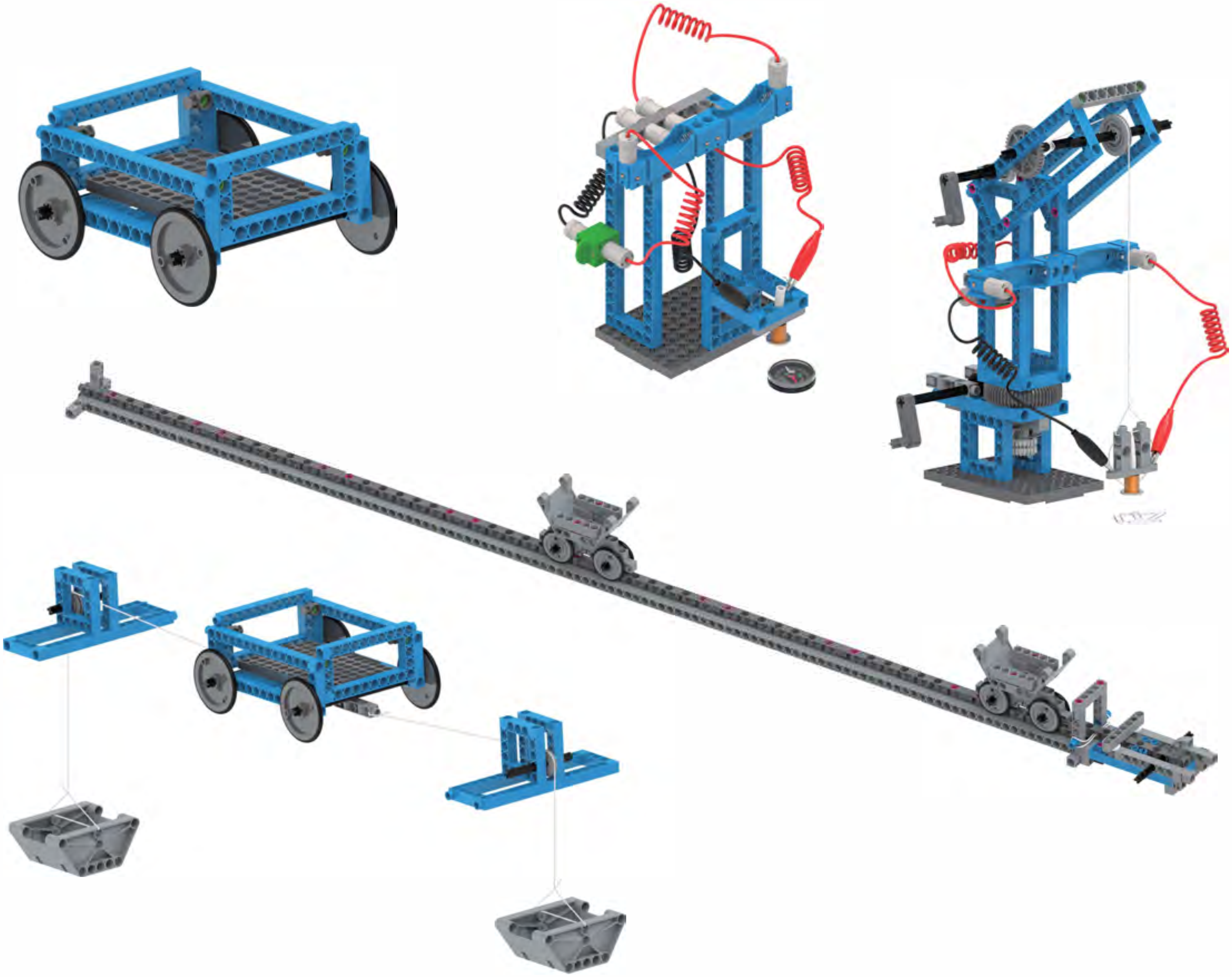


Forces & Interactions

Middle School Classroom Kit

THAMES & KOSMOS

Lesson Plans and Assembly Instructions

ALIGNED TO NGSS NEXT GENERATION SCIENCE STANDARDS

Thames & Kosmos, 89 Ship St., Providence, RI, 02903, USA | 1-800-587-2872 | www.thamesandkosmos.com

Safety Information

WARNING. Only for use by children aged 8 years and older. Instructions for parents or other supervising adults are included and have to be observed. Keep packaging and instructions as they contain important information.

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

WARNING. Not suitable for children under 8 years. This product contains small magnets. Swallowed magnets can stick together across intestines causing serious infections and death. Seek immediate medical attention if magnet(s) are swallowed or inhaled.

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

Safety for Experiments with Batteries

- To operate some of the models, you will need 2 AA batteries (1.5-volt, type AA/LR6) which could not be included in the kit due to their limited shelf life.
- The supply terminals are not to be short-circuited. A short circuit can cause the wires to overheat and the batteries to explode.
- Different types of batteries or new and used batteries are not to be mixed.
- Do not mix old and new batteries.
- Do not mix alkaline, standard (carbon-zinc), or rechargeable (nickel-cadmium) batteries.
- Batteries are to be inserted with the correct polarity. Press them gently into the battery compartment.
- Non-rechargeable batteries are not to be recharged. They could explode!
- Rechargeable batteries are only to be charged under adult supervision.
- Rechargeable batteries are to be removed from the toy before being charged.
- Exhausted batteries are to be removed from the toy.
- Dispose of used batteries in accordance with environmental provisions, not in the household trash.
- Be sure not to bring batteries into contact with coins, keys, or other metal objects.
- Avoid deforming the batteries.
- The wires are not to be inserted into socket-outlets.
- Not to be connected to more than the recommended number of power supplies.
- Warning! Do not manipulate the protective device in the battery compartment (PTC). This could cause overheating of wires, eruption of batteries and excessive heating.
- As all of the experiments use batteries, have an adult check the experiments or models before use to make sure they are assembled properly. Always operate the motorized models under adult supervision. After you are done experimenting, remove the batteries from the battery compartments. Note the safety information accompanying the individual experiments or models!

Notes on Disposal of Electrical and Electronic Components

The electronic components of this product are recyclable. For the sake of the environment, do not throw them into the household trash at the end of their lifespan. They must be delivered to a collection location for electronic waste, as indicated by the following symbol:

Please contact your local authorities for the appropriate disposal location.

Forces & Interactions

Middle School Classroom Kit

Lesson Plans and Assembly Instructions

THAMES & KOSMOS

Thames & Kosmos, 89 Ship St., Providence, RI, 02903, USA | 1-800-587-2872 | www.thamesandkosmos.com

700100-02-160823

2nd Edition 2019, 2023 Thames & Kosmos, LLC, Providence, RI, USA
Thames & Kosmos® is a registered trademark of Thames & Kosmos, LLC.

Technical product development: Genius Toy Taiwan Co., Ltd., Taichung, Taiwan, R.O.C.
Lesson plan development: Molly Ward, M.S. Science Education
Editing: Ted McGuire
Layout: Mark Geary
Graphics and Packaging: Dan Freitas
Illustrations: Genius Toy Taiwan Co., Ltd., Taichung, Taiwan, R.O.C., and Thames & Kosmos

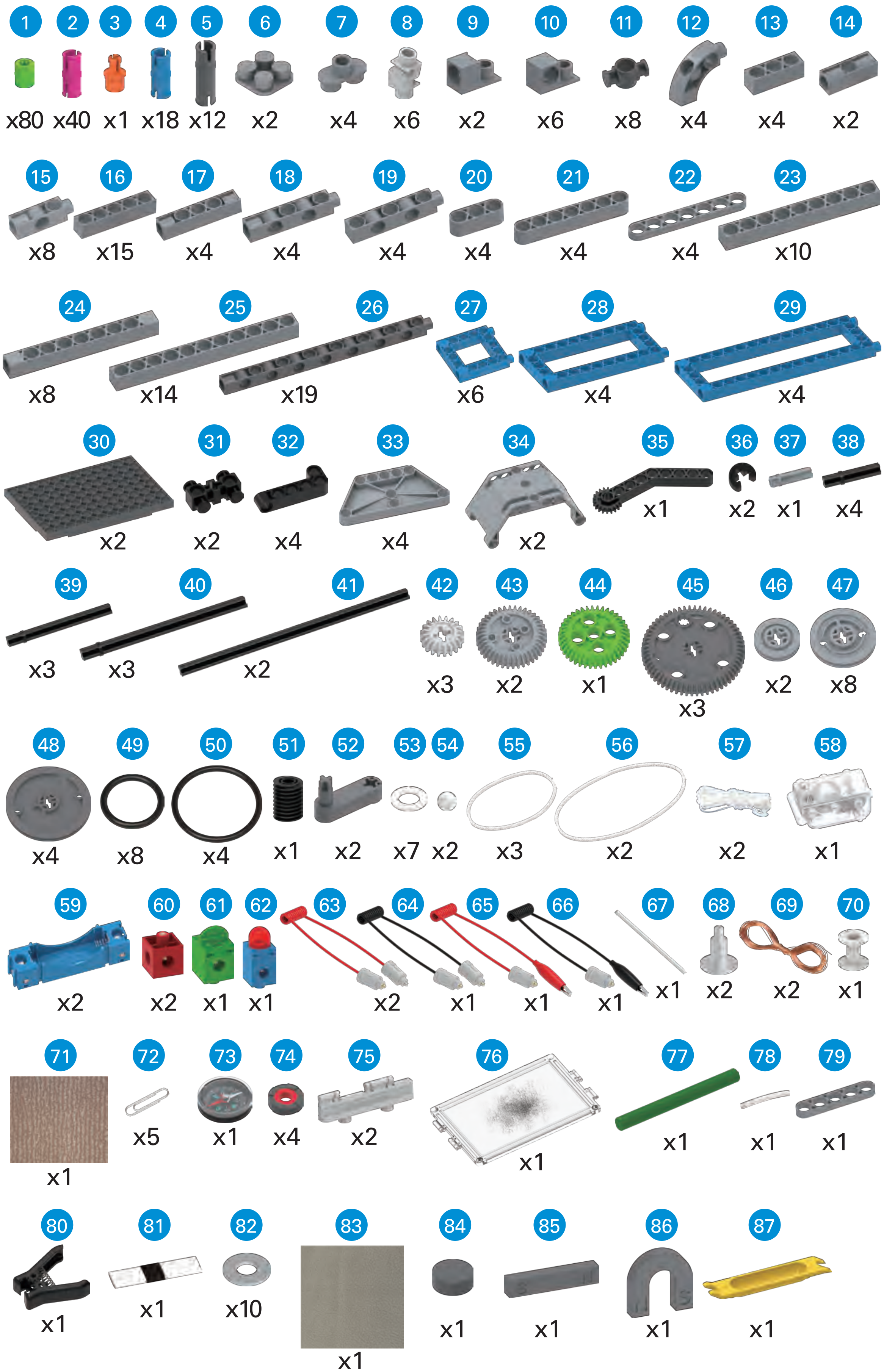
Distributed in North America by Thames & Kosmos, LLC. Providence, RI 02903
Phone: 800-587-2872; Web: www.thamesandkosmos.com

We reserve the right to make technical changes.

Printed in Taiwan / Imprimé en Taiwan

Table of Contents

Kit Contents



Kit Contents

No.	Description	Quantity	Part No.
1	Short anchor pin	80	7344-W10-C2G1
2	Connector pin	40	1187-W10-E1K
3	Shaft plug	1	7026-W10-H1O
4	Joint pin	18	7413-W10-T1B
5	Long joint pin	12	7413-W10-U1S1
6	Base plate connector	2	7026-W10-I1SK
7	Two-to-one converter	4	7061-W10-G1S2
8	Hinge	6	7061-W85-F1SK
9	90-degree converter - Y	2	7061-W10-Y1S2
10	90-degree converter - X	6	7061-W10-X1S2
11	1-hole connector	8	7430-W10-B1S
12	Curved rod	4	7061-W10-V1S2
13	3-hole rod	4	7026-W10-Q2S1
14	3-hole cross rod	2	7026-W10-X1S2
15	3-hole dual rod	8	7413-W10-Y1S2
16	5-hole rod	15	7413-W10-K2S1
17	5-hole cross rod	4	7413-W10-R1S1
18	5-hole dual rod - Y	4	7413-W10-X1S2
19	5-hole dual rod - X	4	7413-W10-W1S1
20	3-hole wide rounded rod	4	7404-W10-C1S
21	7-hole wide rounded rod	4	7404-W10-C2S
22	7-hole flat rounded rod	4	7404-W10-C3S
23	9-hole rod	10	7407-W10-C1S
24	9-hole cross rod	8	7407-W10-C2S
25	11-hole rod	14	7413-W10-P1S2
26	15-hole dual rod	19	7413-W10-Z1S2
27	Square frame	6	7413-W10-Q1B
28	Short frame	4	7413-W10-I1B
29	Long frame	4	7413-W10-J1B1
30	Base plate	2	7125-W10-A1SK
31	3-hole bolt rod	2	7406-W10-B1D
32	5-hole L rod	4	7406-W10-B2D
33	Trapezoidal plate	4	7408-W10-A1S
34	Trapezoidal cover	2	7408-W10-B1S
35	Crankshaft gear	1	7411-W10-C(1/2)D
36	Axle lock	2	3620-W10-A1D
37	Motor shaft	1	7026-W10-L1S1
38	35-mm axle	4	7413-W10-O1D
39	70-mm axle	3	7061-W10-Q2D
40	100-mm axle	3	7413-W10-L2D
41	150-mm axle	2	7026-W10-P1D
42	Small gear (20 teeth)	3	7026-W10-D2S
43	Medium gear (40 teeth)	2	7346-W10-C1S
44	Medium spindle gear (40 teeth)	1	7408-W10-D1G

No.	Description	Quantity	Part No.
45	Large gear (60 teeth)	3	7026-W10-W5S
46	Small pulley wheel	2	7344-W10-N3S2
47	Medium pulley wheel	8	7344-W10-N2S2
48	Large pulley wheel	4	7344-W10-N1S1
49	Medium O-ring	8	R12-07S
50	Large O-ring	4	R12-09S
51	Worm	1	7344-W10-A1D
52	Crank	2	7063-W10-B3S1
53	Washer	7	3620-W10-B1
54	Polystyrene foam ball	2	K30#7366-1
55	70-mm rubber band	3	R10-02
56	100-mm rubber band	2	R10-05
57	200-cm string, white	2	R39-W85-200
58	Geared motor box	1	1114-W85-E1K
59	AA battery holder	2	7050-W85-O2B
60	Cube connector	2	7050-W85-3R
61	Switch	1	7050-W85-2G
62	Bulb and fixture	1	7050-W85-6R
63	Red connector wire	2	7050-W85-5R
64	Black connector wire	1	7050-W85-5D
65	Red connector wire with clip	1	7050-W85-5RC
66	Black connector wire with clip	1	7050-W85-5DC
67	Metal rod	1	M10#7061
68	Iron rod	2	M10#7343
69	Copper wire, coated	2	7344-W85-B2
70	Winding reel	1	7343-W10-A1SK
71	Sandpaper	1	E41-18
72	Paper clip	5	E41-20
73	Compass	1	R48#7344-1
74	Ring magnet	4	7065-W85-A
75	Iron filings board connector	2	1210-W10-B1SK
76	Iron filings board	1	7344-W85-B1
77	Green hollow rod	1	7330-W11-B1G
78	Clear plastic flexible tube	1	1155-W85-80
79	5-hole flat rounded rod	1	7443-W10-C2S
80	Clip with spring	1	7389-W85-B1D
81	50-cm thread, black	1	R39#3430
82	Metal washer (weight)	10	M10#3430
83	Fleece cloth	1	R33#3430
84	Circle magnet	1	R48#3430
85	Bar magnet	1	R48#3430-1
86	Horseshoe magnet	1	R48#3430-2
87	Anchor pin lever (part separator tool)	1	7061-W10-B1Y

NGSS Alignments

The following Next Generation Science Standards (NGSS) are addressed by the lessons in this kit. At the beginning of each lesson, there are more details about the standards and dimensions addressed, and the specific connections to the activities are described.

