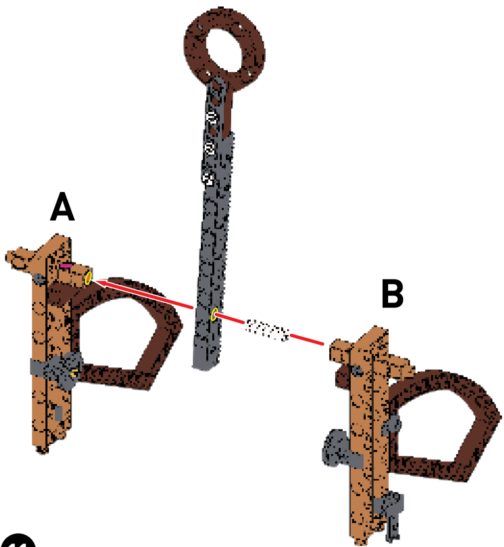

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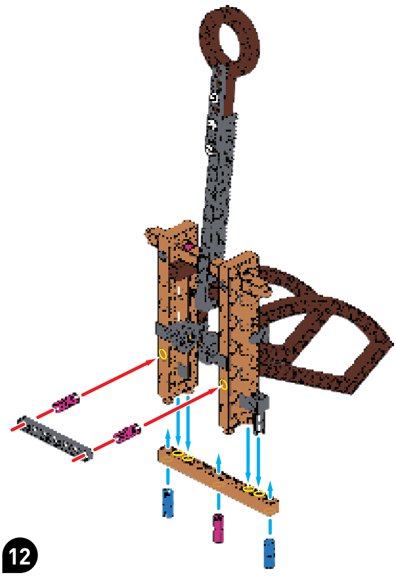

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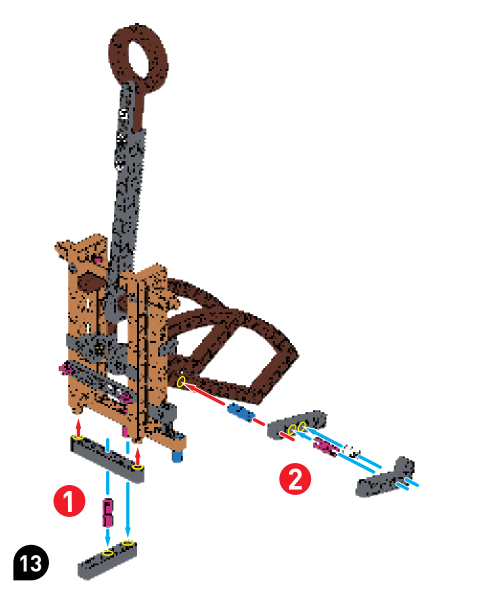
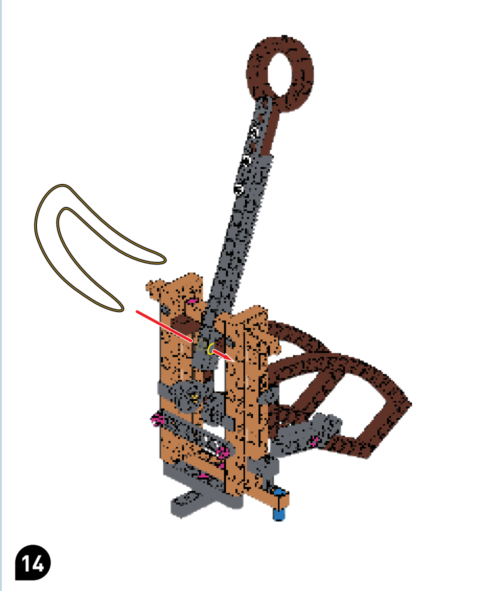

1
2
13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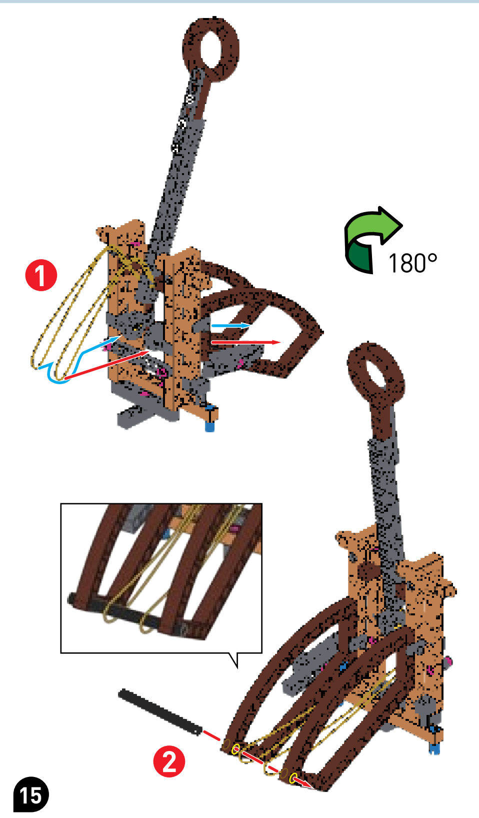
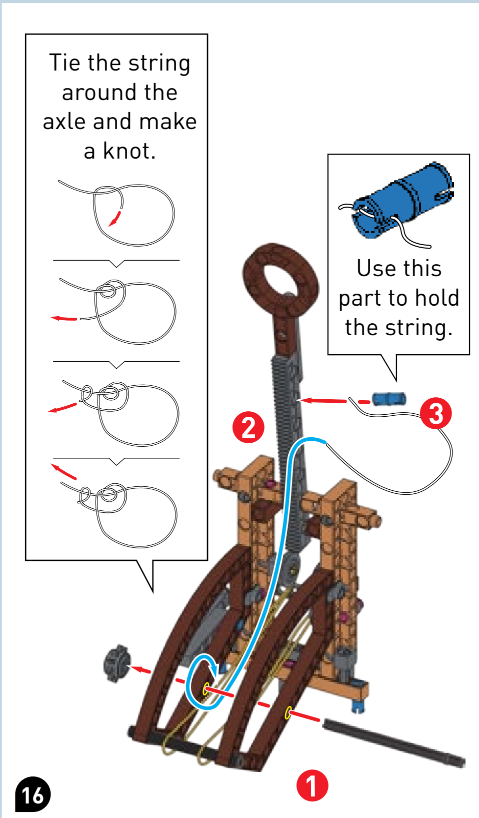

1
180°
2
15


Tie the string around the axle and make a knot.
Use this part to hold the string.
2
3
1
16

EXPERIMENT 1

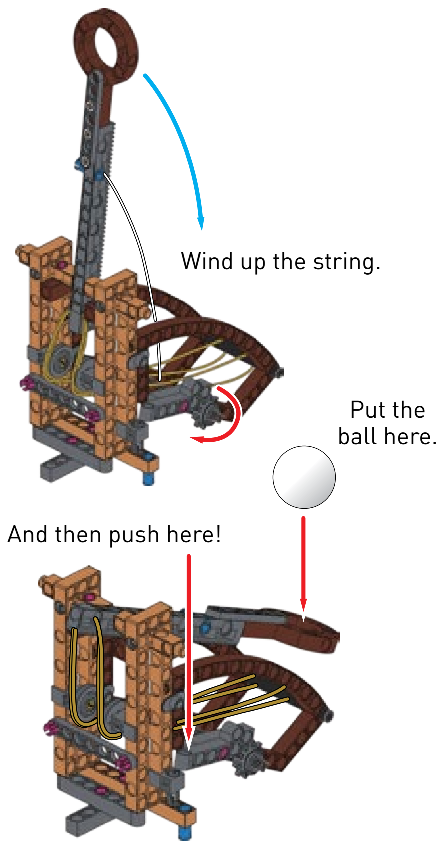
How does varying the amount the elastic is stretched impact the launch?

Here's how

1. Fire the foam ball at the target you made in the preparation steps.
2. Vary how far you pull the arm back each time. Mark the distance that the foam ball goes using a piece of tape.

>> What do you notice about the velocity (speed) of the projectile when you stretch the rubber band more?

>> What are you changing when you pull the arm of the catapult further back?



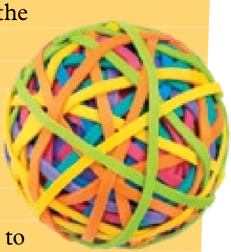
WHAT'S HAPPENING?

When the rubber band is stretched, it wants to return to its original shape. This property is called elasticity. To stretch the rubber band requires energy.

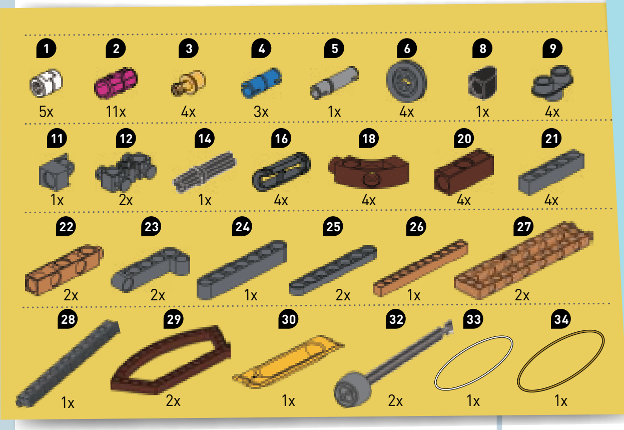
When the rubber band is stretched before releasing the arm of the catapult, all the energy is stored energy, or **potential energy.**

When you release the rubber band, the potential energy is converted into **kinetic energy,** or the energy of motion.

This is why when you stretch the rubber band more, the ball flies farther — because you are adding more energy to the rubber band.

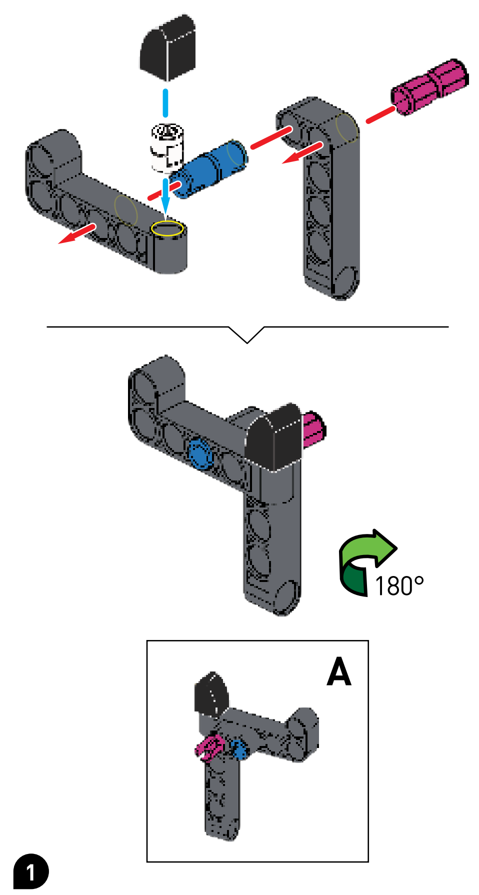


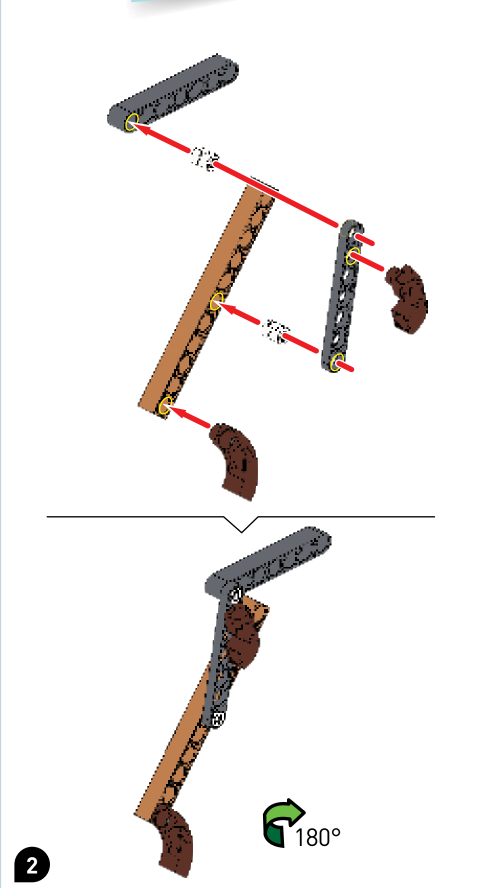
MODEL 2: REVERSE-DRAW CROSSBOW

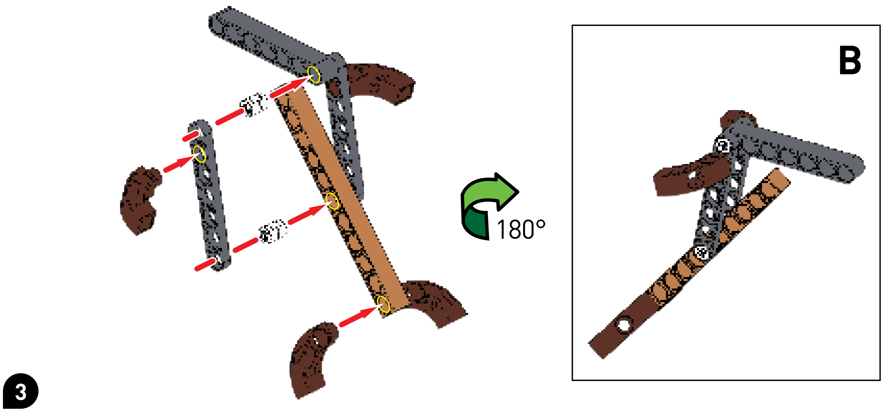


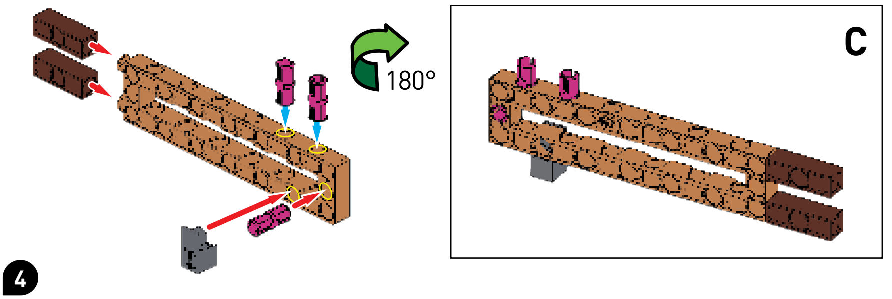
A modern innovation in crossbow design is the placement of the limbs at the rear of the stock. This arrangement provides several advantages over the classic crossbow design. Compare the design to the more traditional crossbow (model 4).

One advantage is that the modern crossbow allows the string to be in contact with the bolt for a longer amount of time. This means that more energy is transferred from the string to the bolt, giving it a greater velocity.






180°
B
3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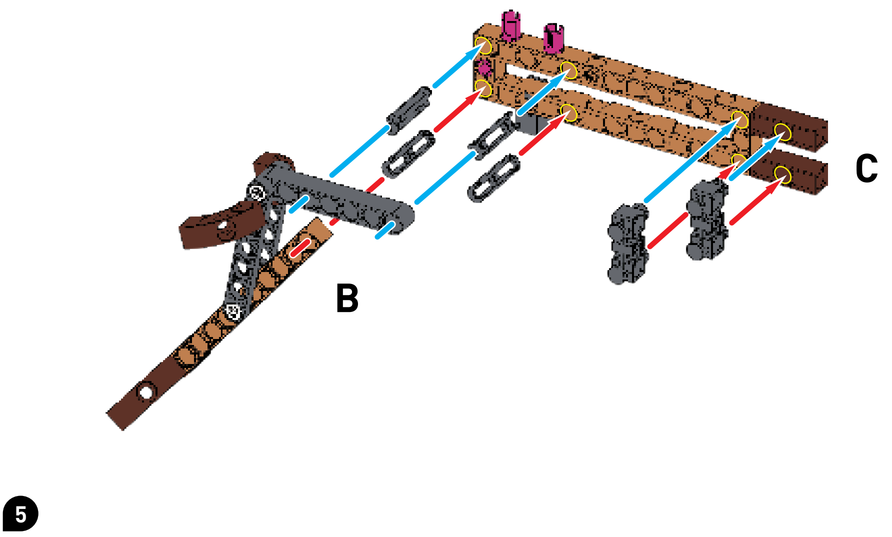
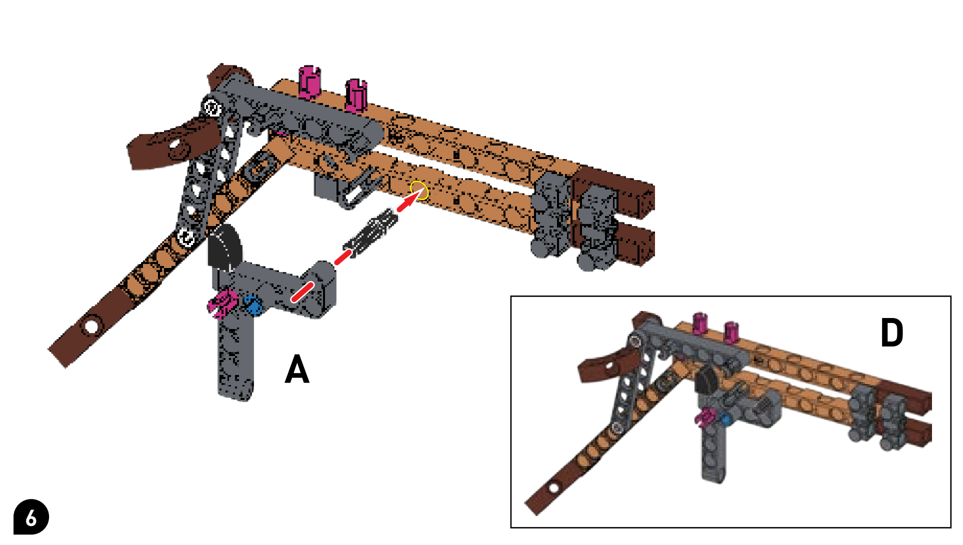
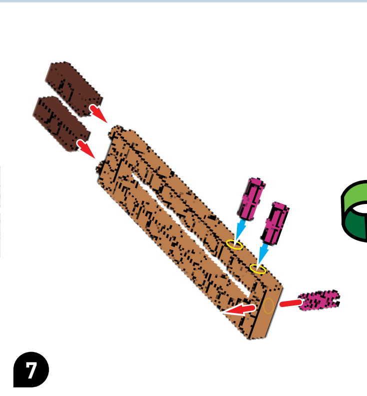
C
4


B
C
5


A
D
6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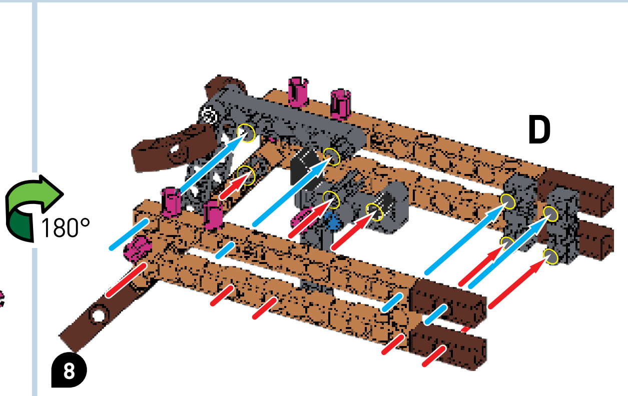
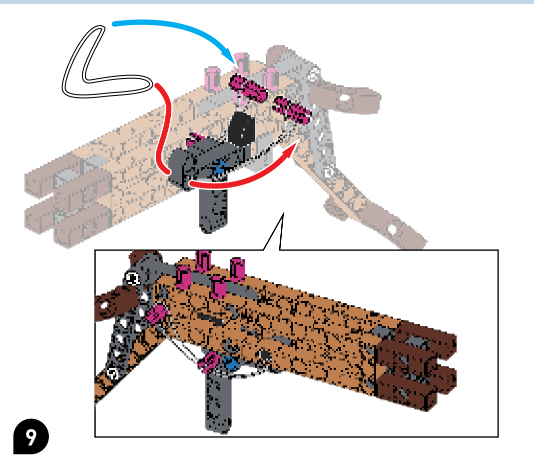

180°
D
8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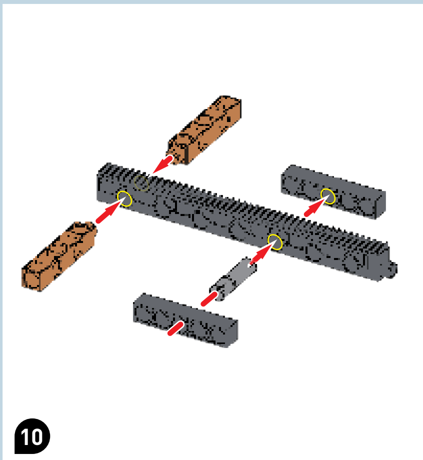
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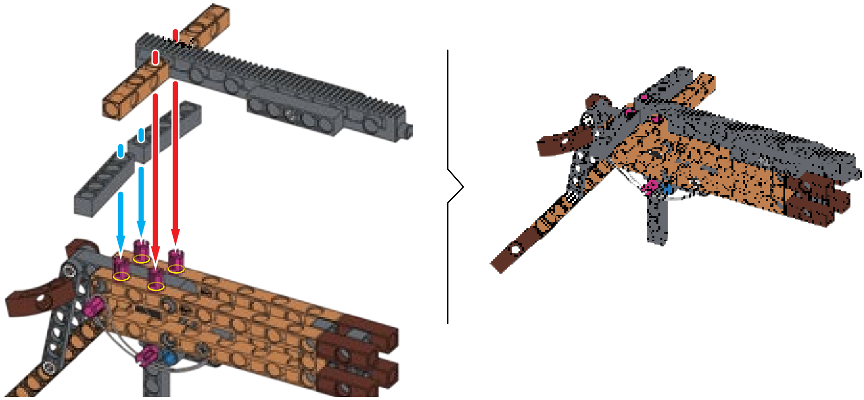