Standards Addressed		**Activities**									
		1. Visualizing Forces	**2. Experimenting with Newton's Second Law**	**3. Collisions: One Moving and One Stationary Car**	**4. Collisions: Two Moving Cars**	**5. Engineering Challenge: Newton's Third Law**	**6. Magnetic Fields**	**7. Electric Fields**	**8. Magnetic Forces**	**9. Electromagnetic Forces**	**10. Electromagnet Applications**
MS-PS2-1	Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.		●	●	●	●					
MS-PS2-2	Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	●	●	●	●	●					
MS-PS2-3	Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.								●	●	●
MS-PS2-5	Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.						●	●			
MS-ETS1-1	Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.										●
MS-ETS1-2	Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.					●					●
MS-ETS1-3	Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.					●					
MS-ETS1-4	Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.					●					●

Introduction and Overview

The Forces & Interaction Classroom Kit was designed for NGSS middle school classrooms. The ten activities in this kit were developed specifically to align to eight of the standards, summarized on the previous page. Each activity is intended to be performed in one or two 45-50 minute class periods.

Each activity follows the instructional model of the five E's: Engage, explore, explain, elaborate, evaluate. Each activity has a hands-on, model-building component and an experimental component. The model building is not simply a means to an end to obtain an experimental setup; the model building is an essential aspect of the educational intent of the kit. Students learn while assembling the models and then they continue to learn while conducting experiments and activities with the built models. While engineering is intrinsic to the entire process, specific engineering design challenges are presented in Activities 5 and 10.

Each activity section is presented in two parts: The lesson plan for the teacher followed by the step-by-step assembly instructions for the models for the students. The models can be built individually or by students working in groups. The teacher can assist with model assembly as much as needed according to each group of students.

Each kit can be used by up to four students working in a group. Obviously, the smaller the group, the more hands-on time each student will get with the kit. We recommend having one kit specifically for the teacher to use for demonstration and reference.

Please follow all of the tips for using the building system in this kit on pages 9 and 10, and all instructions provided in each set of assembly steps.

The durable plastic parts in this kit are intended to be used again and again. They were specifically designed for classroom use. Leave enough time at the end of each activity period for the students to disassemble the models and place the parts neatly back in their storage bins.

Introduction and Overview

One of the most important tips is to use the anchor pin lever to separate the parts during disassembly. The parts are intentionally designed to fit together very securely so that the models are strong enough to withstand the forces they are subjected to in the experiments. Thus, the anchor pin lever is critical in taking the firmly connected pieces apart again.

Any materials that are needed for the activities that are not already included in the kit are listed in italics in the materials lists at the beginning of each activity.

A digital version of these lesson plans are available for free download on our website. You can download and print multiple copies of the instructions. The digital version also has live hyperlinks, so you can click the various reference links throughout the activities. Scan the QR code to the right to find the digital version of this lesson plan.

Digital lesson plan download

Online videos of each model in action can be accessed by scanning the QR codes at the end of each set of assembly steps.

Online videos of models

If a part breaks or gets lost, don't worry! Please contact us for replacement parts. Thames & Kosmos has a dedicated tech support and customer service staff ready to assist you.

Missing or broken piece? Technical question?
Don't worry! Contact Thames & Kosmos Tech Support:

CALL
800-587-2872
(M-F, 9-5 ET)

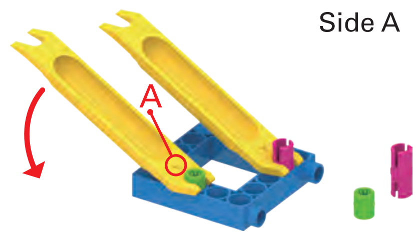
EMAIL
support@thamesandkosmos.com

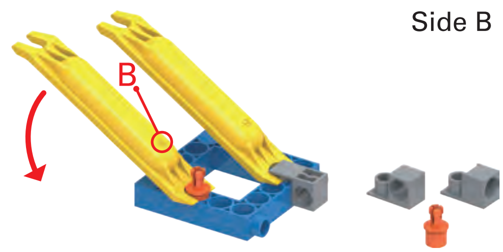
WEB FORM
Scan this QR Code:

Using the Building System

Here are some helpful tips for using the building system in this kit.

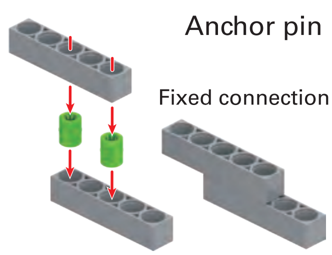
The **anchor pin lever** is required for disassembling the models. Use side A like a crowbar to pry anchor pins and joint pins out of holes. Use side B to pry up shaft plugs and other tightly connected parts.



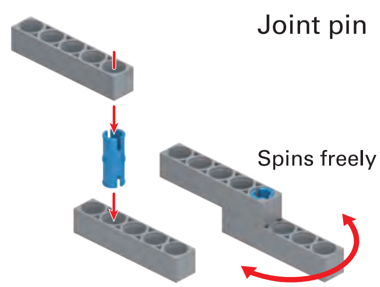


Many of the small **connectors** look alike, but it is important to always use the correct one pictured in the assembly instructions.

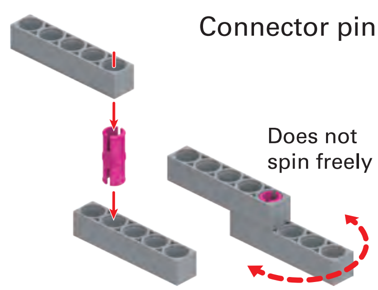
The **short anchor pins** (green in this kit) are used to make fixed, stable connections between rods and other parts.



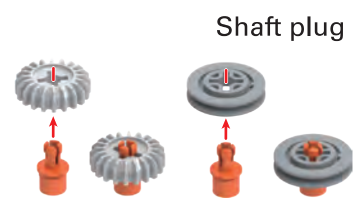
The **joint pin** (blue in this kit) and **long joint pin** (gray in this kit) are used to make pivoting connections between parts, allowing them to spin freely.



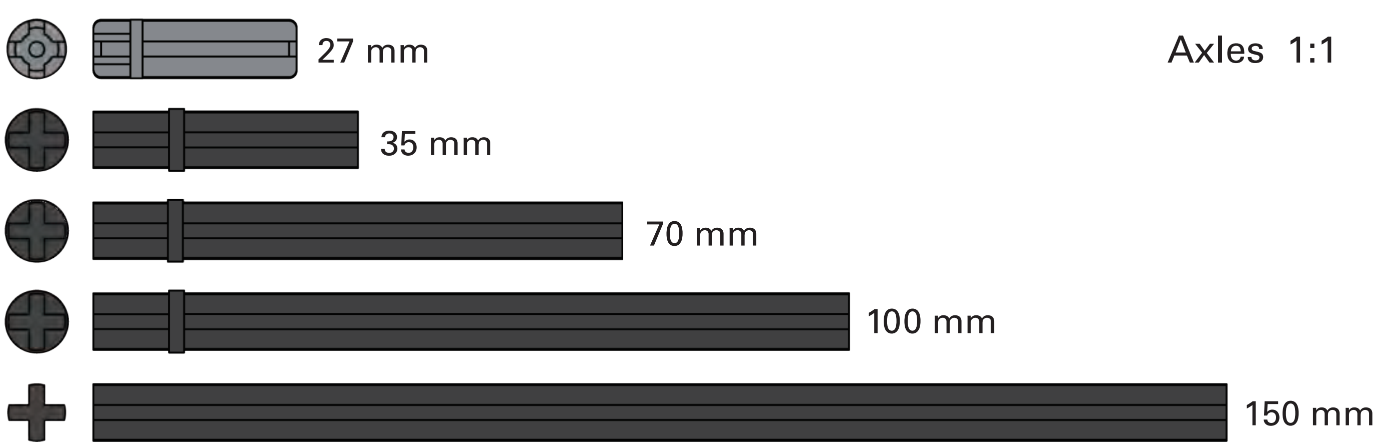
The **connector pin** (pink in this kit) is used to make connections that can be rotated, but that do not spin freely. There is more friction at the joint than with a joint pin.



The **shaft plug** (orange in this kit) is primarily used as an axle for a gear or pulley wheel.



The **axles** come in many sizes. Make sure you always use the correct one pictured in the assembly instructions. The diagram below shows the axles pictured at actual size. Match an axle up to the picture to determine its length when looking for a specific axle called for in the assembly instructions.



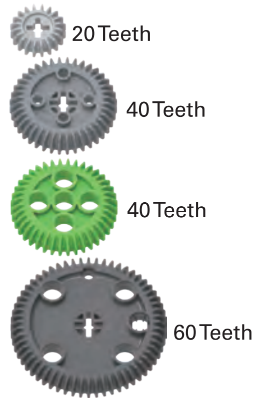
The **gears** are wheels with teeth on them that transmit rotational motion. They come in three sizes: 20 teeth, 40 teeth, and 60 teeth.

The gears can be assembled in many ways. They can be placed in a **single plane,** or they can be placed at a **right angle** to each other to change the axis of rotation. A **worm drive** can also be set up using a worm and worm gear.

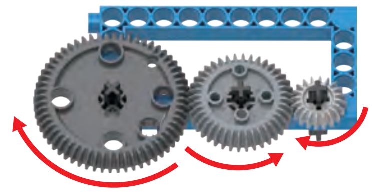
There are many lengths and types of **rods.** The building system is based on a design in which the holes are spaced 10 mm apart. Some of the rods have all their holes oriented in the same direction, and some of the rods have their holes oriented in alternating directions (these are called dual rods). Some of the rods have holes in the ends (called cross rods), some have flat ends, and some have rounded ends. Some of the rods are half as thick as the other rods (called flat rods). Make sure you pay close attention to the assembly diagrams and always use the correct part that is pictured.

The **battery holders** hold one AA battery each. Press the battery into the holder paying attention to the polarity markings on the compartment. The battery holders can be attached to each other in series or in parallel, as shown.

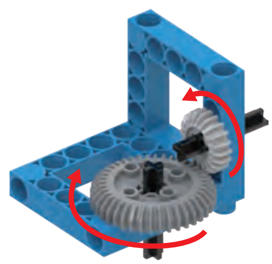
Gears



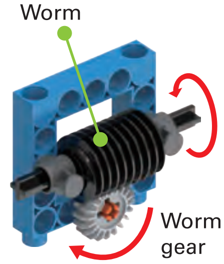
Single-plane transmission



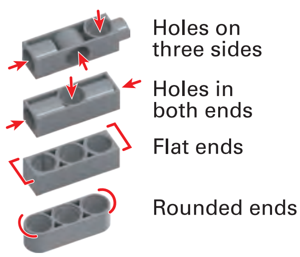
Multi-plane transmission



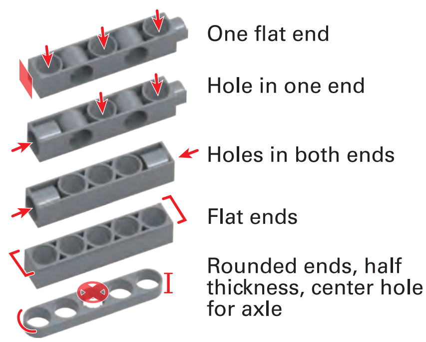
Worm



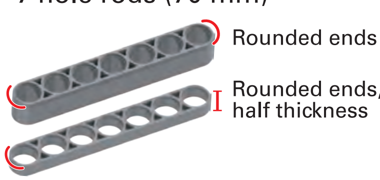
3-hole rods (30 mm)



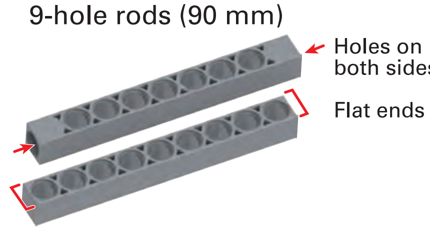
5-hole rods (50 mm)



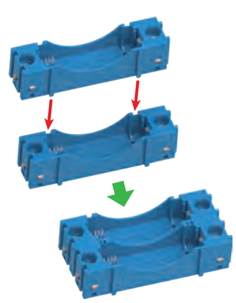
7-hole rods (70 mm)



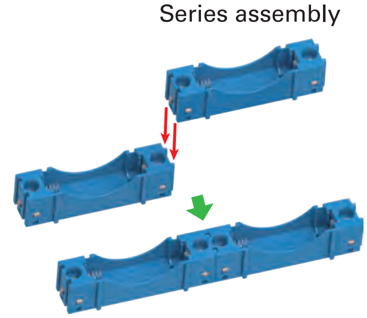
9-hole rods (90 mm)



Parallel assembly



Series assembly



Activity 1

Visualizing Forces

In this activity, students learn or review how to visualize the forces acting upon stationary and moving objects as vector arrows (with magnitude and direction).

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Explore Newton's first law in terms of the sum of the forces acting upon a stationary object.
- Visualize forces as vector arrows with magnitude and direction.
- Share force information with others using a convention of vector arrows with magnitude and direction.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-2	MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	n/a	n/a
Disciplinary Core Ideas	PS2.A: Forces and Motion • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. • All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.	Students observe the motion and magnitude and direction of forces for stationary and moving objects and consider whether or not the sum of the forces acting upon the object is on the object is zero. Students explain why an object is or is not moving by talking about the forces acting upon it. Students learn how to draw force magnitude and direction diagrams for stationary and moving objects.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Crosscutting Concepts	Stability and Change • Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	Students examine the different forces acting upon moving and stationary objects.

Materials Needed

- Assembly instructions for simple car model (located after the instructions for this activity)
- Parts for simple car model (1 set per group of 4 students)
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks (1 per student)*
- *Pencils (1 per student)*
- *Small, medium, and large force arrows (copied from the last page of these instructions, cut out, and laminated, if desired)*
- *Tape*

Notes for Teachers

Because students are learning that the sum of the forces acting upon an object effect its motion, it is necessary for students to start to think about forces as vectors that have both magnitude and direction.

Prior to the Activity

At the end of a prior lesson you might want to ask students who finish early to build cars that will be used for this activity. Also, print, cut apart and if desired laminate the arrows.

Activity Procedure

Part I: Visualizing Forces on a Stationary Object

1. **Engage:** A chair supports a person when she/he sits in it.
2. **Explore:** Divide students into pairs or small groups of up to four. Assign each group to build a car (if not built previously, follow the instructions for Model 1). When finished, students should place the car on the table where everyone in the group can see it.
3. Ask students to make a sketch of the stationary car in their science notebooks. After students have sketched the car, ask them if they think any forces are acting on the car. If so, ask them to draw the forces they think are acting on the car (however they want).