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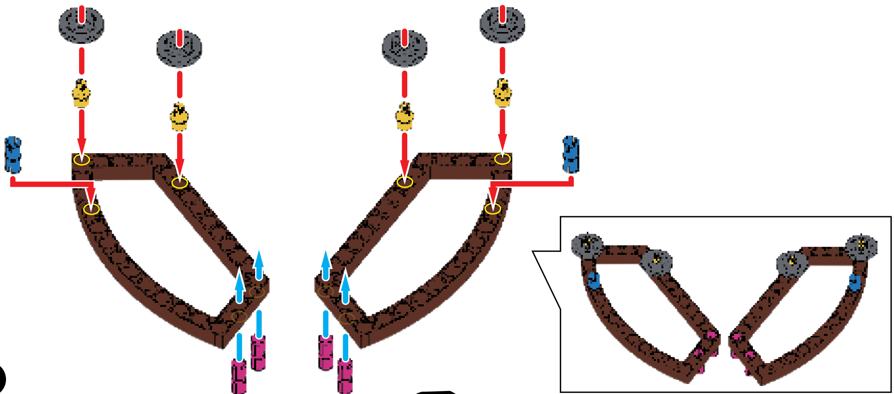

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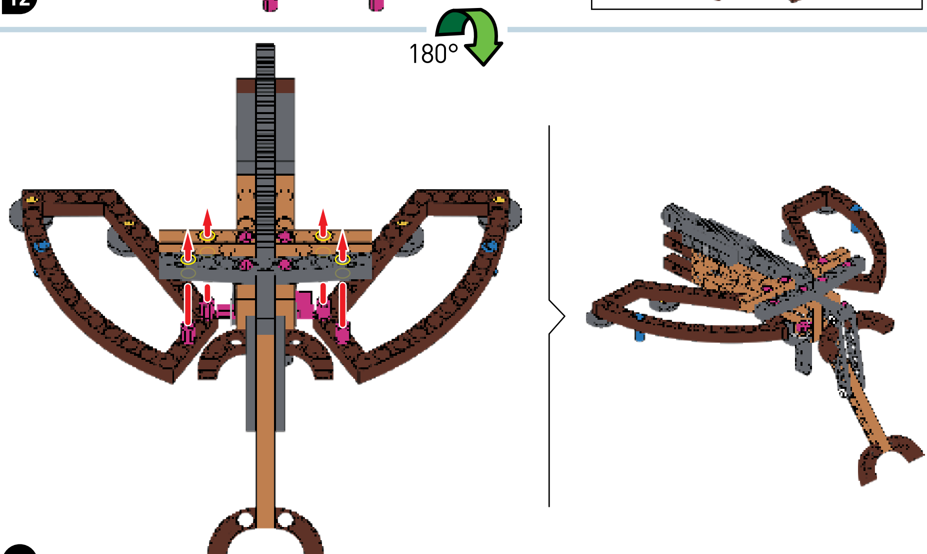

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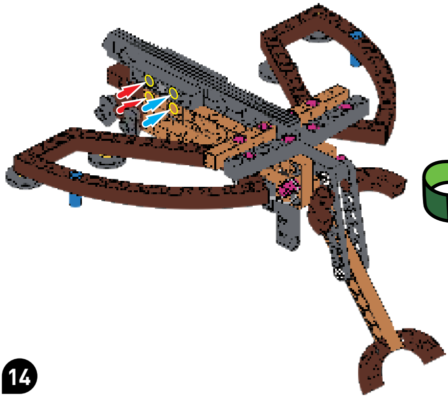

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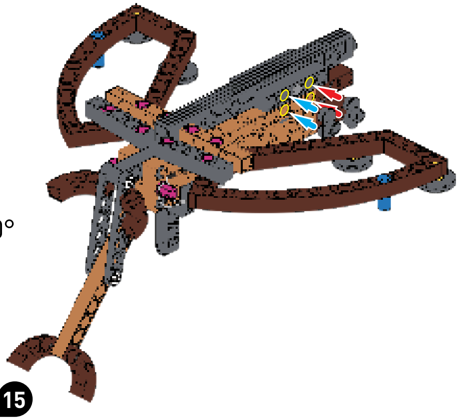

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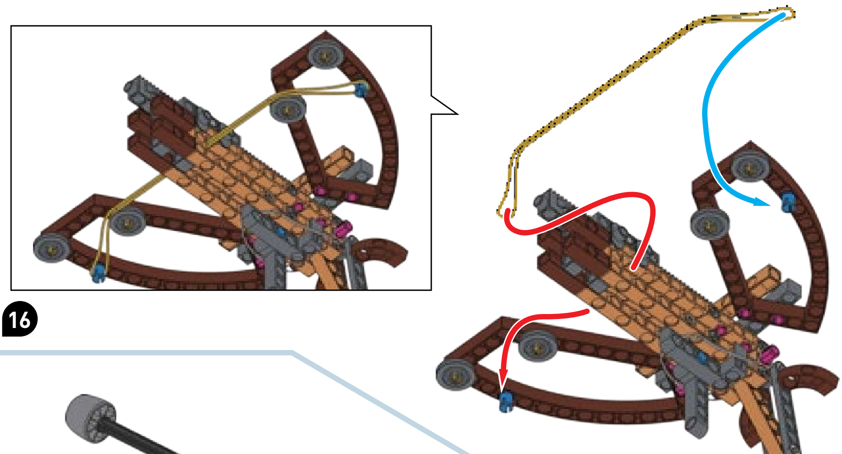

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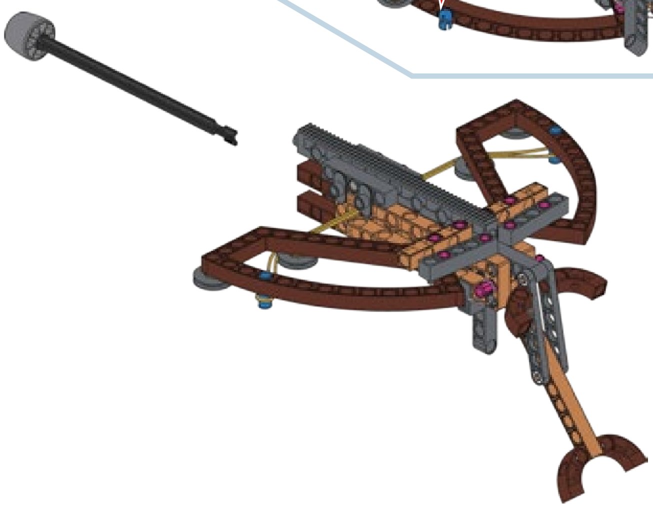
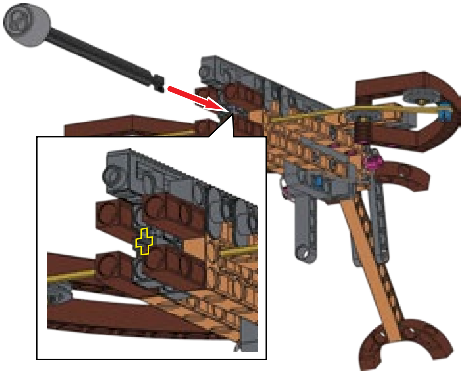


Done!

EXPERIMENT 2

How can you vary the velocity of the projectile?



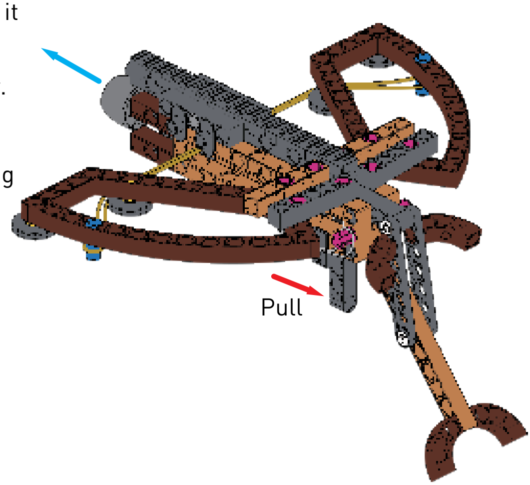
Here's how:

1. Stand at the mark you set up in the preparation steps.
2. Load a bolt into the crossbow by lining up the bolt with the plus-sign-shaped hole. Make sure both strands of the large rubber band are pushed inward by the bolt. Push the bolt inward until it clicks into place.
3. Hold the crossbow horizontally. Release the bolt towards the target by pulling the trigger. Mark where the bolt lands using a piece of tape.
4. Now stretch the rubber band around the other set of pulley wheels. What do you notice about the rubber band?
5. Hold the crossbow at the same height and distance from the target when shooting the bolt. Measure and compare the distances the bolts traveled.

>> What happens when you pull the trigger?

>> What do you notice about the speed of the bolts?

>> Try looping the rubber band around the pulley wheel to make it even tighter. How far does the bolt travel?



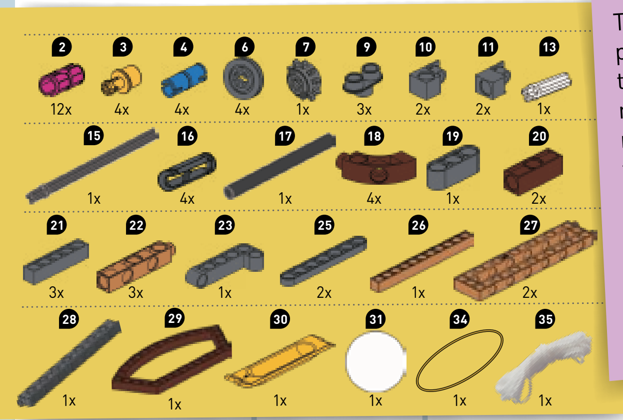
WHAT'S HAPPENING?

As you learned in Experiment 1, when you stretch the rubber band tighter you add more potential energy to the rubber band. That means more potential energy to launch the bolt. This energy is then changed to kinetic energy, the energy of motion, which can be calculated by the equation:

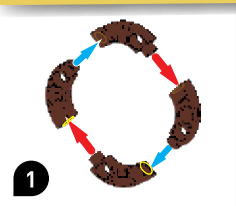
$$\mathbf{KE = {}^{1}/_{2}mv^{2}}$$

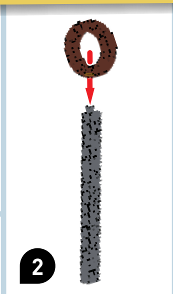
where m is the mass and v is the velocity. Since the mass of the bolt stays constant, the only thing that is changing when you stretch the rubber band more is the velocity. This is why the bolt travels faster when you tighten the rubber band.

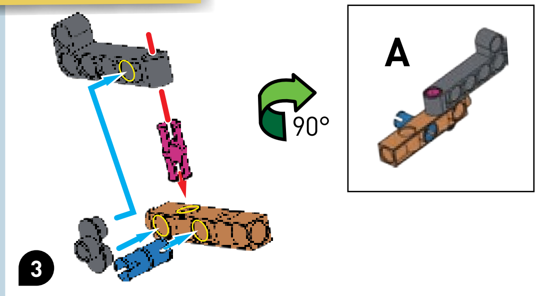
MODEL 3: ONAGER

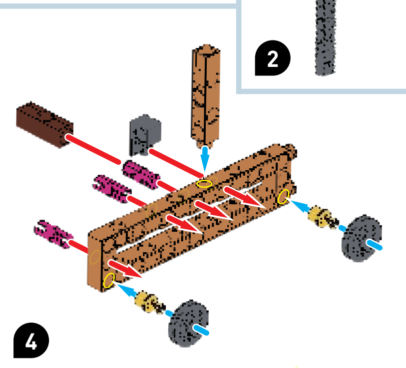


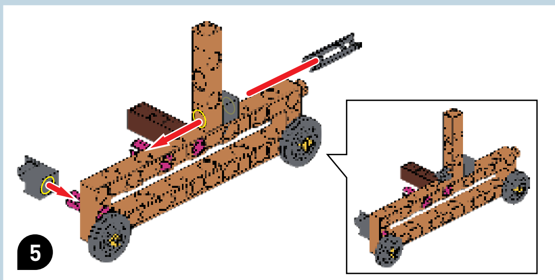
The onager is often what people think of when they think of a catapult. It gets its name from the Greek word meaning donkey, because of the kicking action of the machine. Originally, onagers released projectiles from slings.