4. When all students are done drawing forces, have them set their science notebooks open to their drawing on their table/desk and conduct a short gallery walk around the classroom so that students can see each other's ideas. This will also serve as a quick formative assessment for teachers to assess initial understanding.
5. Return to seats. Lead a short discussion — did everyone identify the same forces acting on the car? Did everyone draw them the same way? Did students include both the car and the table in their drawings? Were arrows used? Were arrows the same length (magnitude)? Same direction? Why is it important to have agreement about how we will visualize forces?
6. **Explain:** Move one car to the front or center of the room, or use one group's materials that everyone can see. On the board, show students a quick sketch of the car/table system (figure 1).

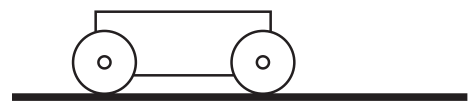


Figure 1

7. Is the car moving up or down? Left or right? Why or why not? What does that tell us about the forces present within the system (Newton's first law, balanced forces — the sum of the forces within the system is zero)? Discuss with the group to come to a consensus about the forces present within the system when the car is not moving (balanced, equal and opposite (Newton's third law*) — the downward force of gravity on the car and the upward force of the table on the car). Students should use different arrows and the model car and table to show how they think the forces should be represented (you may want to use small pieces of tape to hold the arrows in place). Explain that the different length of the arrows represent the magnitude or how large the force is (small arrows = small force, medium arrows = medium force, large arrows = large force). To show equal and opposite force use the same size arrows pointing in opposite directions. One arrow should originate on the table — it is acting upon the car. The other should originate on the car — it is acting upon the table. Show students how to draw these force vectors (magnitude and direction) on the drawing of the car on the board (figure 2).

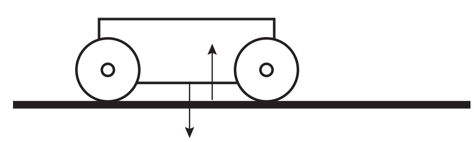


Figure 2

Explain that when discussing forces it is good practice to name the direction of each force and what it is acting upon.

"The _____ force of _____ on _____."

Force 1: downward force of gravity on the car

Force 2: upward force of the table on the car

8. Ask students to draw a second sketch (force diagram) in their science notebooks of the stationary car with arrows (vectors) representing the forces acting upon it using the new convention. Ask students to draw vector arrows showing the magnitude and direction of forces acting upon this car, as before.

   *Newton's third law (when object X exerts a force on object Y, then object Y exerts and equal and opposite force on X) is not the focus of this activity, but this scenario does provide an example of Newton's third law, so you may decide to discuss it.

Part II: Visualizing Forces on a Moving Object

9. **Elaborate:** Start the next part of the activity by asking students why the car is not moving? Students should be able to explain that the car is stationary because there is nothing pushing or pulling on it. They are describing Newton's first law — an object at rest stays at rest.

10. Ask the students to show you what needs to happen for the car to move. When the craziness surrounding car pushing has calmed down, ask students if they observed the other half of Newton's first law — an object in motion stays in motion. Why or why not? Students will have observed their cars coming to a stop either due to friction or because the car hit something. Focus on friction (collisions will be addressed in a later activity). Students will likely understand that a force was required to change the car's motion initially, but may not recognize that it is the force of friction that cause it to stop again. Discuss all of the forces acting students think might be acting within the system and have students add another sketch to their science notebook showing what they think is happening (this serves as a formative assessment for teachers).

11. Explain that the class will now work together to draw a force diagram for a moving object. In a location visible to all students, demonstrate giving a car a push as shown in the diagram (figure 3). After the force is applied by a hand and the car is in motion (in this case, the hand has pushed the car to the left), what forces are acting within the system?** The car is not moving up or down, so the force of the car on the table and the force of the table on the car are still equal and opposite and add up to zero. The car is moving to the left, but it slows to a stop. The rightward force of friction is slowing the car down. The sum of the forces on the car is not zero, so the object is in motion, but since the force acting up the car is opposite its motion, it slows down and eventually stops. Use the arrows and tape to help students visualize these force vectors. Ask students to draw a force diagram for a car in motion in their science notebooks.

    When students are finished, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins. Or, if students are going to complete Activity 2, set the cars aside.

    Force 1: downward force of gravity on the car

    Force 2: upward force of Earth on the car

    Force 3: rightward force of friction

    **For this activity, avoid force diagrams including the hand on the car/car on the hand. This complicates the system and may lead to student confusion.

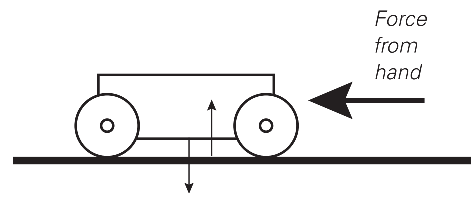


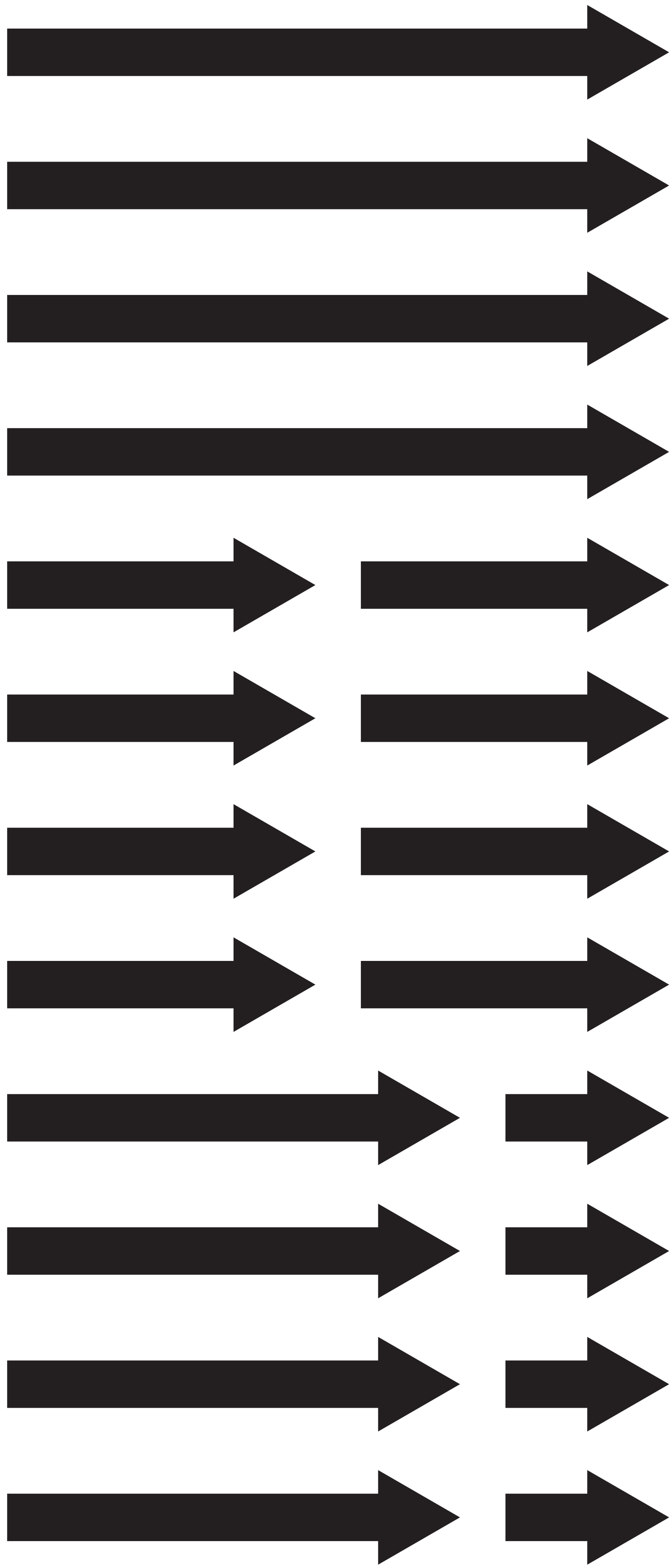
Figure 3

12. **Evaluate:** Ask students to draw a force diagram for a car moving to the right to check for understanding. Collect students' science notebooks and review the sketches to check for misconceptions.

More Resources Related to Forces and Motion

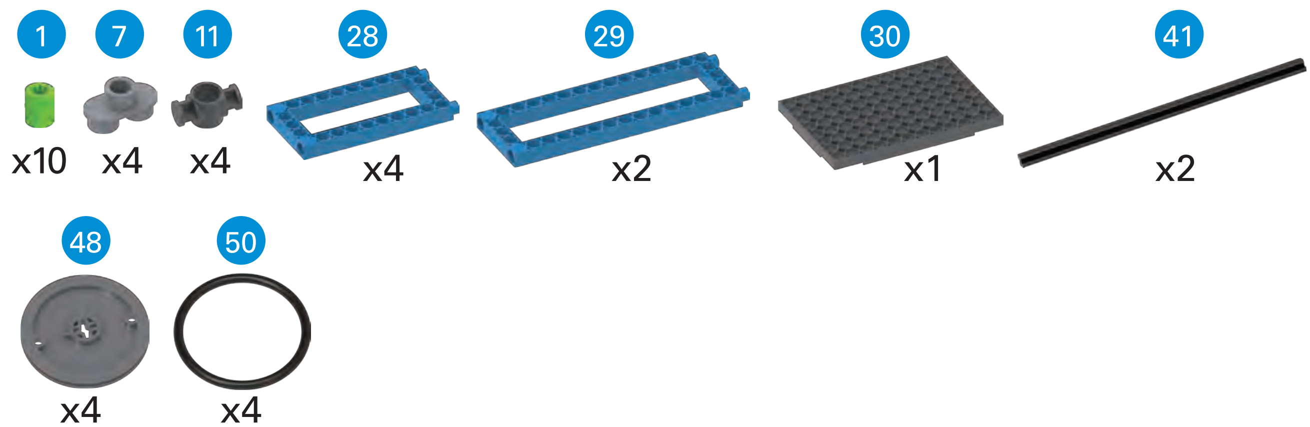
Drawing Free Body Diagrams	http://www.physicsclassroom.com/class/newtlaws/Lesson-2/Drawing-Free-Body-Diagrams	A step beyond drawing forces as in this activity.
PhET Force and Motion Basics	https://phet.colorado.edu/en/simulation/forces-and-motion-basics	Interactive simulations

Force Arrows (Copy and Cut Out)

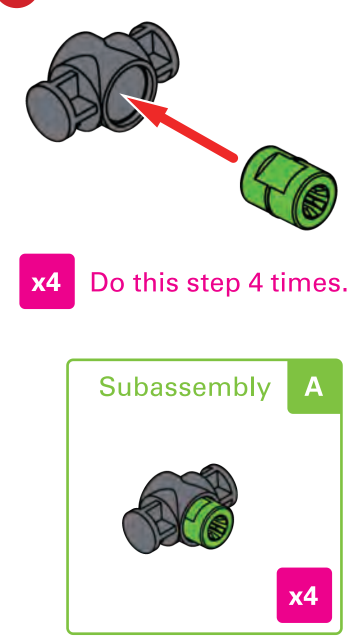


Assembly Steps for Activity 1: Simple Car Model

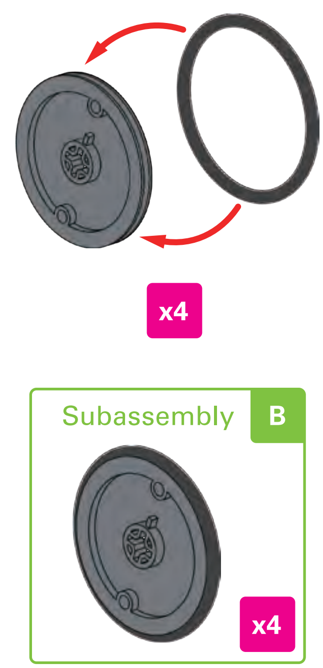
You will need:



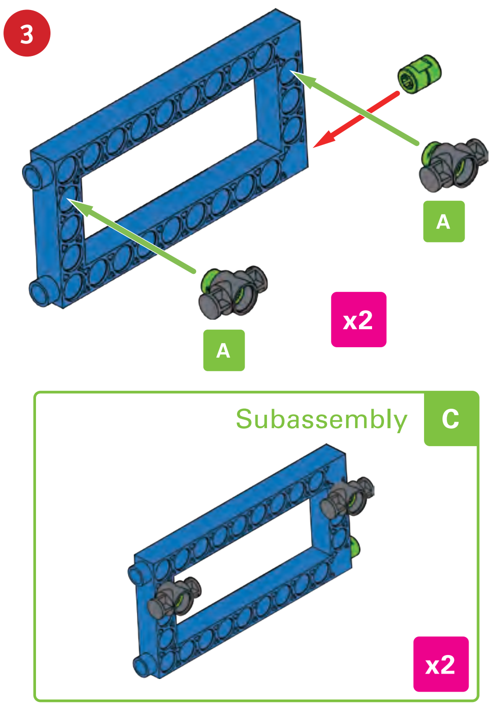
1



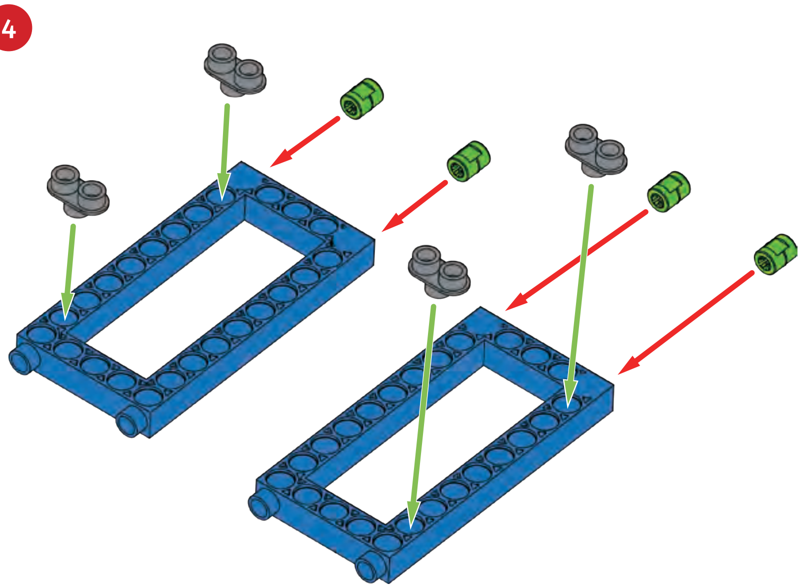
2



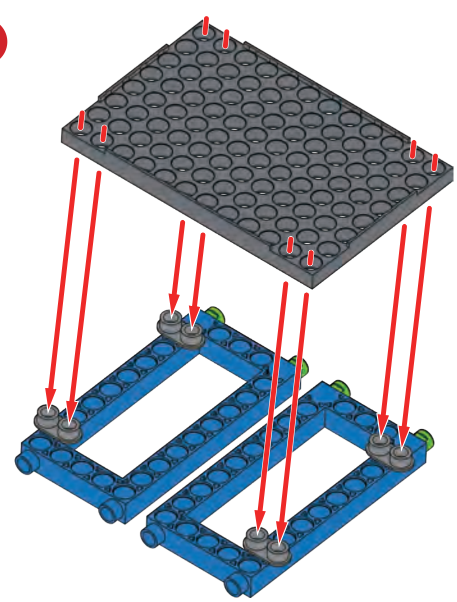
3



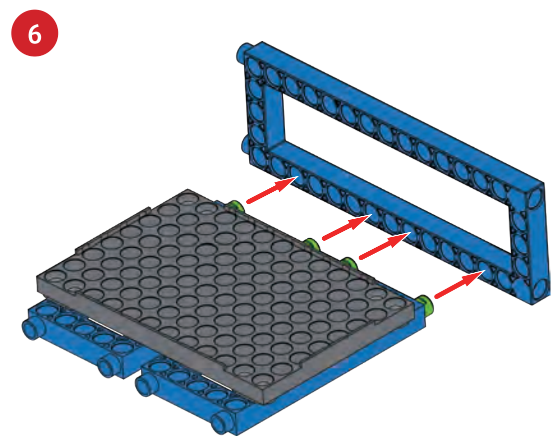
4

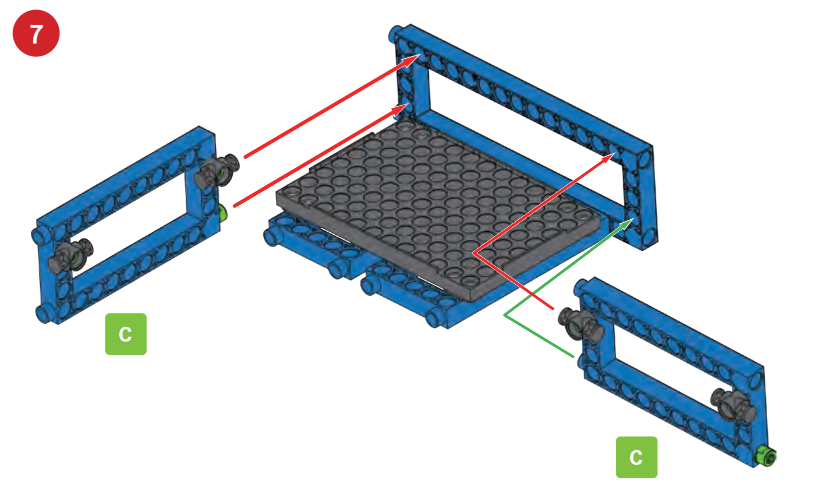


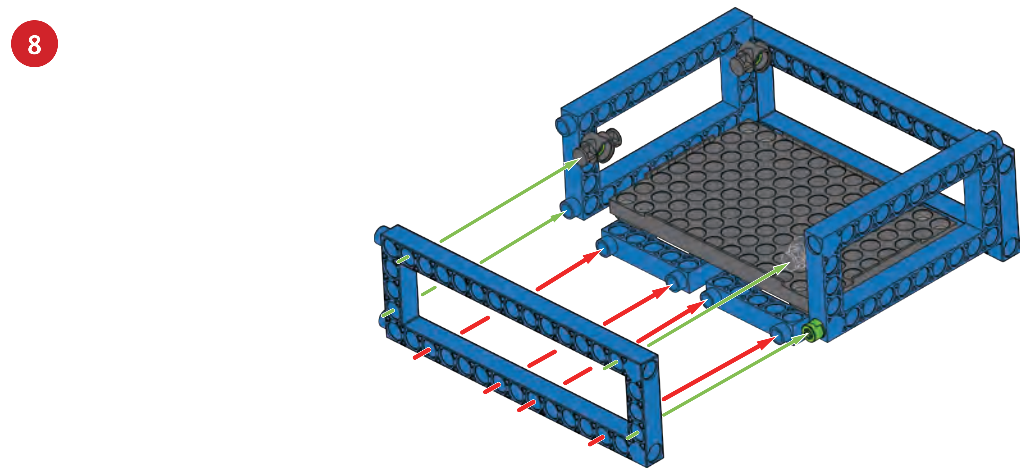
5

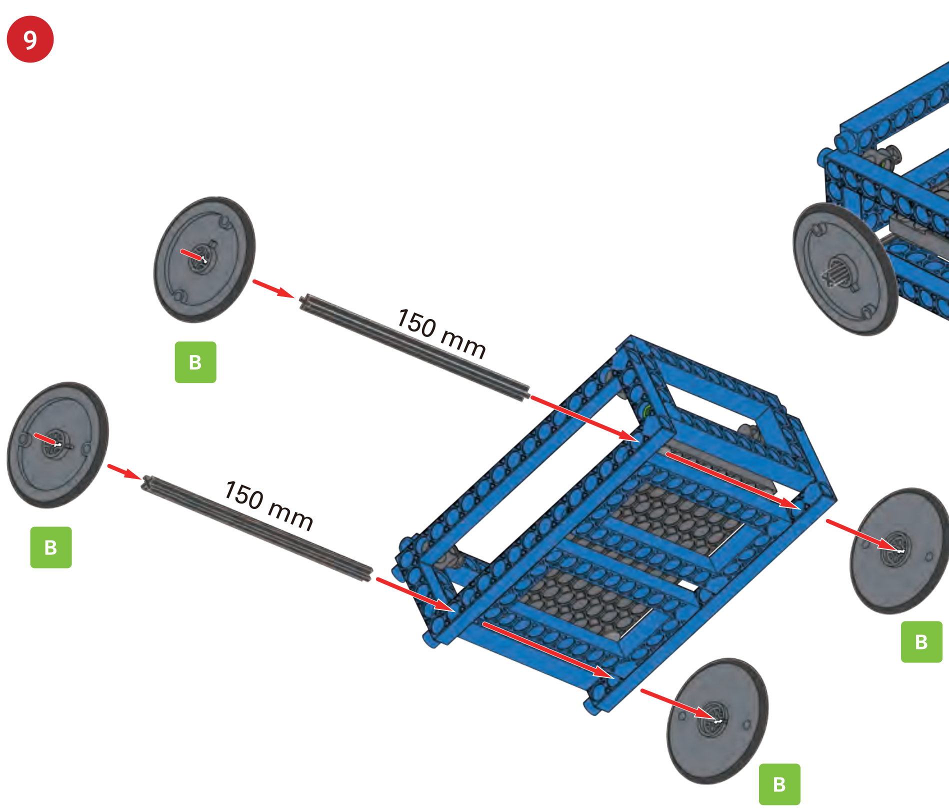


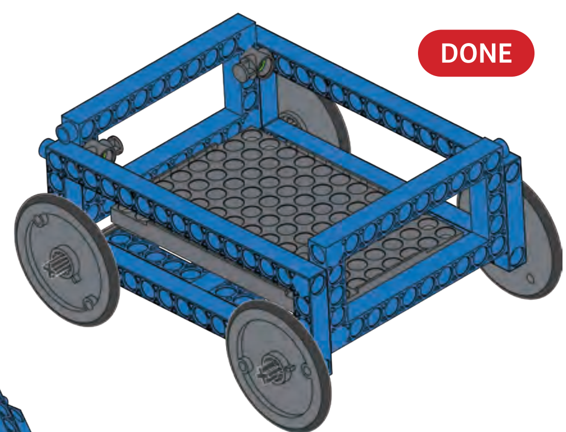
Assembly Steps for Activity 1: Simple Car Model Continued











Scan this QR code video:

Activity 2

Experimenting with Newton's Second Law

Students investigate changes in motion due to varying the force and mass (one variable at a time).

Duration: One or two 45-50 minute classroom periods

Age Group: Middle school

Objectives:

Students will:

- Practice designing experiments with guidance from a teacher.
- Design an experiment to determine how force affects motion of an object.
- Design an experiment to determine how mass affects the force required to move an object.
- Model and communicate about forces acting within a system using force drawings.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-1	MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.
MS-PS2-2	MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Planning and Carrying Out Investigations • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. Connections to Nature of Science Scientific Knowledge is Based on Empirical Evidence • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	Students think about independent and dependent variables, constants and controls, tools and measurements, and how they will plan their investigation to accommodate for good experimental design. Students experiment to identify connections between force and motion, and mass and motion.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Disciplinary Core Ideas	PS2.A: Forces and Motion • For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).	Students demonstrate Newton's third law to understand how forces and motion are related.
	PS2.A: Forces and Motion • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.	Students experiment with forces, mass and motion.
	• All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.	Students use force diagram convention to describe forces acting upon objects.
Crosscutting Concepts	Stability and Change • Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	Students observe stability and change related to forces.
	Systems and System Models • Models can be used to represent systems and their interactions — such as inputs, processes and outputs — and energy and matter flows within systems.	Students use a system model to experiment with forces, mass and motion.

Materials Needed

- Assembly instructions for simple car model with weight baskets (located after the instructions for this activity)
- Parts for simple car model with weight baskets, including simple car model from Activity 1 (1 car and weight basket setup per group of 4 students)
- Anchor pin levers (1 per group)
- *Science notebooks*
- *Pencils*
- *Stopwatches or access to smartphone timers*
- *Soccer ball (actual or photo)*
- *Ping pong ball (actual or photo)*
- *Bowling ball (actual or photo)*

Notes for Teachers

During scientific experimentation, it is critical for students to understand the importance of varying only one aspect of the system at a time so that any change that occurs can be attributed to the variable that was manipulated. Students should think about how they plan to test different variables one at a time prior to starting their investigation.

Activity Procedure

Part I: Balanced Forces

1. **Engage:** Show students a soccer ball. Does it move if we don't do anything to it? (The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change.) How far and fast will the ball move with a light tap? How far and fast will it move with a quick kick? Allow students to take it outside and try it out. (For any given object, a larger force causes a larger change in motion.) Next, show students a ping pong ball and a bowling ball. Which would be more difficult to roll? Can they move the ping pong ball with the force from simply blowing on it? How about the bowling ball? Allow students to try it out. (The greater the mass of the object, the greater the force needed to achieve the same change in motion.)
2. **Explore:** Show students the simple car (from Activity 1). Set it on a table where students can see it. Ask students, "what factors affect this car's motion?" Students should discuss various factors that do or could apply force to the car (such as the table, push of a hand, pull of a hand, blowing on it, etc.) and if and how they might affect how it moves (or make it move at all, which is a change in motion). They should also recognize, with guidance and strategic questioning, that the mass of the car is also a factor in how it moves (e.g., how might this car move differently if we set a book on top of it?). The concept of mass could be saved for discussion until after the first part of this activity is completed.
3. Divide students into pairs or small groups (no more than 4 per group).
4. Instruct students to build the car (or use car from Activity 1), the guide wheels and weight containers. Attach weight

baskets to either side of the car with the string and set the strings up to run over the guide wheels on a table as shown in diagram (figure 1).

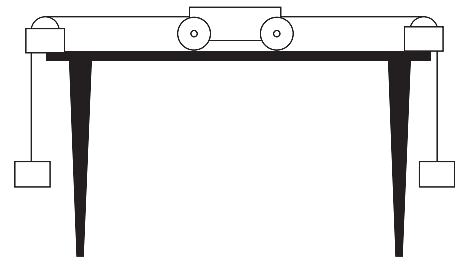


Figure 1

5. Instruct students to make a drawing of all the forces acting upon the car in their science notebooks (figure 2). Students should understand that the strings pulling on either side of the car are forces. Is the car moving up or down? Why not? (The force of the table on the car and force of the car on the table are equal and opposite and therefore there is no change in motion.) Is the car moving side to side? Why not? (The forces pulling the car right and left are equal and opposite and therefore there is no change in motion.)

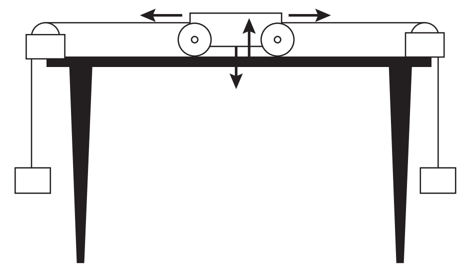


Figure 2

6. With this system setup and some weights (the included metal washers, or other weights) the students have all the tools they need to design an experiment to test:

    a. how changes in <u>force</u> acting upon the car affect the car's motion (rightward and leftward forces can be varied by adding weight to the baskets), and

    b. how changes in the car's <u>mass</u> affect the car's motion (mass can be varied by adding weight to the car).

    For Part I of this activity, students should focus on designing an experiment to test <u>forces.</u> Use as much guidance as necessary for student groups to work together to plan and carry out the investigation about force. An example experiment is outlined below.

<u>Example Force Experiment</u>
Driving Question: How does magnitude and direction of force affect motion?
How will the car's motion change if the amount of force pulling it on one direction or the other is changed (using the metal washers or other weights to add weight to either or both sides and change forces acting on car)?

Best practices for designing an experiment:

- You may need to use technology as an extension of your senses to make observations (for example, rulers to measure distances or stopwatches to time events).
- Start with a hypothesis related to what you are studying. Using "if … then … because" might be helpful (e.g., <u>If</u>

weight is added to the basket on the right then the car will move to the right because the sum of the magnitude and direction of the forces is greater to the right).

- Identify a baseline or control to which other results can be compared. In this case, the system setup with balanced forces is a good control.
- Define the independent variable. (During Part I of this activity, force will be the only variable in the system changed by the experimenter. The magnitude of the force (represented by the weight added to the weight baskets) is the independent variable.)
- Test only one independent variable at a time.
- Define the dependent variable. (When experimenting with forces the motion of the car depends on the force so the motion of the car (magnitude and direction) is the dependent variable).
- Identify constants (everything else besides the weight added (force) and car's motion remains constant).
- Determine which measurements should be taken and how they should be recorded. For example:

	Independent Variable	Dependent variable	
Trial	Weight/force	Motion (descriptive or subjective)	Motion (measured/timed from point a to point b)
Control	Equal/balanced, no weights in either basket	Car does not move	
1	5 metal washers in right basket — greater force to the right	Car moves to the right	2 seconds
2	10 metal washers in right basket — force on right is twice as much as in trial 1	Car moves to the right more quickly	<1 second
3	5 metal washers in left basket — greater force to the left	Car moves to the left	2 seconds
4	10 metal washers in the left basket — force on left is twice as much as in trial 1	Car moves to the left more quickly	<1 second
5	5 metal washers in each basket — forces are balanced	Car does not move	

7. **Explain:** When students have completed their experiment, they should summarize and share their results with their peers. Work with student groups to correctly explain how

force affects motion (the motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change.) They should be able to explain force and motion in terms of force vector arrows (e.g., motion is to the right in the diagram below because the total sum of the forces is positive in that direction). For example, figure 3.

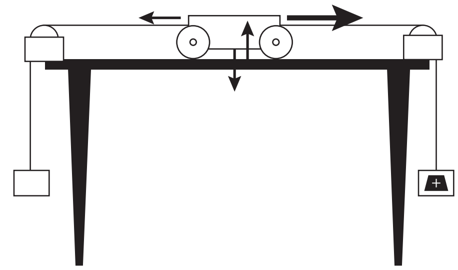


Figure 3

Part II: Mass and Motion

8. **Elaborate:** When students have completed an investigation of force and motion, they should now turn their attention to how the mass of an object affects its motion. Again, the setup they already have will serve as a basis for this experimental design. The end goal of their experiment is to find evidence that the greater the mass of the object, the greater the force needed to achieve the same change in motion.

<u>Example Mass Experiment</u>
Driving Question: How does the car's mass affect its motion? How does increasing or decreasing the car's mass affect the amount of force needed to achieve the same motion?

The independent variable becomes the mass of the car and the dependent variable its change in motion. Force should remain the same for each trial (but should be unbalanced so that there is motion), but mass will vary.

Best practices for designing an experiment:

- You may need to use technology as an extension of your senses to make observations (for example, rulers to measure distances or stopwatches to time events).
- Start with a hypothesis related to what you are studying. Using "if … then … because" might be helpful (e.g., <u>If</u> weight is added to the car, <u>then</u> more metal washers (or other weights) will need to be added to the basket to move the car the same distance <u>because</u> the greater the mass, the greater the force needed to achieve the same motion.)
- Identify a baseline or control to which other results can be compared. In this case, because we are studying change in motion, an unbalanced force is necessary to test the hypothesis, so a good baseline would be the motion of the

car with three metal washers in the weight basket and no weight in the car.

- Define the <u>independent</u> variable. (When experimenting with mass, mass will be the only variable in the system changed by the experimenter. The magnitude of the mass (represented by the weight added to the car) is the independent variable).
- Test only <u>one</u> independent variable at a time.
- Define the <u>dependent</u> variable. (We are interested in the magnitude of the force, so force (represented by the number of metal washers that must be added to the basket to achieve the same motion is the dependent variable).
- Identify <u>control</u> variables (everything else besides the weight added to the car (mass) and force it takes to achieve the same motion remains constant).
- Determine which measurements should be taken and how they should be recorded. For example:

	Independent Variable	Dependent Variable
Trial	Mass of car	Amount of force it takes to move car 1 foot to the right (represented by amount of weight added to right basket)
Control	Car only	3 metal washers
1	Car with 3 metal washers	6 metal washers
2	Car with 6 metal washers	9 metal washers

When students are finished, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

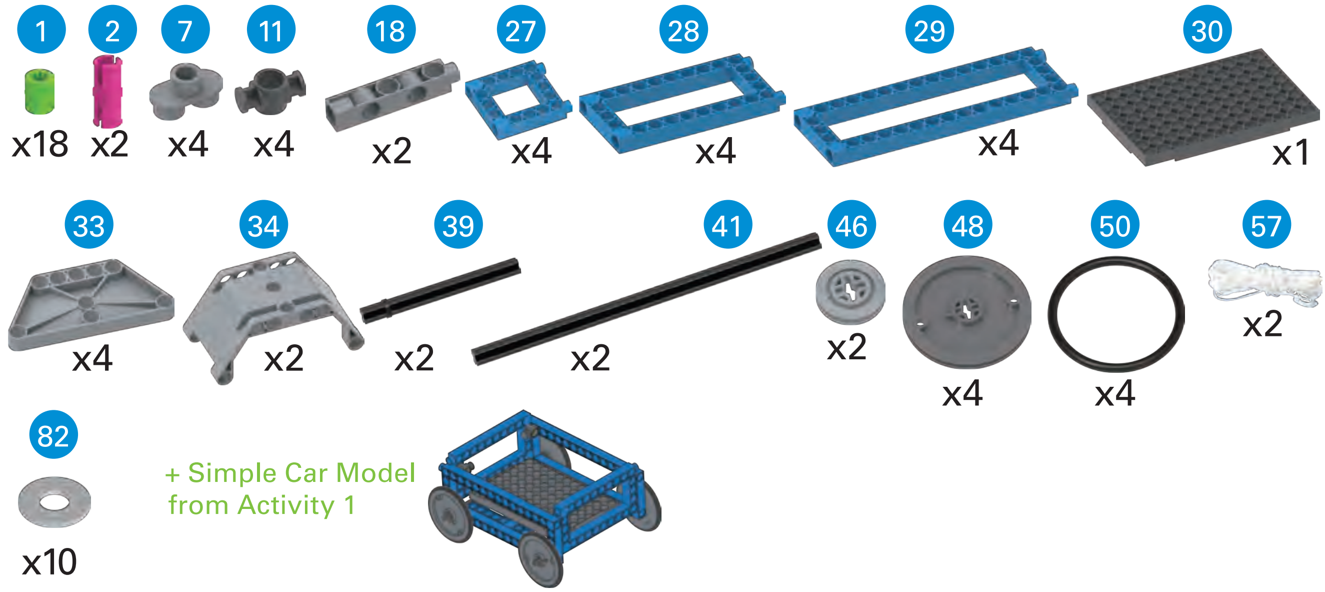
9. **Evaluate:** Throughout and/or after Part I and then Part II, work with students to identify misunderstandings related to both experimental design technique and force, mass and motion. Experimental design in Part II could be used to evaluate understanding of experimental design after students complete Part I with more guidance.

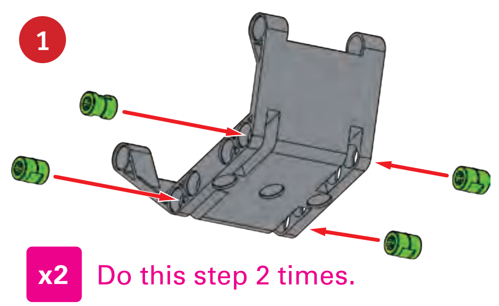
Extension

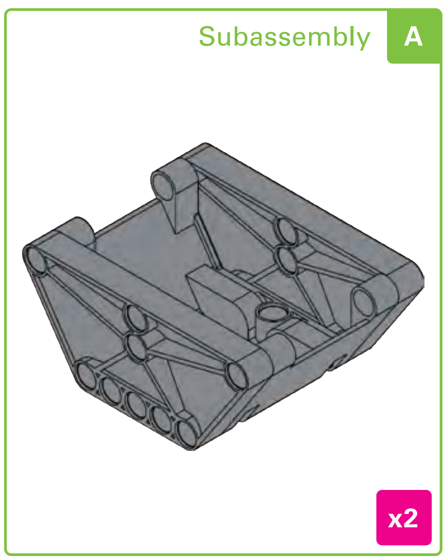
Have the students repeat their experiments and see if the data trends remain the same or change.

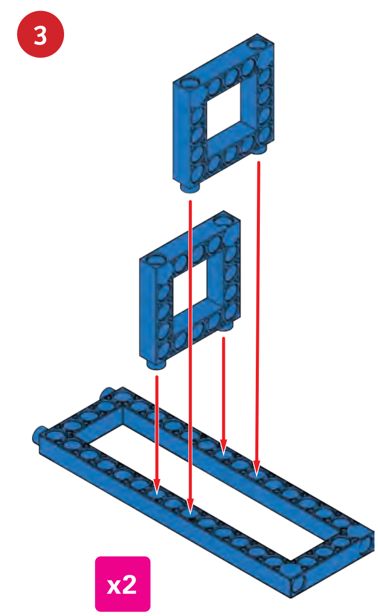
Assembly Steps for Activity 2: Simple Car Model with Weight Baskets

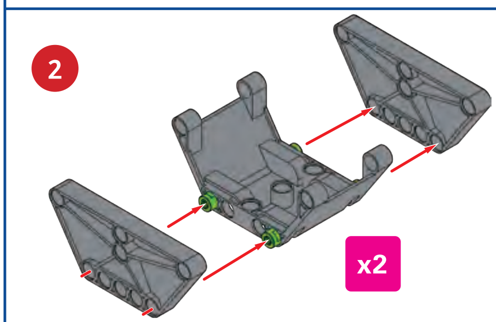
You will need:

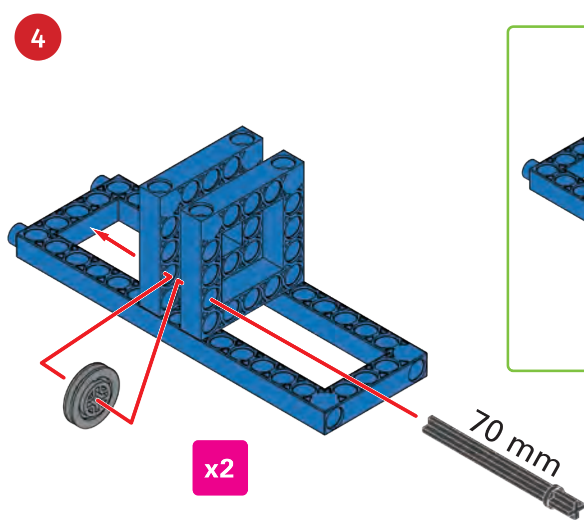


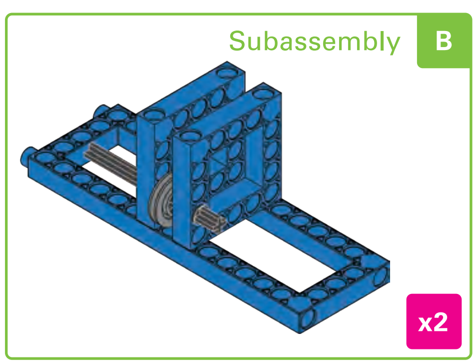


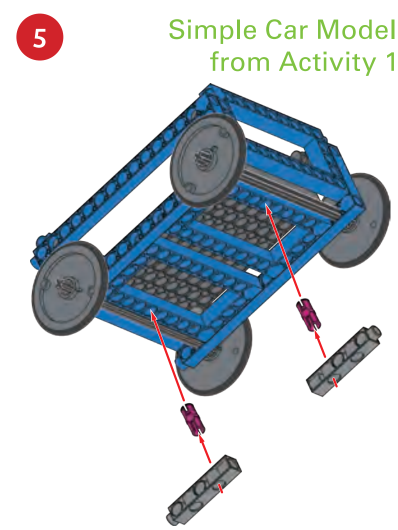






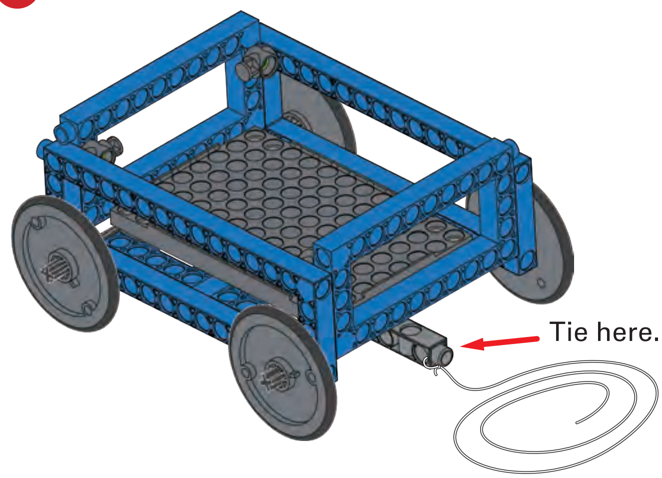




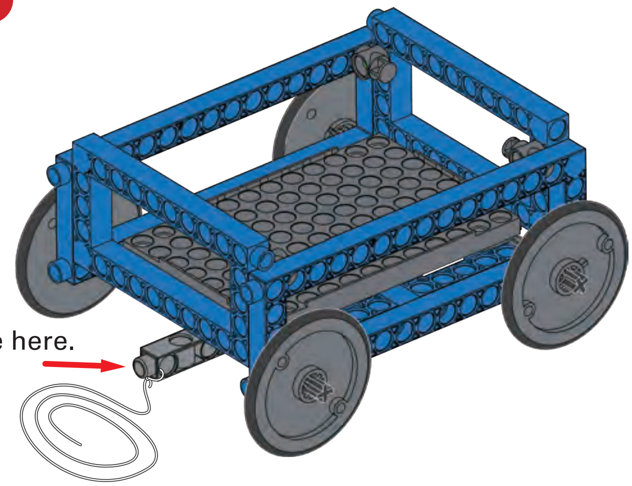


Assembly Steps for Activity 2: Simple Car Model with Weight Baskets Continued

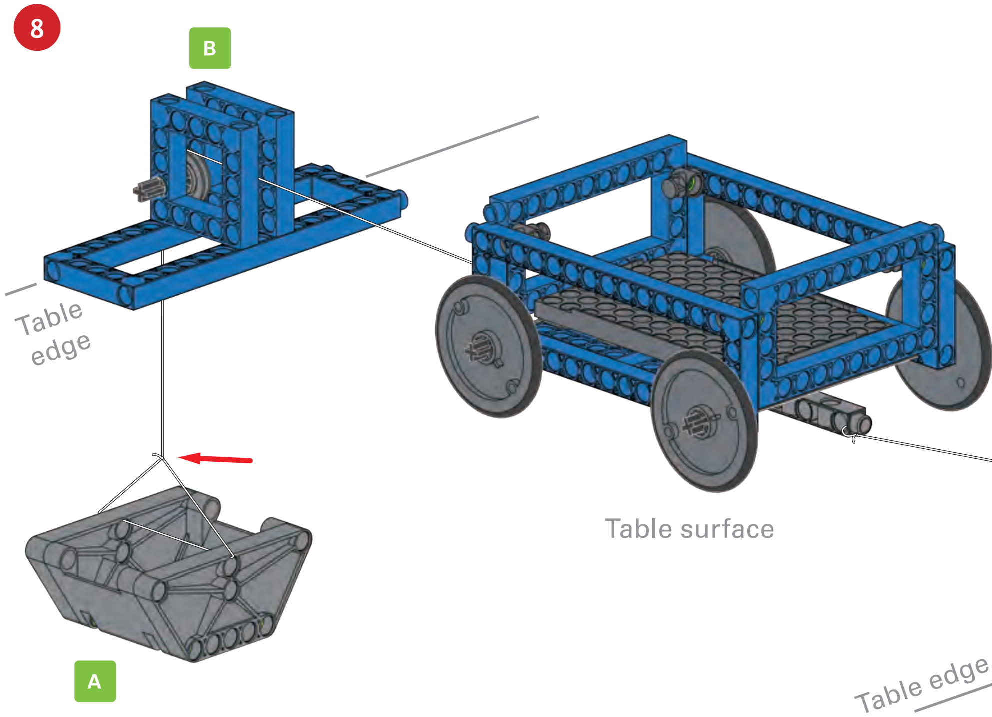
6



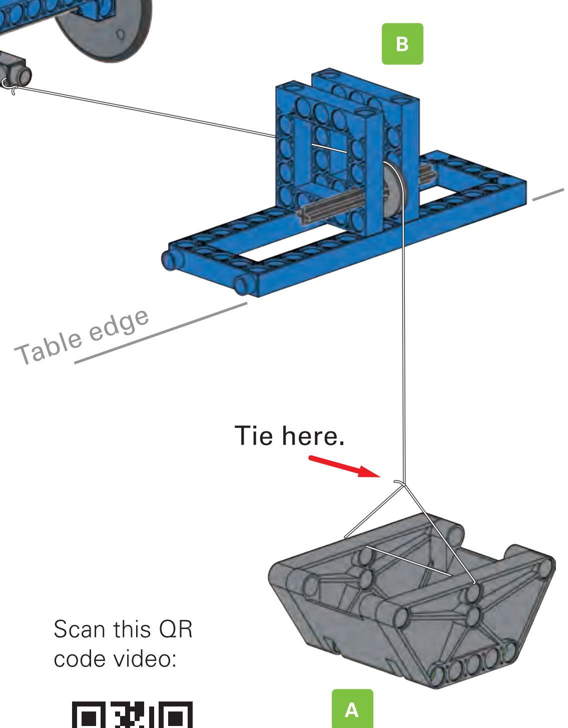
7

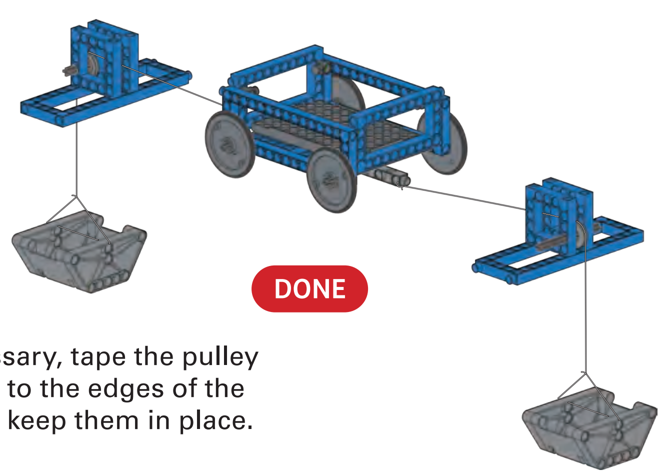


8



Measure and cut the pieces of string to length such that the baskets can hang off the opposite edges of the table and pull the car from one side of the table to the other.