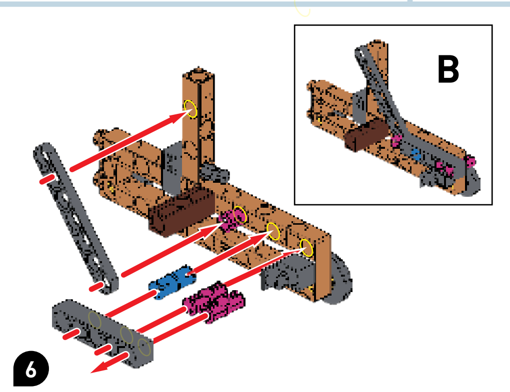


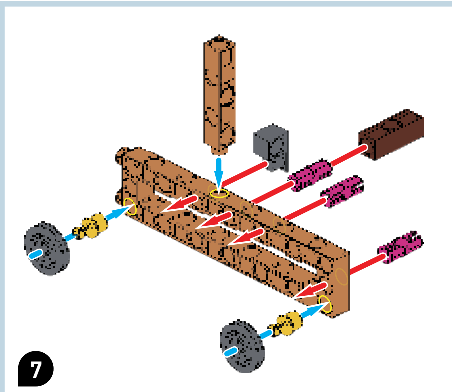


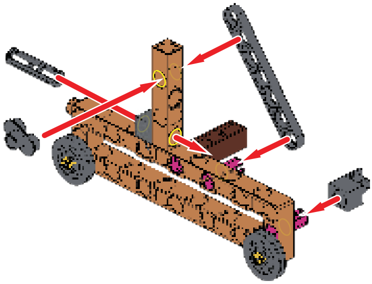












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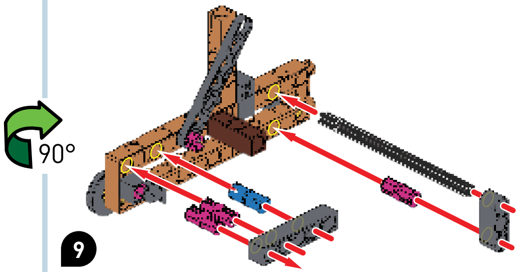

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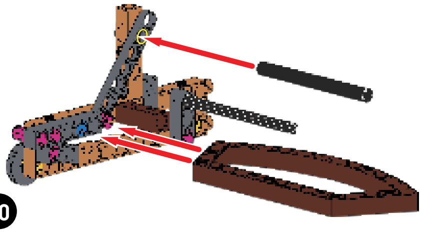

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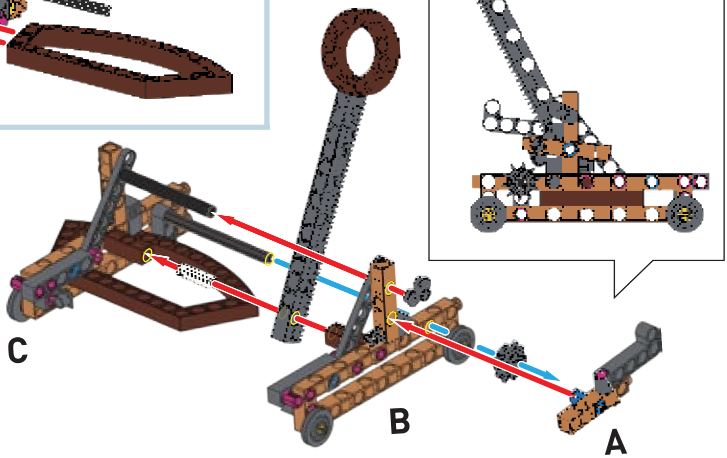

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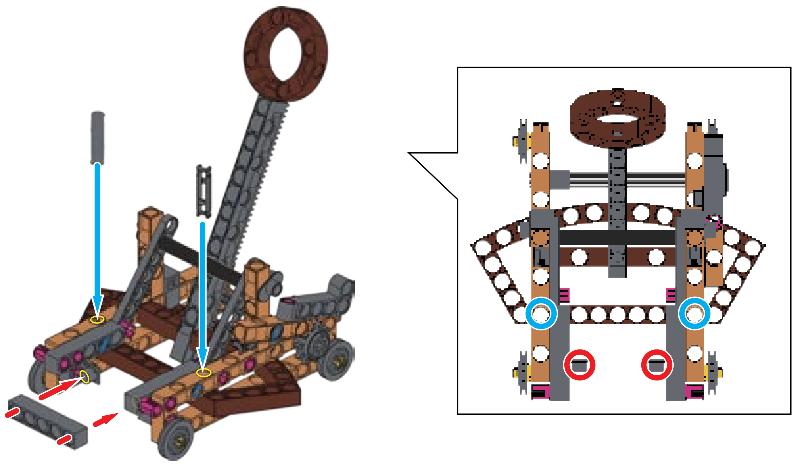

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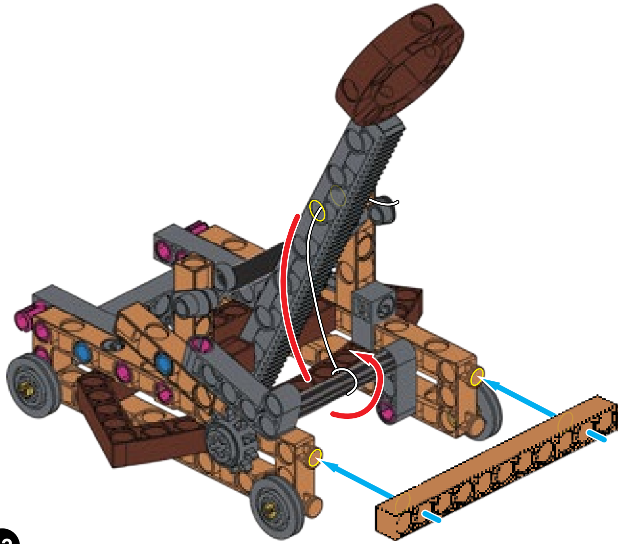
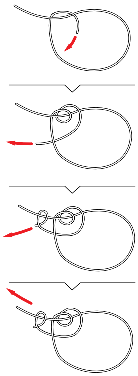


Tie the string around the axle and make a knot.



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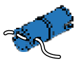
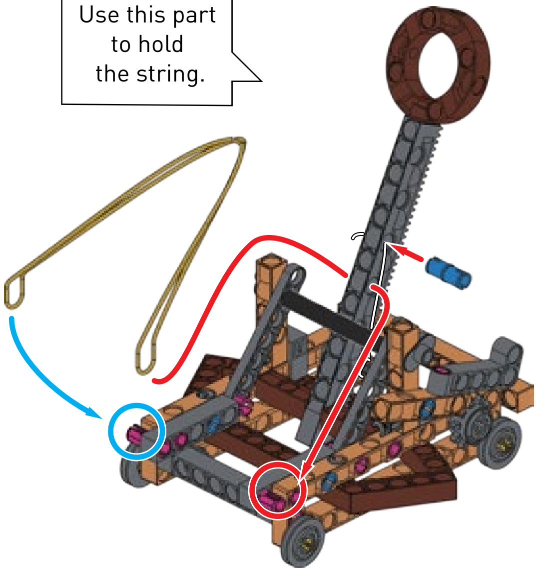
Use this part to hold the string.





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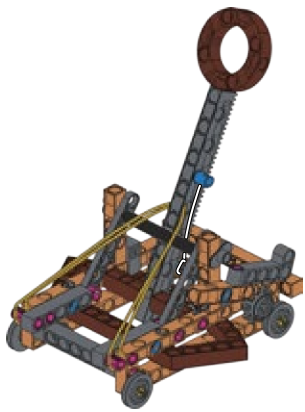

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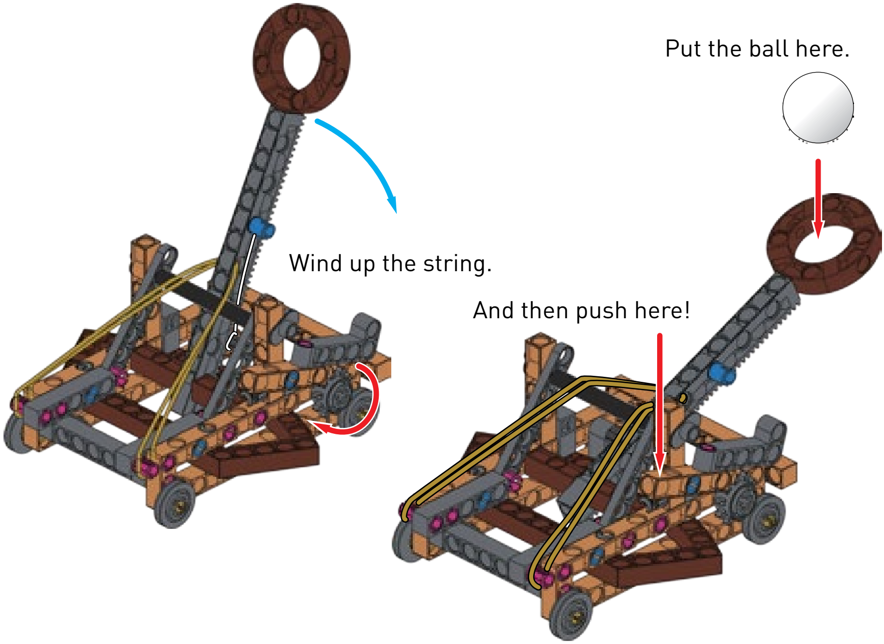
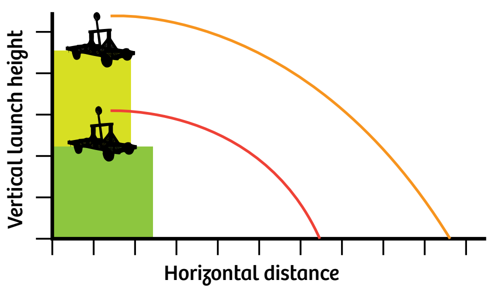


WHAT'S HAPPENING?

If everything else remains the same, when the height from which the projectile is shot increases, the time that the object is in the air will also increase. Because the horizontal velocity of projectiles is constant, this also means that the projectile launched from the table will travel farther than the projectile launched from the floor. Maximizing the time that an object is in the air is important for a tennis lob, a football punt, and diving.



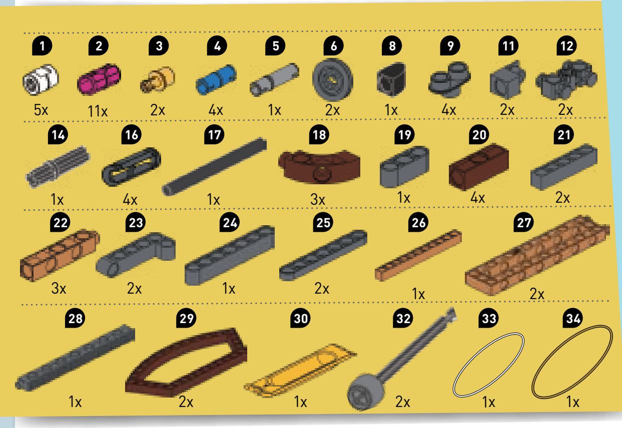
EXPERIMENT 3

How does varying the height of release impact the launch?

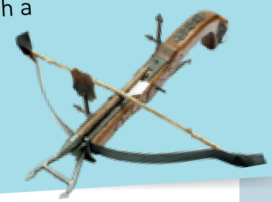
Here's how:

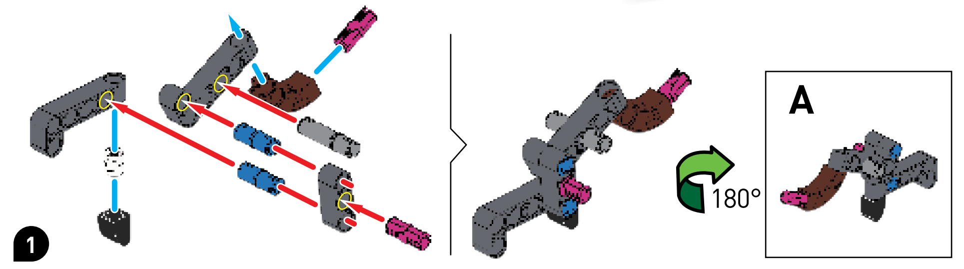
1. Get a stopwatch ready. You will use this to measure the length of time the projectile is in the air.
2. Place the onager on the floor. Use the ratchet to wind up the string. Load a foam ball, and fire the ball by pressing the release trigger. How long was the projectile airborne?
3. Now place the onager on the end of a table and shoot the foam ball off the table onto the floor. How long was the projectile airborne compared to when you launched it from the floor?

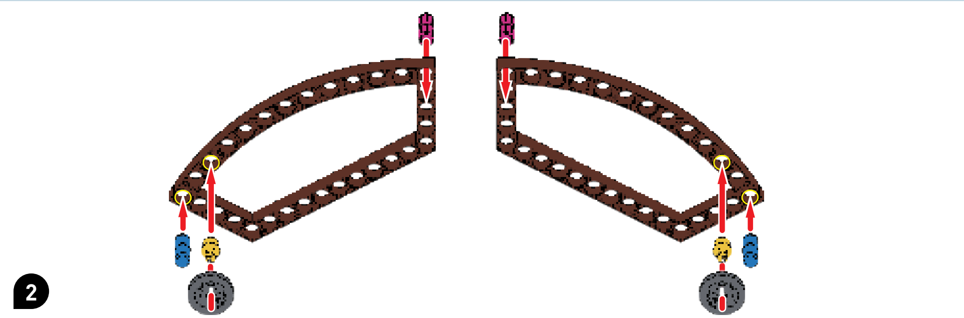
MODEL 4: CROSSBOW

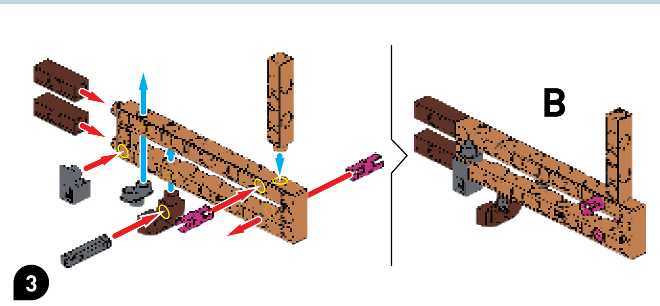


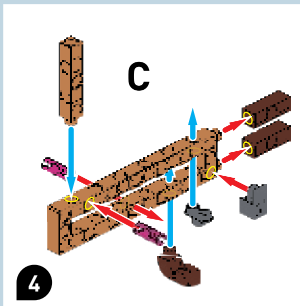
The crossbow is a bow that has been turned on its side and mounted to a piece of wood called a stock. Instead of arrows, a crossbow shoots projectiles called bolts. The crossbow was very popular throughout ancient Europe and Asia because it was faster to learn how to shoot accurately with a crossbow than it was with a regular bow.

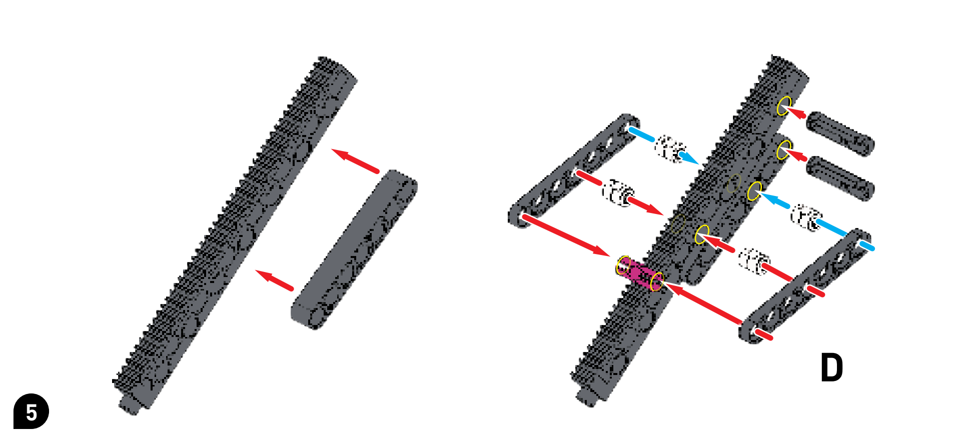








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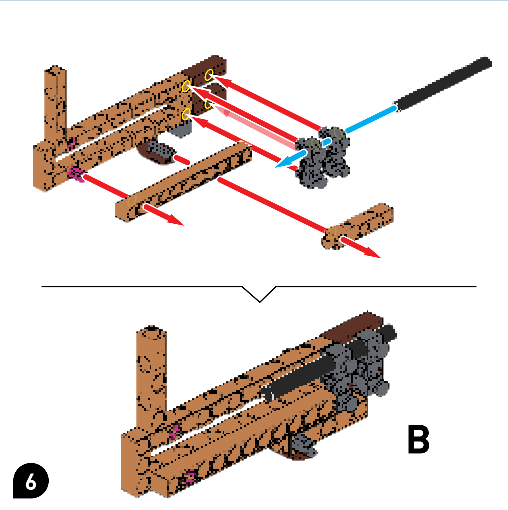
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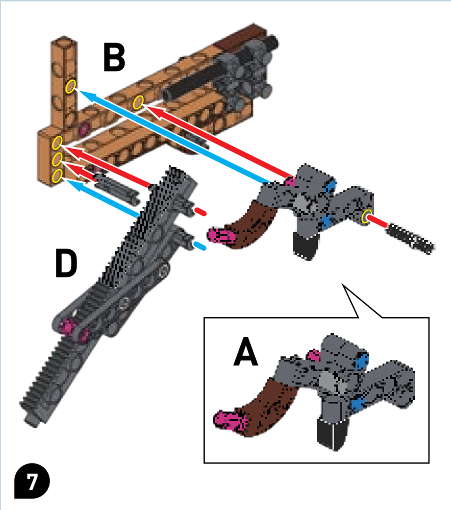
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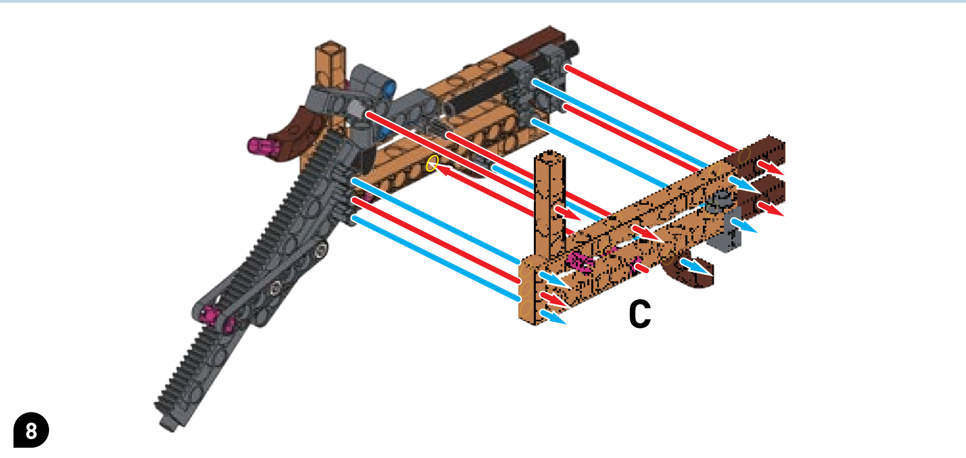
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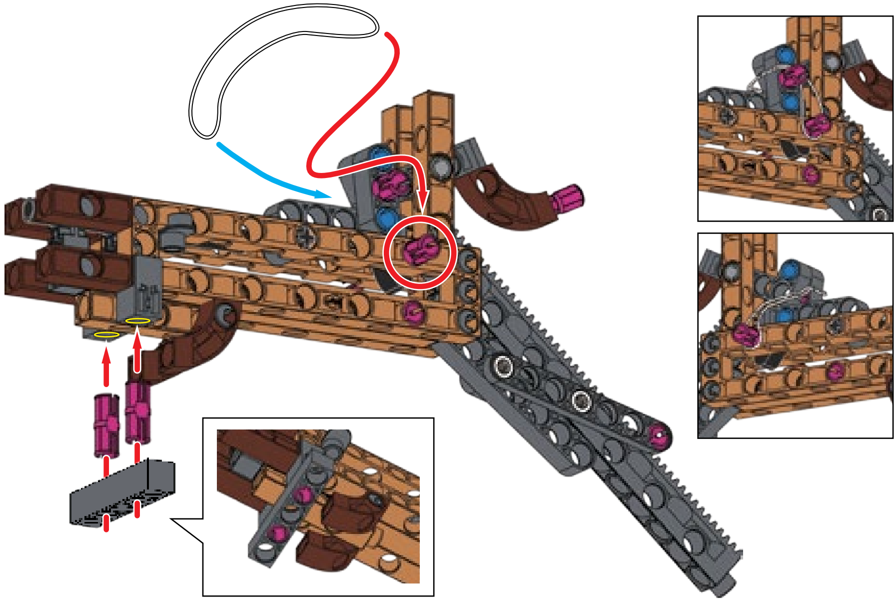

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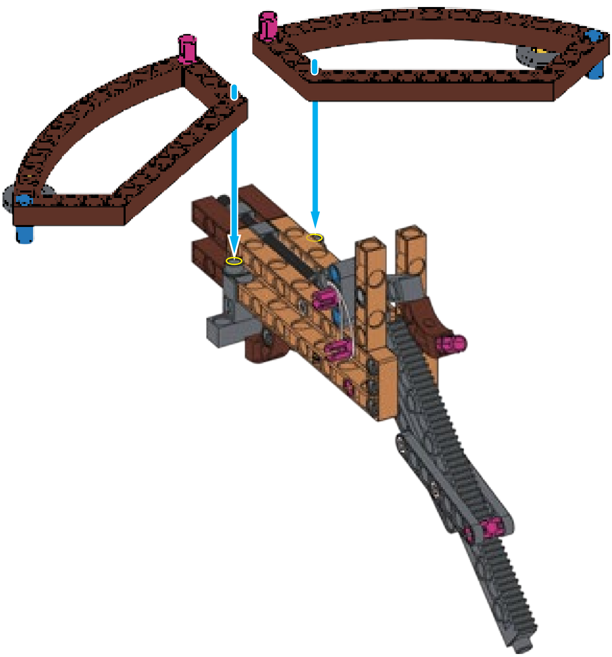