Scan this QR code video:

If necessary, tape the pulley holders to the edges of the table to keep them in place.

Activity 3

Collisions: One Moving and One Stationary Car

Through this activity, students expand their understanding of motion by thinking about the forces involved when a moving object collides with a stationary object.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Experiment with how velocity and mass (momentum) affect the motion of moving and stationary objects during a collision.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-1 MS-PS2-2	MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Planning and Carrying Out Investigations • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. Connections to Nature of Science Scientific Knowledge is Based on Empirical Evidence • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	Students recognize the importance of consistency of controls between investigation trials (placing cars in the same location for different trials). Students use observations as evidence on which to base explanations.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Disciplinary Core Ideas	PS2.A: Forces and Motion • For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). PS2.A: Forces and Motion • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. • All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.	Students examine forces in collisions and consider Newton's third law. Students draw force diagrams to explain motion of different objects during collisions.
Crosscutting Concepts	Systems and System Models • Models can be used to represent systems and their interactions — such as inputs, processes and outputs — and energy and matter flows within systems. Stability and Change • Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	Students create a system model and observe the interaction of its components during changes to the system. Students observe stability and change related to collisions.

Materials Needed

- Assembly instructions for collision test track with one launcher (located after the instructions for this activity)
- Parts for the collision test track with one launcher (one set per group)
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks*
- *Pencils*
- *Wet erase markers (one per group)*
- *Rulers (one per group)*

Notes for Teachers

Students should come into this activity with a basic understanding of force vector arrows that represent the magnitude and direction of forces. This activity focuses on a specific type of collision between a moving and a stationary moveable object (such as a moving and a stationary car, or a rolling and a stationary billiard ball). At this level, focus is on changes of motion and forces in one dimension at a time. Students should be able to observe and predict motion of objects in various one dimensional collision scenarios.

Newton's Third Law and Collisions

When thinking about collisions at the middle school level, the focus should be placed on the idea that when two objects collide, the force of object A on object B is equal and opposite to the force of object B on object A (figure 1).

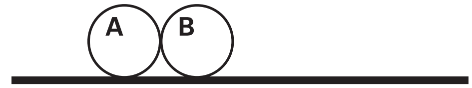


Figure 1

However, any moving object has momentum (p), which is directly influenced by mass and velocity, both speed and direction ($p = mv$). Although students don't need to get into quantitative analysis of momentum, they can observe that the speed that one or both objects are moving, the direction one or both objects are moving, and the objects' masses can all have an affect on the resulting motion of both objects after collision.

A and B have the same mass. A is moving to the right and B is stationary (figure 2). The force of A on B and B on A will be equal and opposite at the moment of collision. What happens to A and B after the collision? The motion of A and B depends on the type of collision. Read below.

Figure 2

Elastic and Inelastic Collisions

In a perfectly elastic collision, object A stops when it collides with object B. All force is transferred to object B and object B's motion continues in the same direction at the same speed (figure 3).

For a collision to be perfectly elastic, there must be no friction and no air resistance, circumstances not found outside a laboratory setting. However, a perfectly elastic collision can be simulated. To observe a perfectly elastic collision visit: https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html

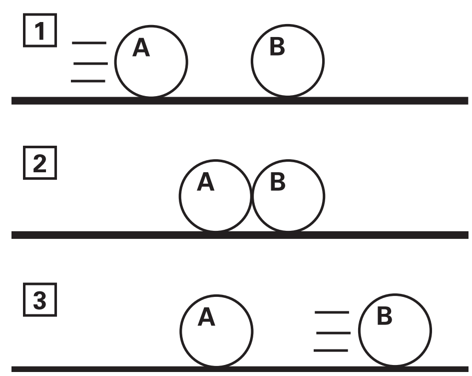


Figure 3

The opposite of a perfectly elastic collision is completely inelastic collision. In this type of collision, A collides with B and both continue to move in the direction of A's motion together, but at half the speed because the two objects together now have twice the mass (figure 4).

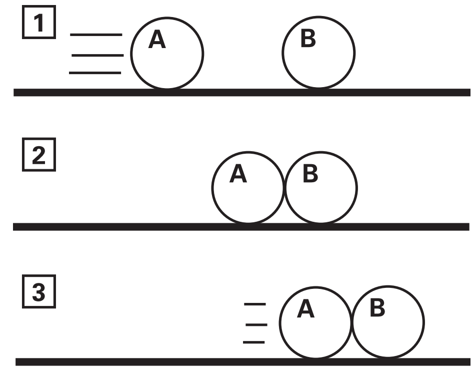


Figure 4

In the real world, most collisions are inelastic, but not perfectly inelastic. This means both objects change motion after a collision. If object A is moving toward object B, which is stationary, when A collides with B, it is likely that B will move to the right, but A will also continue to move (figure 5). Whether object B moves and the direction of motion for A is dependent on the mass and velocity for both objects.

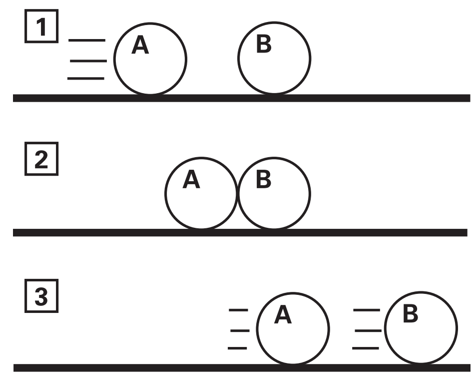


Figure 5

Activity Procedure

Part I: Collision Between a Moving and a Stationary Car

1. **Engage:** Ask students if any of them have ever been bowling. Discuss or share a video of a bowling ball striking pins. Explain that today's class is all about crashes (collisions), like those between a moving bowling ball and stationary bowling pins.

2. **Explore:** Explain that students are going to get to have some fun exploring how objects interact during a collision. Today's focus will be on how one moving car interacts with one stationary car (students will want to experiment with collisions between two moving cars which is addressed in a separate activity).

3. Divide students into pairs or small groups (up to four students per group). Distribute building materials and instructions. Monitor as students build the track and two cars.

4. When all groups are ready, demonstrate how to use the rubber band launcher correctly. An axle holds the launcher rod in place. To launch the car, quickly pull the axle out of the launcher while holding the track in place.

   Ask students to place the two cars on the track. Allow students ample time to explore collisions between the two cars. Circulate and remind students to focus on collisions between one moving and one stationary car. After students have had some unstructured time, reign in their focus by asking them to record some specific observations in their science notebooks. Encourage students to make sketches to explain their observations.

a. What do you observe when a moving car collides with a stationary car? How does the moving car's motion change? How does the stationary car's motion change?

b. What happens if the moving car is moving slowly? Quickly?

5. When students have completed their observations, facilitate a group discussion around the above questions. What was observed? Did everyone observe the same thing? Why or why not? Do we have enough information (data) to come to a conclusion about the motion of these cars after a collision? Why or why not? What can we do to investigate further? Lead the discussion toward a more organized investigation to gather data. As a class, come up with an experimental design to test observations. Students may come up with something different than described below, or the teacher can help them come up with the experimental design explained below. Students should then return to their groups to conduct the more structured experiment.

6. **Explain:** Using tape, students should label the left-hand car "1" and the right-hand car "2" (figure 6). Car 1 should be at the end of the track pushed up against the launcher and car 2 some distance away (if desired, all groups can measure a consistent distance and data can be compiled for the class). Students should then make a mark on the track indicating where cars 1 and 2 sit using tape or a dry erase marker. Emphasize the importance of consistency of placement as they experiment (for example, placing the center of the right wheel on the mark each time).

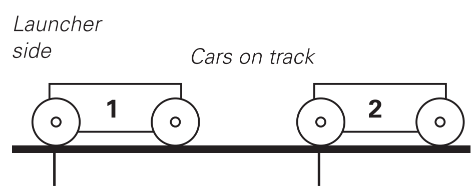


Figure 6

7. Now ask students to sketch the setup in their science notebooks. They should include the track and both cars, as well as the lines.

8. Students have now established a consistent setup. Their first investigation will be to determine how velocity (speed

and direction) affects the motion of the cars when they collide. In this first investigation, students should pull the launcher rod back only halfway when they set it. Before they start, you may want to ask students to predict what they think will happen. You may also want to take the time to have students perform several trials at the same velocity, to determine that their observations hold true each time. Before students begin their trials, help them prepare their science notebooks to record the data. They will be measuring how far and in which direction car 1 and car 2 end up from where they each started.

Trial	Car 1	Car 2
1 (Launcher rod pulled back halfway)	10 inches to the right	15 inches to the right
2 (Launcher rod pulled back halfway)	9 inches to the right	13 inches to the right
3 (Launcher rod pulled back halfway)	9.5 inches to the right	14 inches to the right

9. Give students time to complete the agreed upon number of trials. When they are finished, facilitate a discussion about what happens when a moving object collides with a stationary but movable object. You may decide to use the arrows from Activity 1 as visuals for force direction and magnitude during this discussion.

    a. When car 1 is moving and collides with car 2, what is the resulting motion for both cars?

Part II: Collisions at Varying Speeds

10. **Elaborate:** Students now have a general understanding about how motion changes when two cars of equal mass collide at a consistent velocity. In Parts II and III students build on this understanding by changing variables that affect momentum to see how that impacts the motion of the two cars. Throughout these investigations students should record experimental design and results in their individual science notebooks.

11. **Speed:** Students repeat the investigation from Part I, but use the rubber band launcher to systematically apply more force to car 1 (more force results in greater velocity). This is achieved by pulling the launcher rod all the way back instead of just halfway back as in Part I. Students should only change one variable at a time (e.g., run several trials at one speed

before testing another). Students should compare what happens in these trials to what happened in Part I. What trends do they identify? (Students should see that when car 1 hits car 2 with greater velocity the resulting motion is the same, but both cars move further. When car 1 hits car 2 with less velocity, the motion is the same but both cars move less far. If the velocity with which car 1 hits car 2 is too small, car 1 may stop and car 2 may remain stationary.)

Trial	Car 1 (fast)	Car 2
4 (Launcher rod pulled back all the way)	16 inches to the right	15 inches to the right
5 (Launcher rod pulled back all the way)	17 inches to the right	18 inches to the right
6 (Launcher rod pulled back all the way)	16 inches to the right	13 inches to the right

Trial	Car 1 (slower)	Car 2
1 (Launcher rod pulled back halfway)	10 inches to the right	5 inches to the right
2 (Launcher rod pulled back halfway)	9 inches to the right	4 inches to the right
3 (Launcher rod pulled back halfway)	9.5 inches to the right	5 inches to the right

Part III: Collisions with Varying Masses

12. **Mass:** Students repeat the initial investigation (velocity constant), but add mass to one car or the other. This is achieved by placing metal washers in the car's basket. Students should only change one variable at a time (e.g., add mass only to car 1 for several trials, then remove extra mass from car 1 and add extra mass to car 2). Students should compare what happens in these trials to what happened in Part I. What trends do they identify?

Trial	Car 1 (mass increased)	Car 2
10 (5 metal washers in car 1)	13 inches to the right	10.5 inches to the right
11 (5 metal washers in car 1)	14.5 inches to the right	11.5 inches to the right
12 (5 metal washers in car 1)	17 inches to the right	15 inches to the right

Trial	Car 1	Car 2 (mass increased)
13 (5 metal washers in car 2)	12.5 inches to the right	9 inches to the right
14 (5 metal washers in car 2)	11.5 inches to the right	8.5 inches to the right
15 (5 metal washers in car 2)	12.5 inches to the right	6.5 inches to the right

13. As a group, discuss the trends that were identified as mass and velocity were varied in collisions between a moving and stationary object. Discuss these questions:

    a. How does velocity (speed and direction) effect motion during this type of collision?

    b. How does mass effect motion during this type of collision?

    When students are finished, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins. Or, if the students are going to complete Activity 4, set the cars and track aside to use for Activity 4.

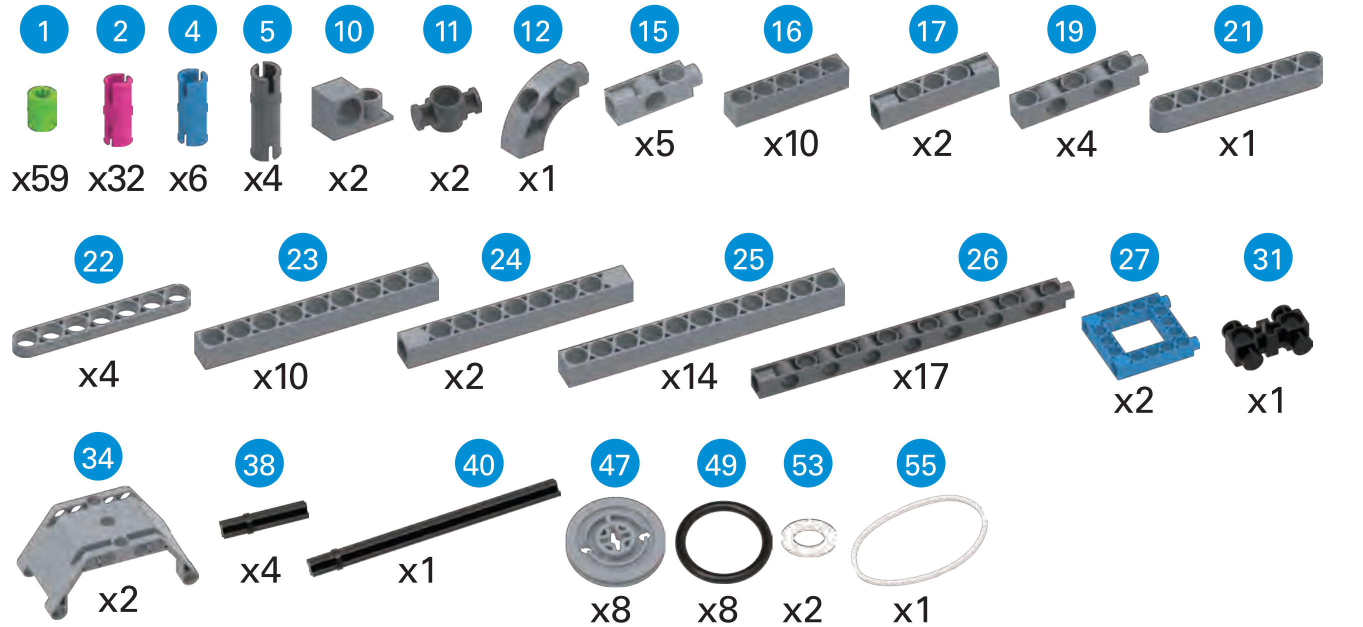
14. **Evaluate:** Provide students with a few scenarios similar to those explored through Parts I, II, and III. In their science notebooks ask them to predict the motion of both cars.

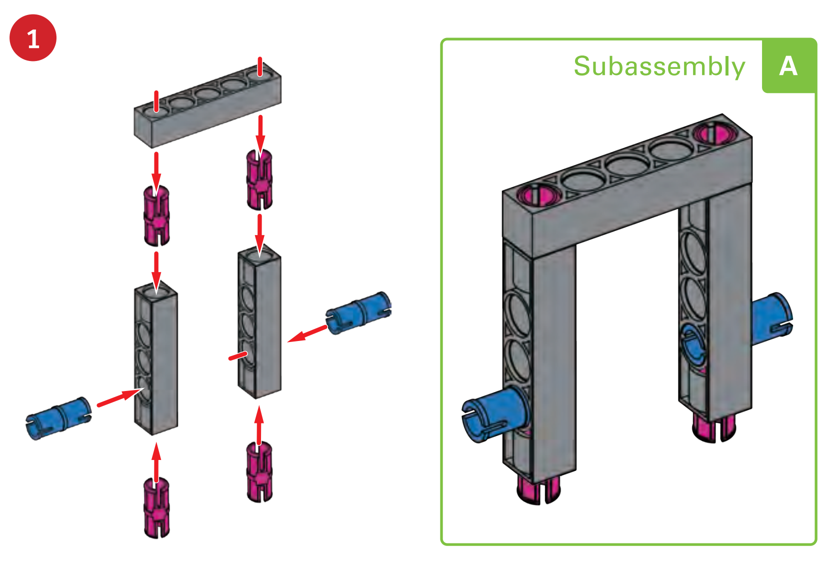
More Resources Related to Forces and Motion

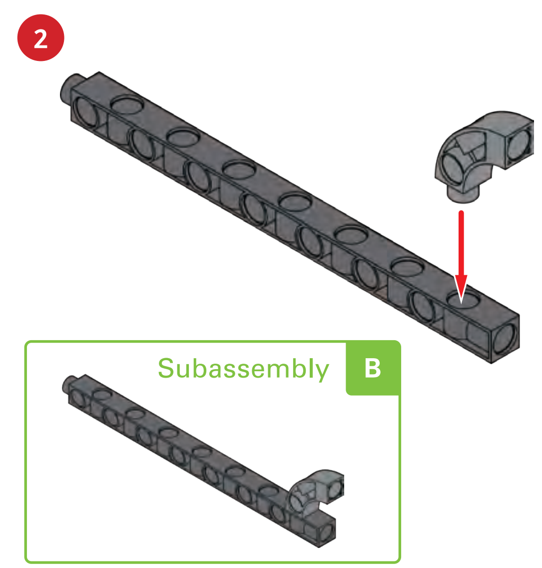
Collision Cart Interactive	http://www.physicsclassroom.com/Physics-Interactives/Momentum-and-Collisions/Collision-Carts/Collision-Carts-Interactive	Good simulation to show completely elastic or completely inelastic collisions between stationary or moving cars.
PhET collision lab	https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html	Introductory level is in one dimension. Elastic/inelastic collision spectrum. Mass and speed can be varied.

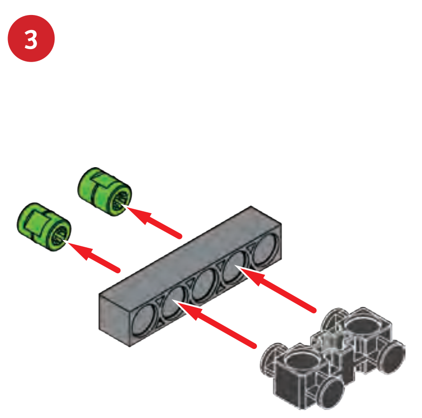
Assembly Steps for Activity 3: Collision Test Track with One Launcher

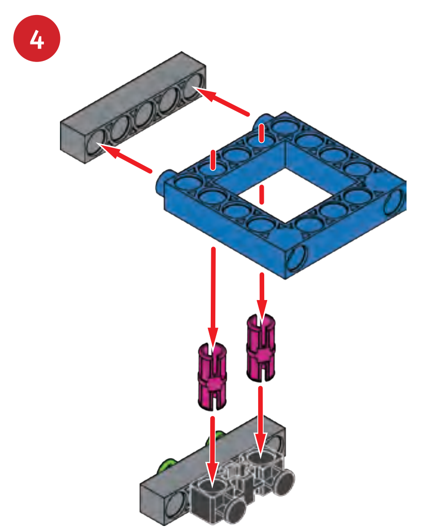
You will need:

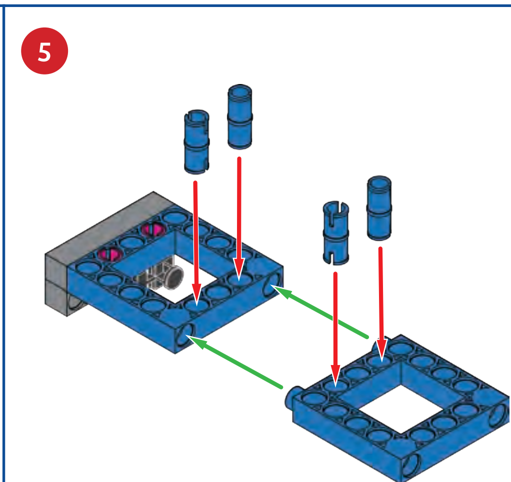






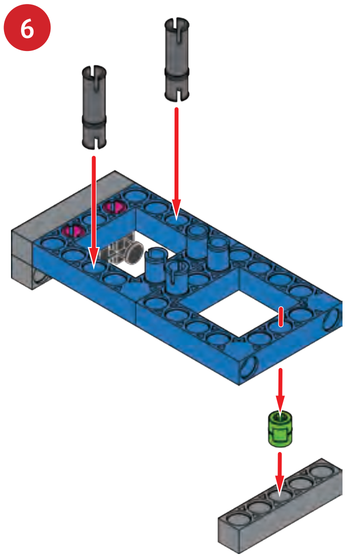




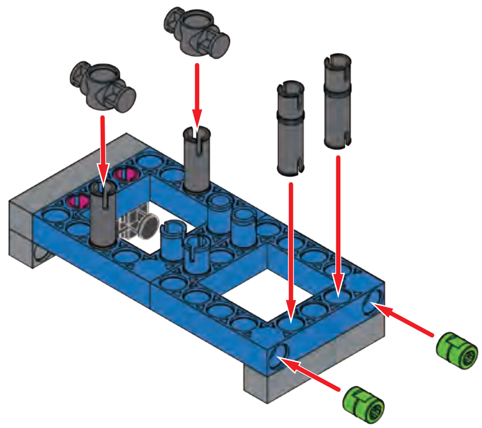


Assembly Steps for Activity 3: Collision Test Track with One Launcher Continued

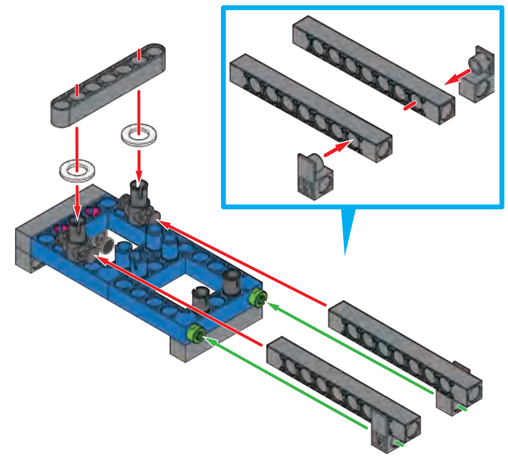
6



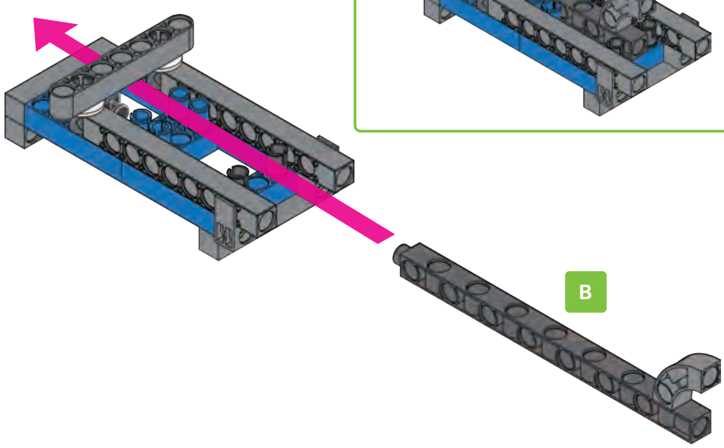
7



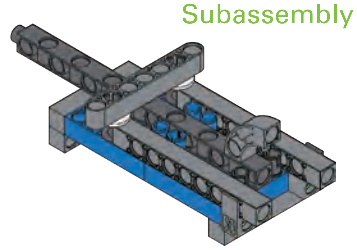
8



9

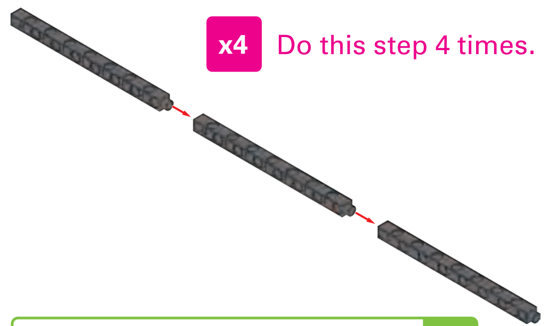


Subassembly C

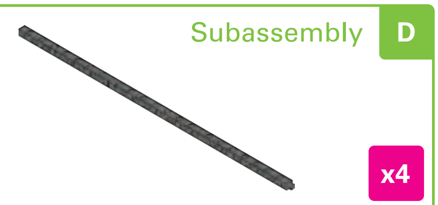


10

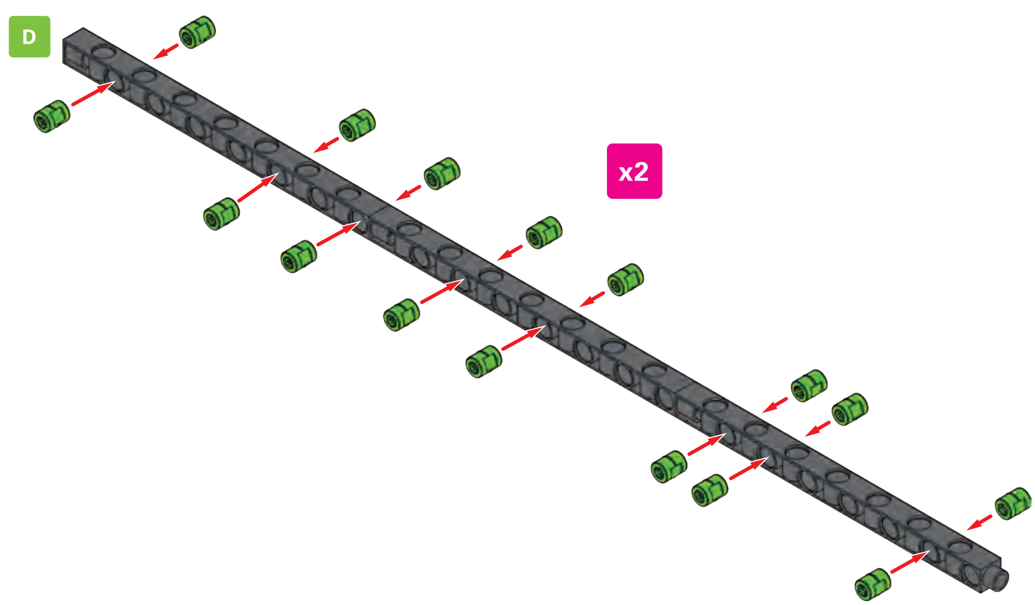
x4 Do this step 4 times.