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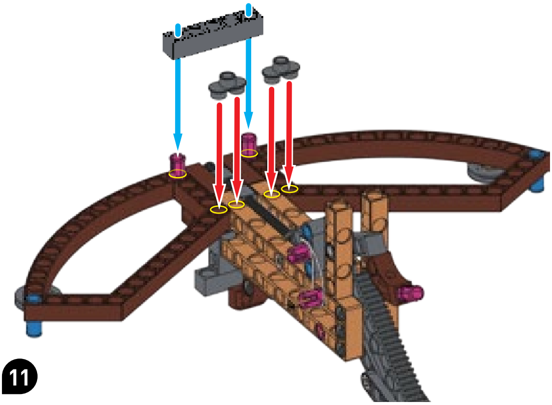

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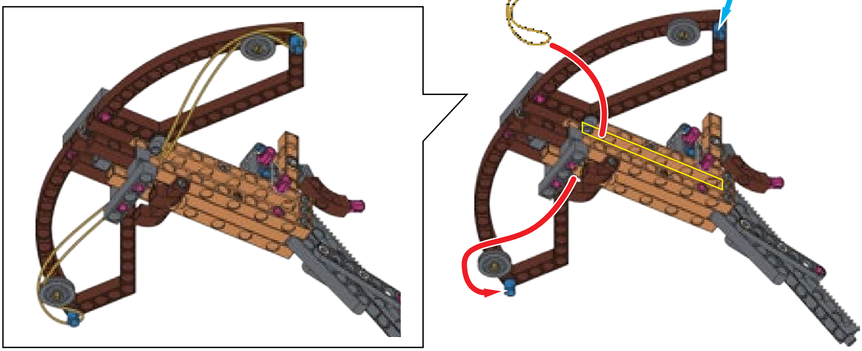
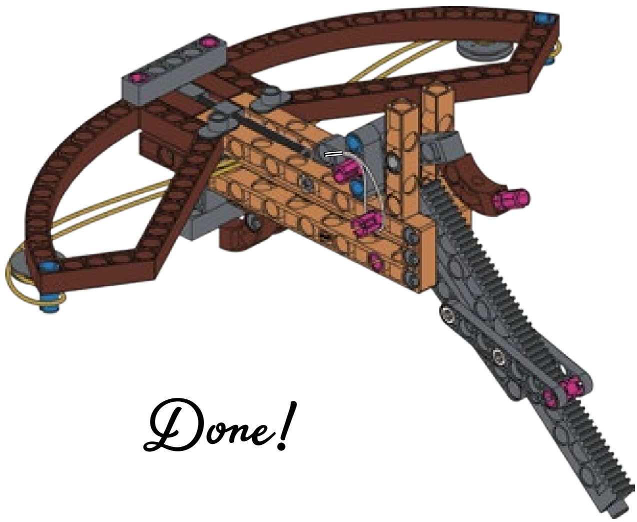
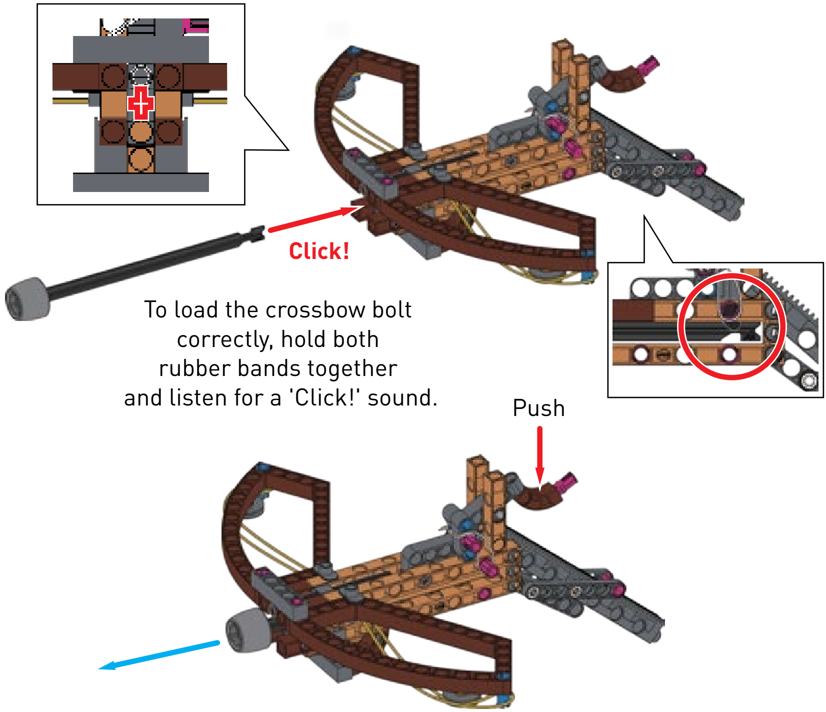




Done!



To load the crossbow bolt correctly, hold both rubber bands together and listen for a 'Click!' sound.

EXPERIMENT 4: HOOKE'S LAW

Here's how:

1. Test the elasticity of the rubber band. Make different bundles of pennies and nickels using tissue paper and tape. (One penny is 2.5 grams; one nickel is 5 grams.)
2. Tape a paper clip to the bundle to use as a hook.
3. Hold the crossbow vertically and hang the weights from the large rubber band using the paper clip. Measure the distance that the rubber band is stretched by each weight. Make a graph of the weight versus the distance the rubber band deforms. What does the graph look like?

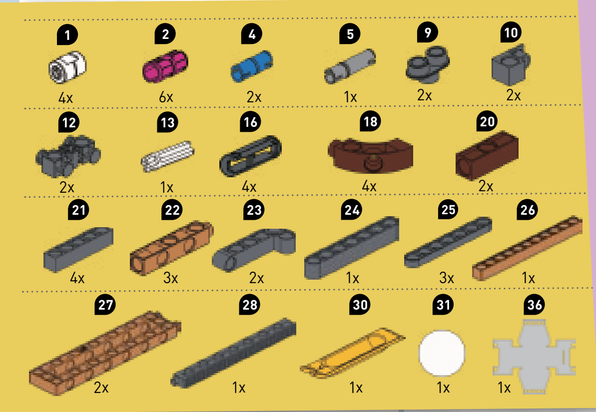
WHAT'S HAPPENING?

Hooke's law states that the distance that something elastic — like a rubber band — is stretched or compressed is **directly proportional** to the amount of force produced. This means that if the rubber band is stretched twice as far (for example, 2 inches instead of 1 inch) then the force produced would double. This is commonly written as:

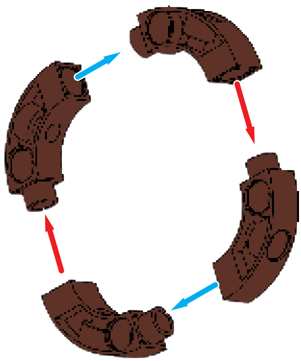
$$F = -kx$$

where F is the force, k is a constant specific to the particular elastic, and x is the distance of displacement. In this experiment you saw how different amounts of weight created different amounts of displacement.

MODEL 5: TREBUCHET



The trebuchet can be thought of as a giant seesaw where one side is pulled down causing the other side to go up and release a mass. Trebuchets developed from ancient slings and originated in China. The first trebuchet required a group of people to pull down on the lever arm in unison to launch the projectile.



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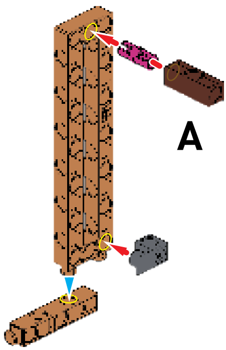

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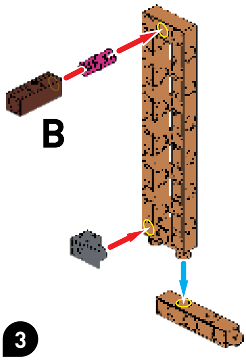

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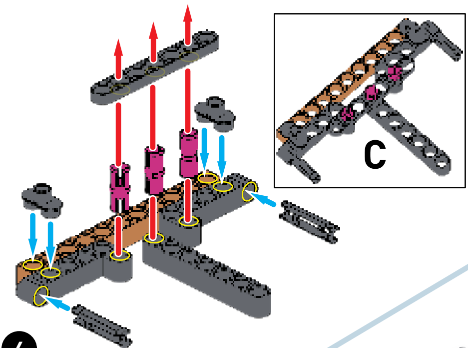

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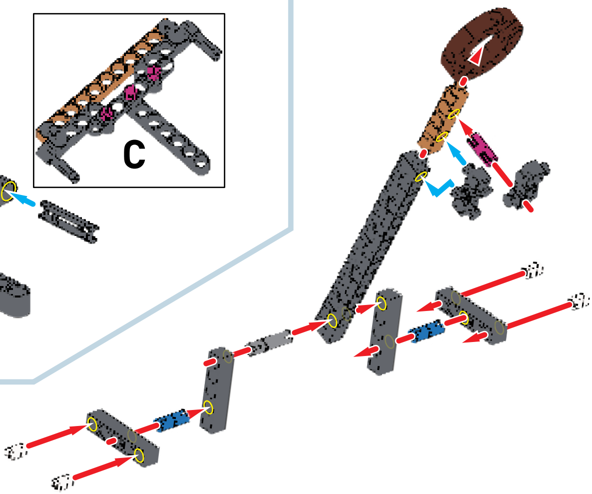

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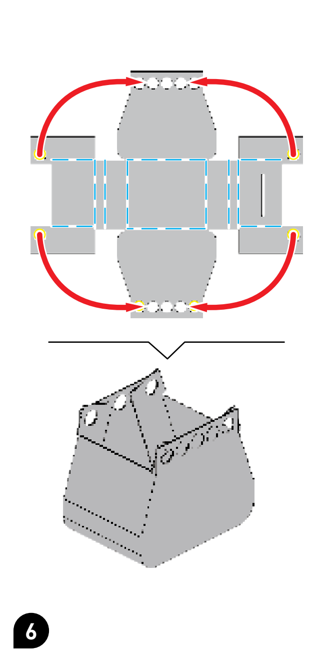
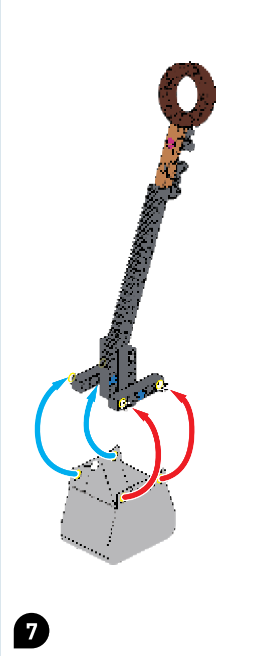
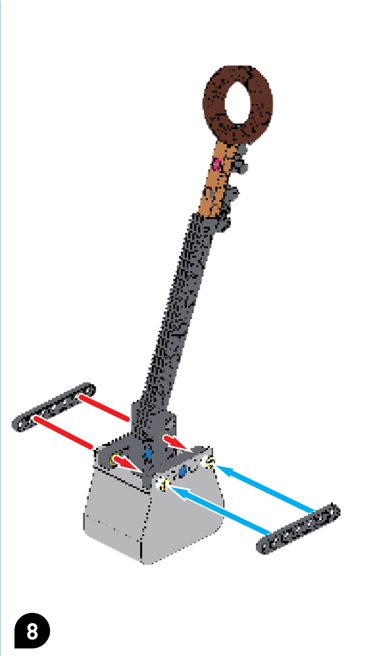
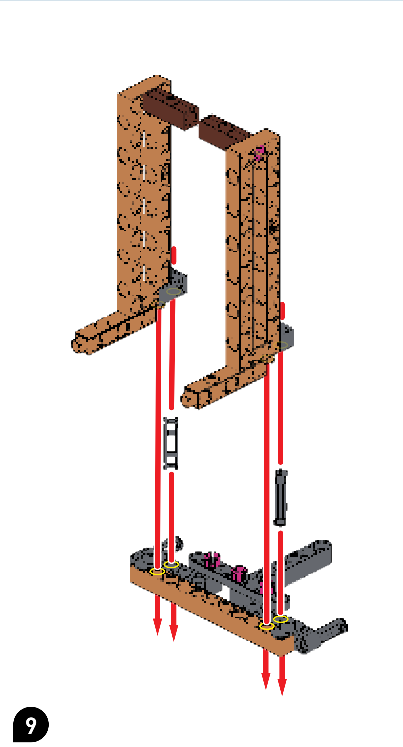
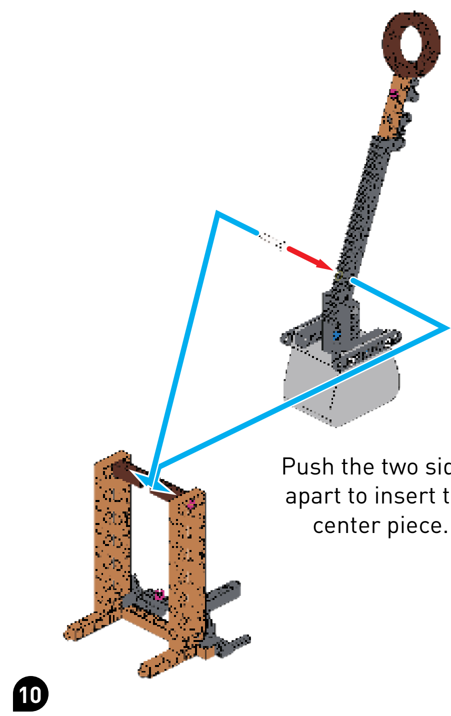








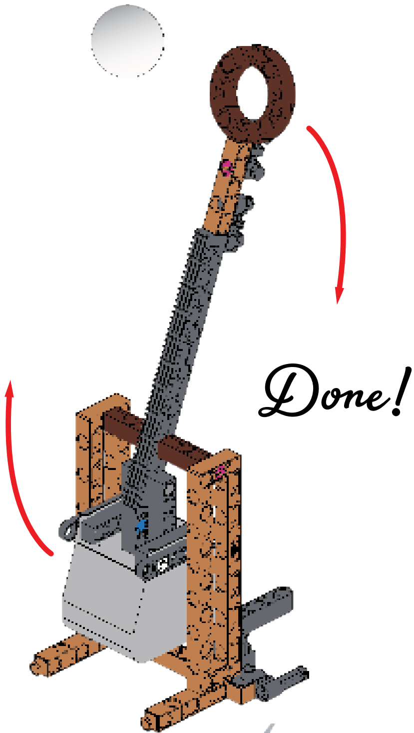


Push the two sides apart to insert the center piece.

EXPERIMENT 5: LEVER ARMS

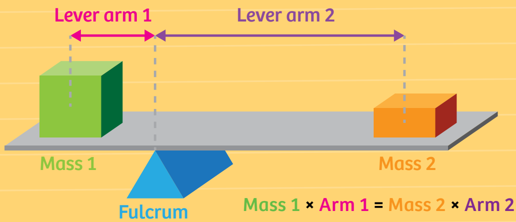
Here's how:

1. Try launching the foam ball a few times with the model set up as shown. Lift up the counterweight and then let it drop. Try loading the basket with different amounts of weight.
2. Now try varying the length of the lever arm by changing the hole where the pivot point, or fulcrum, is located. You can also try changing the length of the arm itself. Observe how far the projectile travels after each change.
3. How could you improve the trebuchet using what you have learned from the crossbow models?

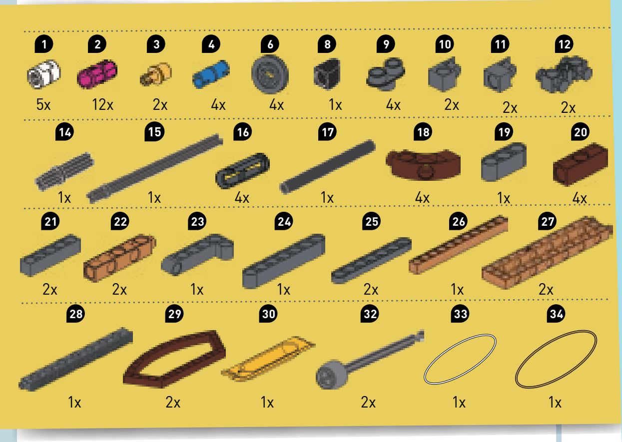


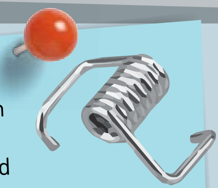
WHAT'S HAPPENING?

The trebuchet makes use of a simple machine called a **lever.** A lever is a beam that pivots at a fixed point called a **fulcrum.** A lever amplifies an input force to provide a greater output force. The ratio of the output to input force is given by the ratio of the distances from the fulcrum to the point of application of those forces. This ratio is known as the **mechanical advantage** of the lever. From your experiments you saw that the distance the ball travels increases as the main trebuchet arm gets shorter and the load arm gets longer, but then decreases again. This is a result of changing the lever arm and also the angle at which the projectile is fired.

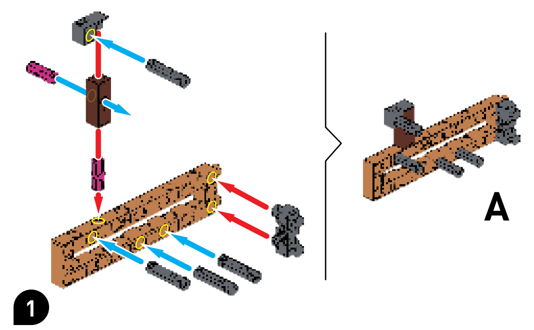


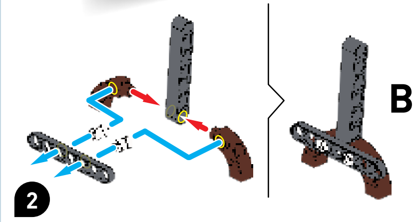
MODEL 6: BALLISTA

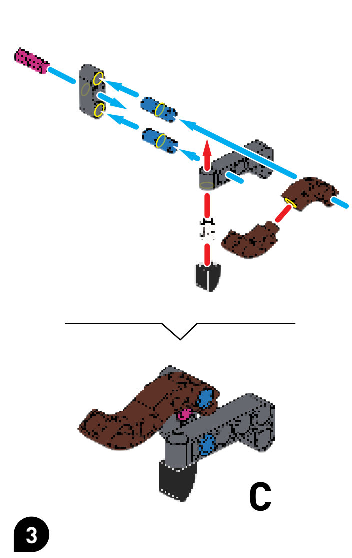


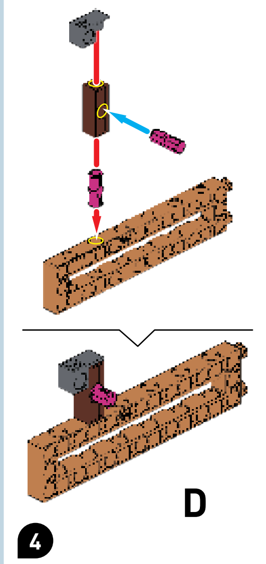


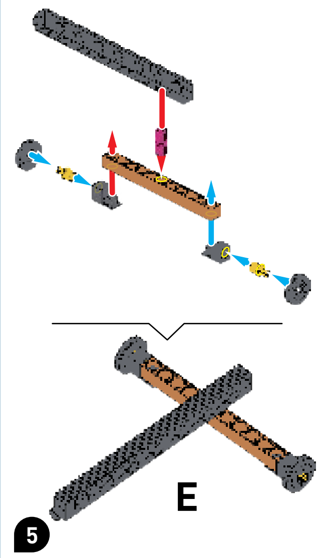
The ballista developed from earlier Ancient Greek handheld crossbows but used a torsion spring to fire instead of a string. Torsion springs apply a force when turned, instead of a normal spring that develops a force when the spring is stretched or compressed. An example of a torsion spring you might be familiar with is the spring in a mouse trap. The torsion spring allowed for the use of lighter projectiles which could reach higher velocities and go longer distances.

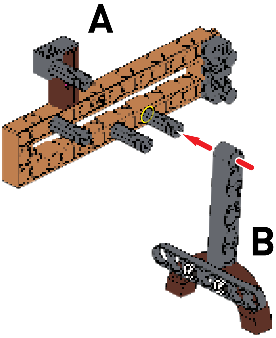












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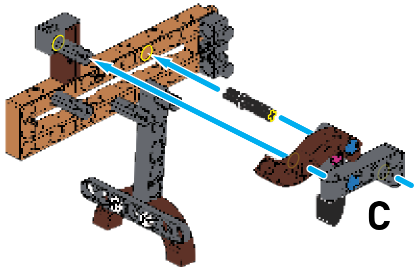

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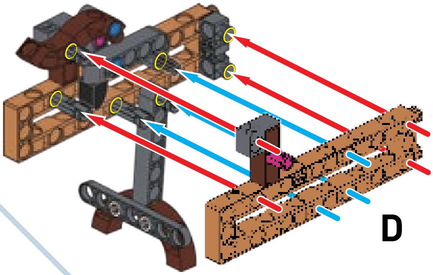

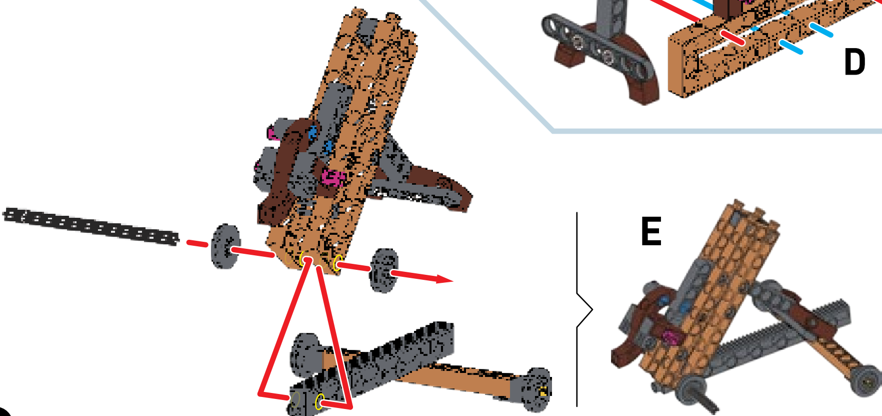

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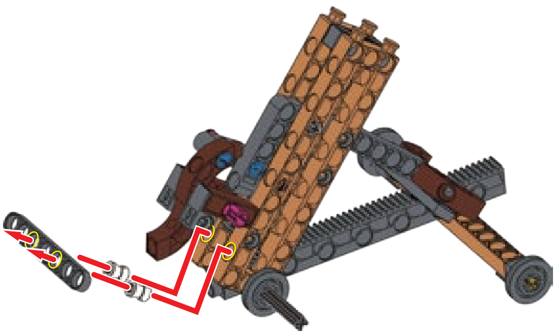

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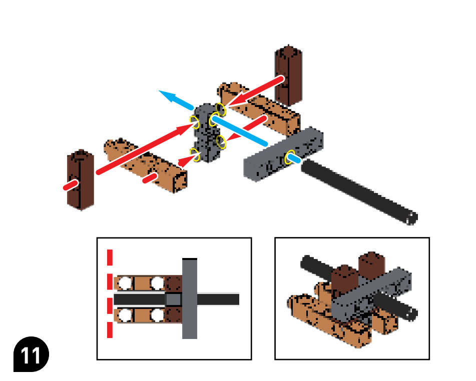
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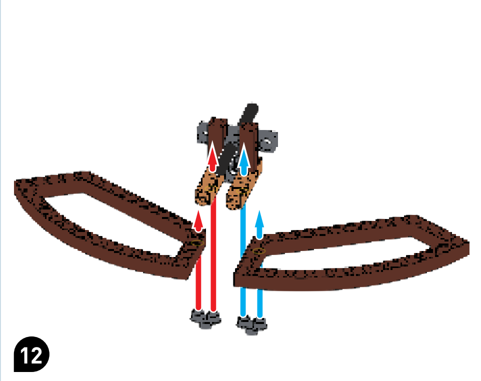
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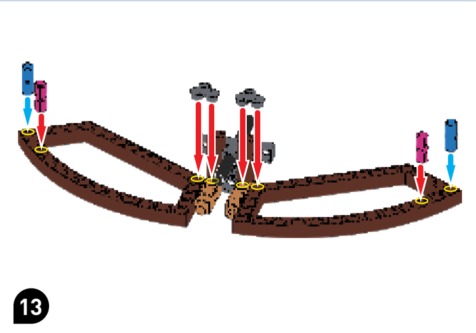
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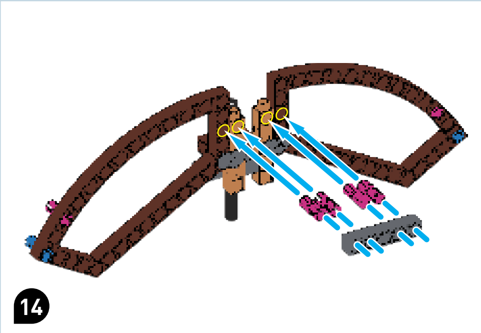
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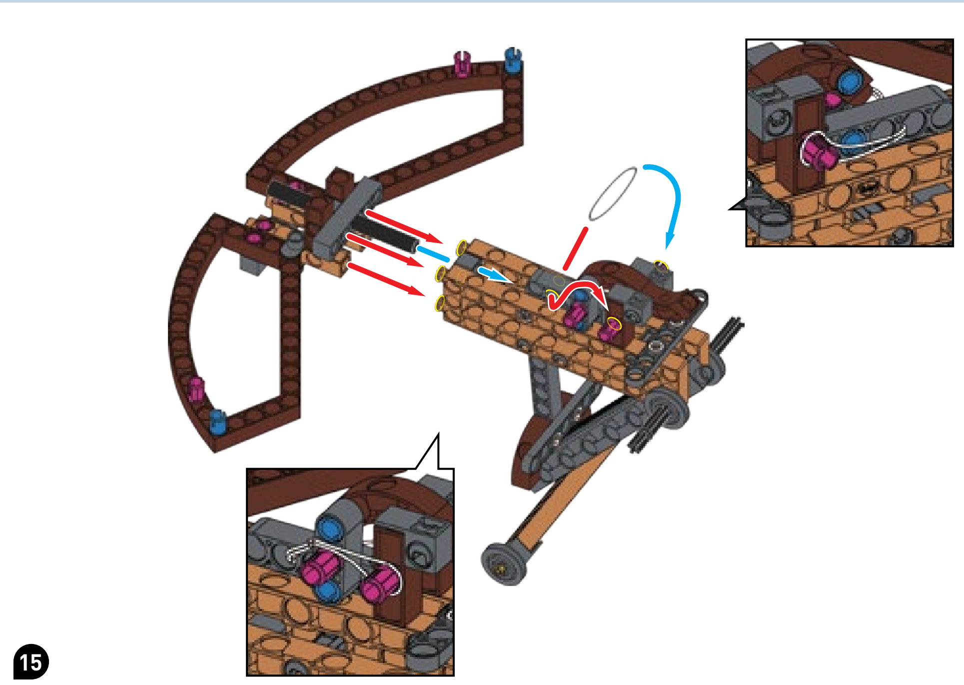
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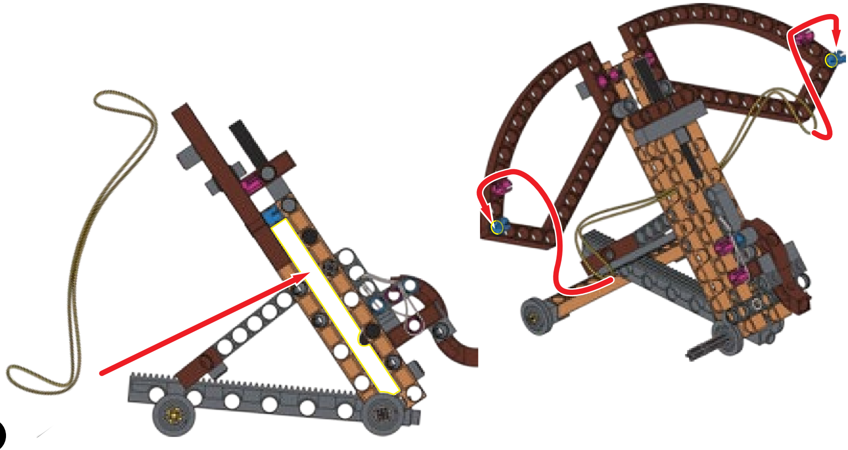
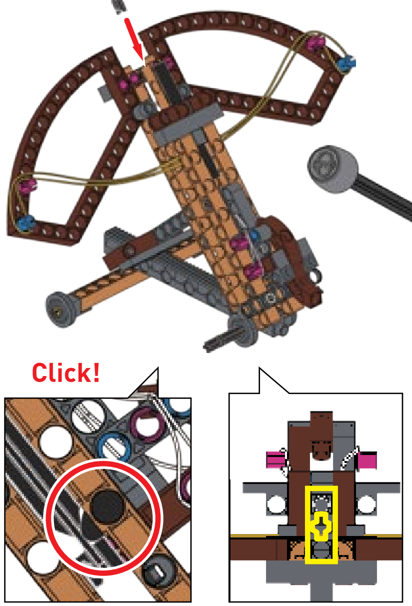
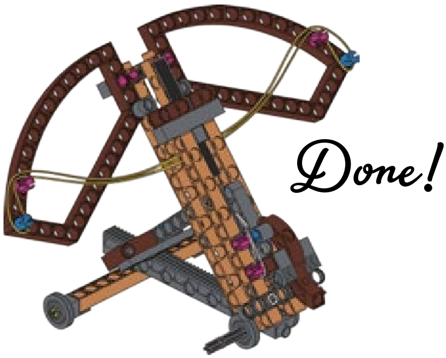
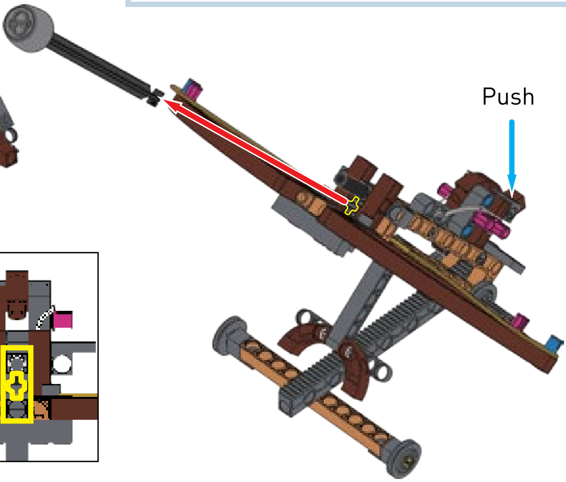


To load the bolt correctly, push both rubber bands together and listen for a 'Click!' sound.

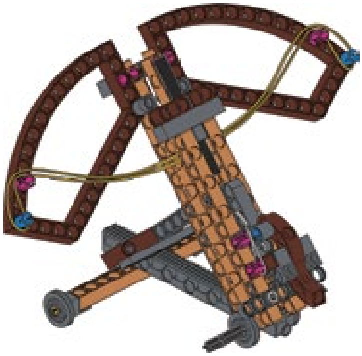






EXPERIMENT 6

How does varying the angle of launch impact the flight?



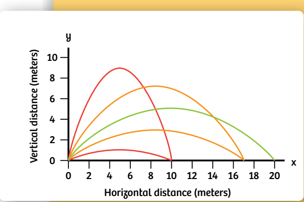
Here's how:

1. Test fire some bolts. Observe the paths that the bolts follow when they are shot from the ballista. Draw a picture of the path that a bolt follows as it flies through the air. How would you describe it?
2. Shoot the ballista horizontally and mark the distance that the bolt travels with a piece of tape. Repeat this process holding the ballista at increasing angles (aiming it higher toward the ceiling).

>> What do you notice about the distances that the bolts travel before they hit the ground when shot at the different angles? What about the heights that the bolts travel?

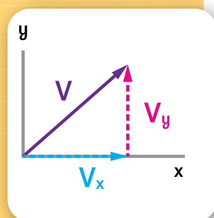
>> At what angle does the bolt fly the farthest?

WHAT'S HAPPENING?



In physics, an object that has been launched into the air near Earth's surface is described by **projectile motion.** In experiment 6, you saw that the bolts followed an arc when they were shot out of the ballista. The shape of this arc changed when the angle at which the bolt was shot changed. You may have also found that the distance that the projectile traveled before hitting the ground increased as the angle increased and then decreased as you kept increasing the launch angle.

The figure above shows the distance that a projectile might travel if shot at the same velocity but different angles. Notice how the projectile goes the farthest when shot at a 45-degree angle. Why do you think this is?



The velocity vector of the bolt can be broken up into a horizontal and vertical part. When the projectile is shot at a 45-degree angle, the velocity is split evenly between the horizontal and vertical parts. The bolt has travels the greatest distance in the x direction when it is launched at this 45-degree angle. Want to prove why? You'll need trigonometry for that!

Projectile motion plays an important part in sports such as baseball, basketball, golf, volleyball, and diving. Maximizing the horizontal distance is important for javelin and shot put throws, long jumps, and football kickoffs. Maximizing vertical height is important for a pole vault, high jump, and a jump ball in basketball.

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