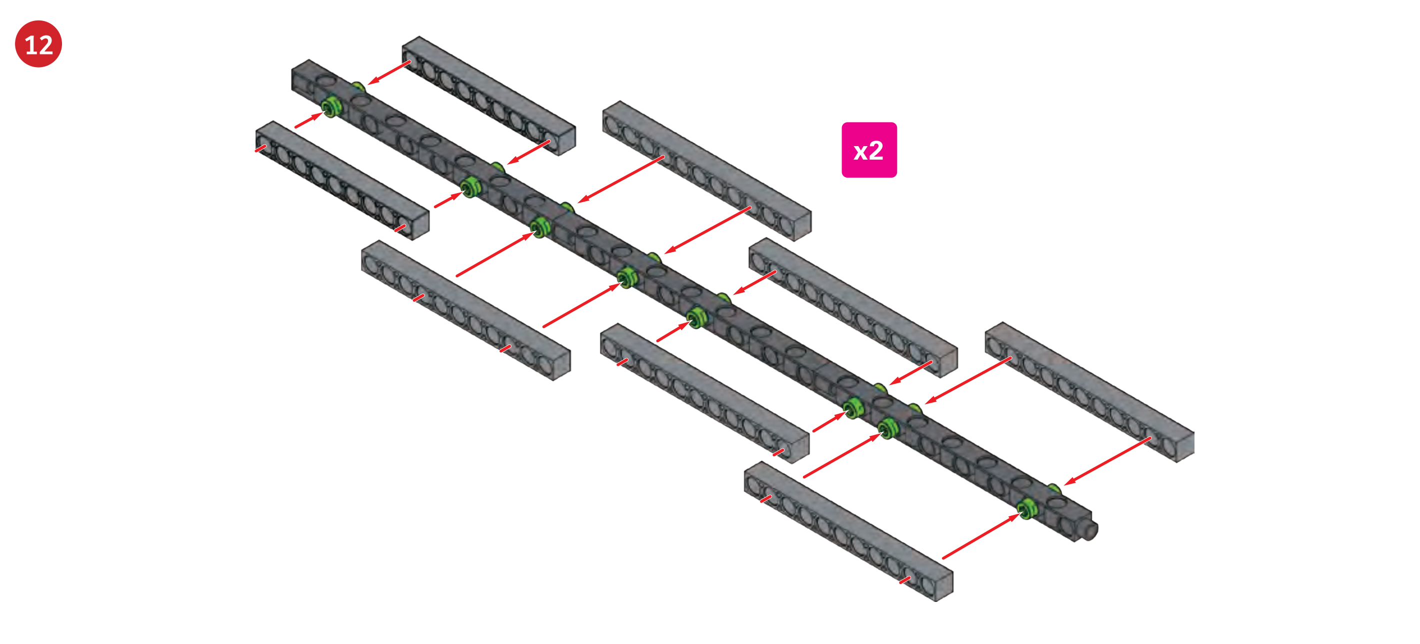
Subassembly D

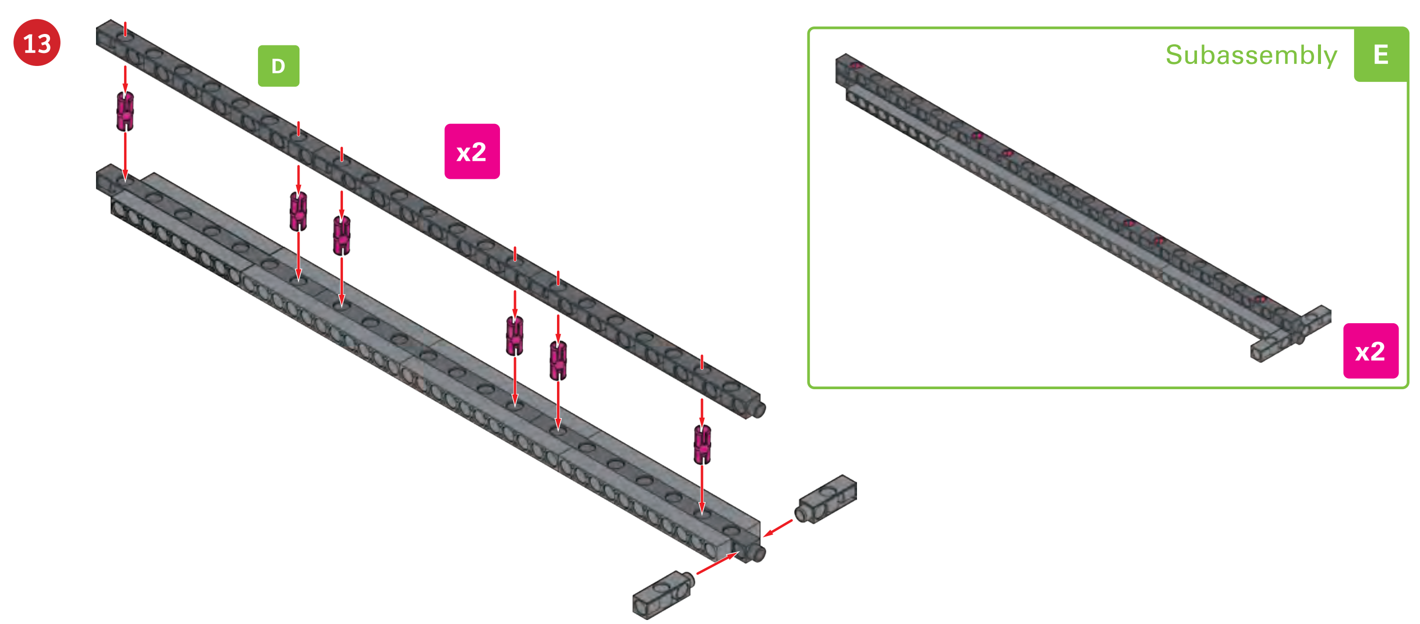


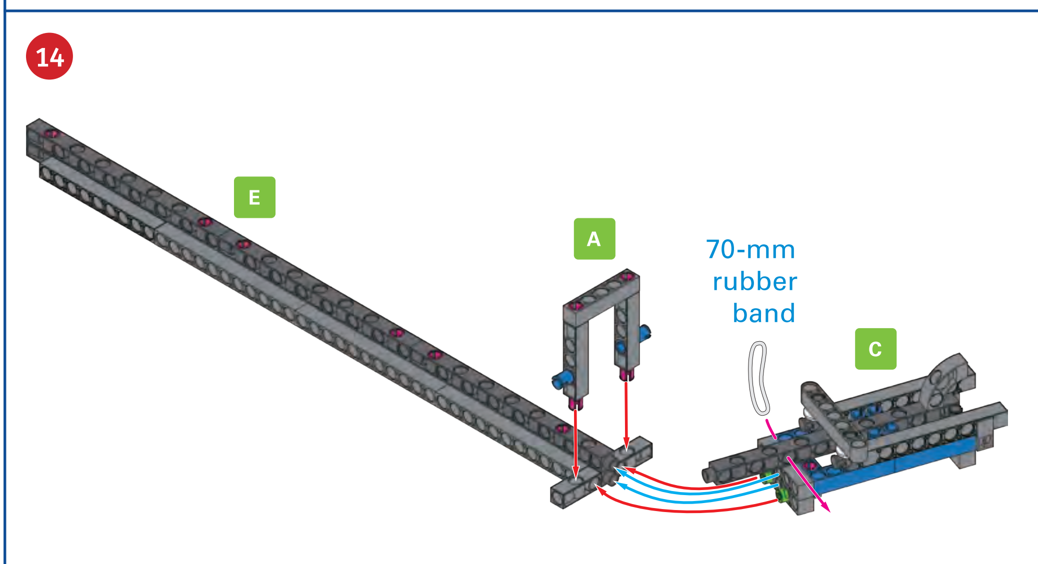
11

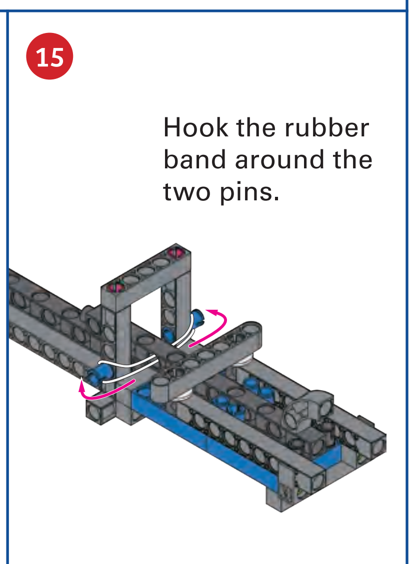


Assembly Steps for Activity 3: Collision Test Track with One Launcher Continued



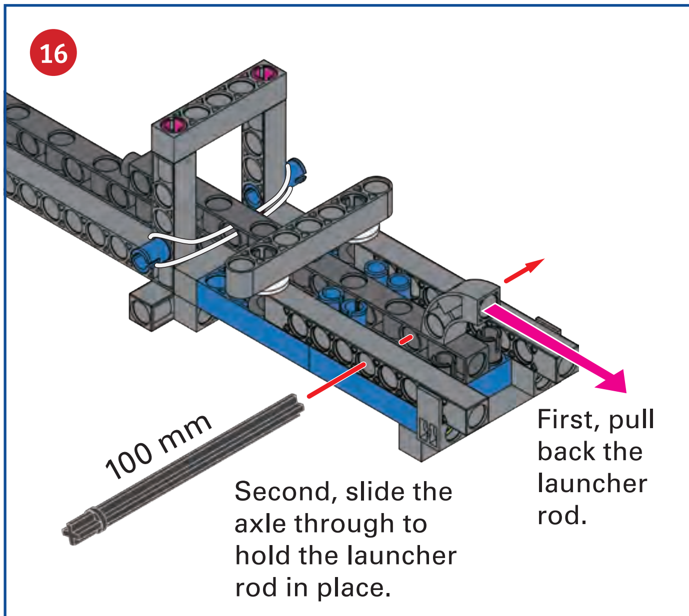


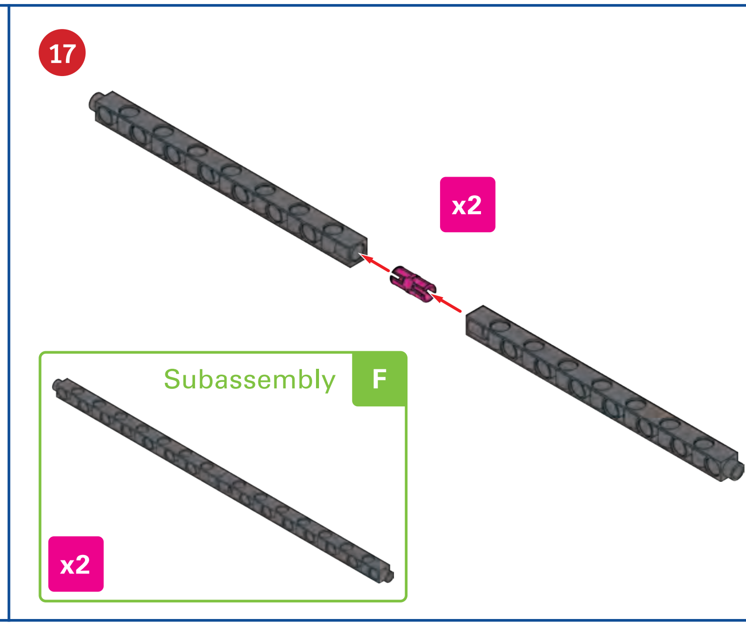


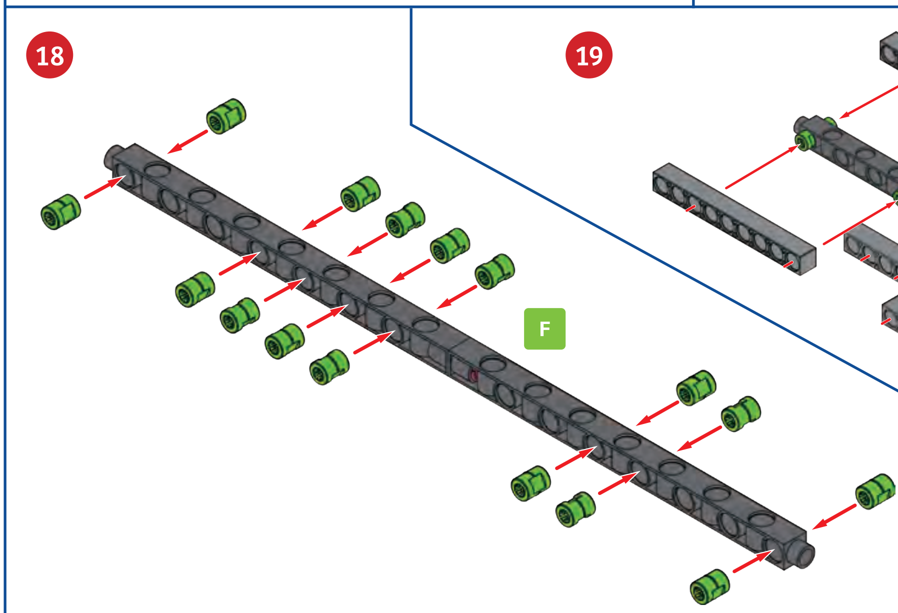


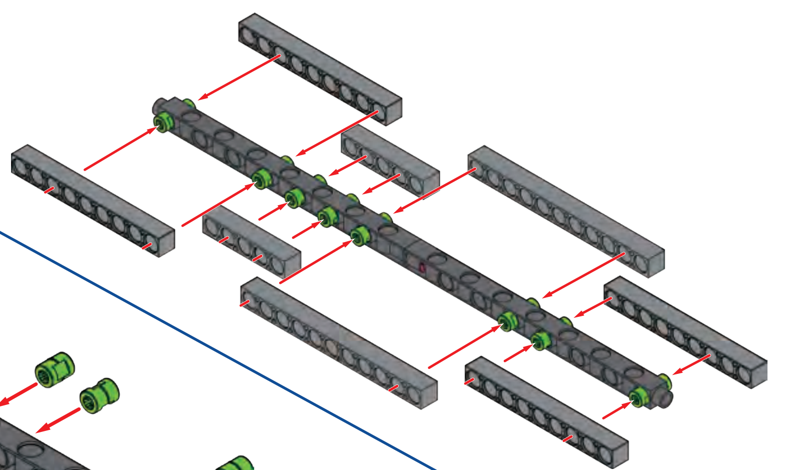
Hook the rubber band around the two pins.

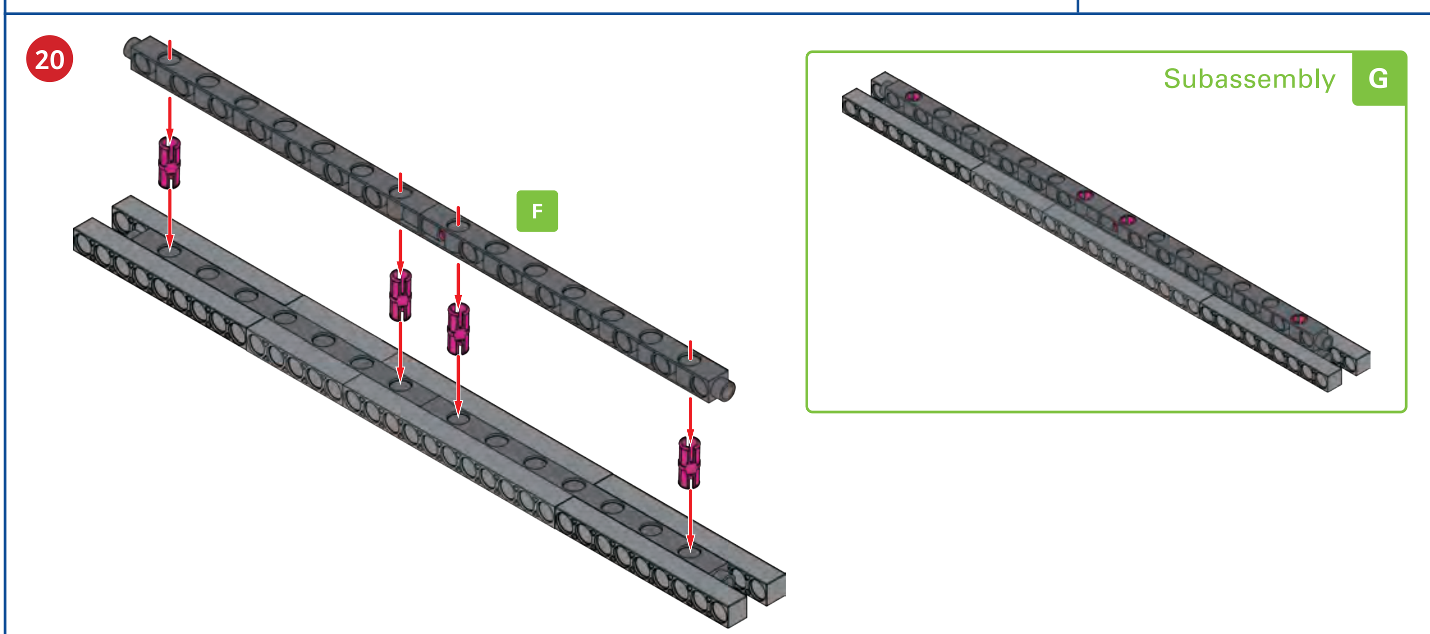
Assembly Steps for Activity 3: Collision Test Track with One Launcher Continued





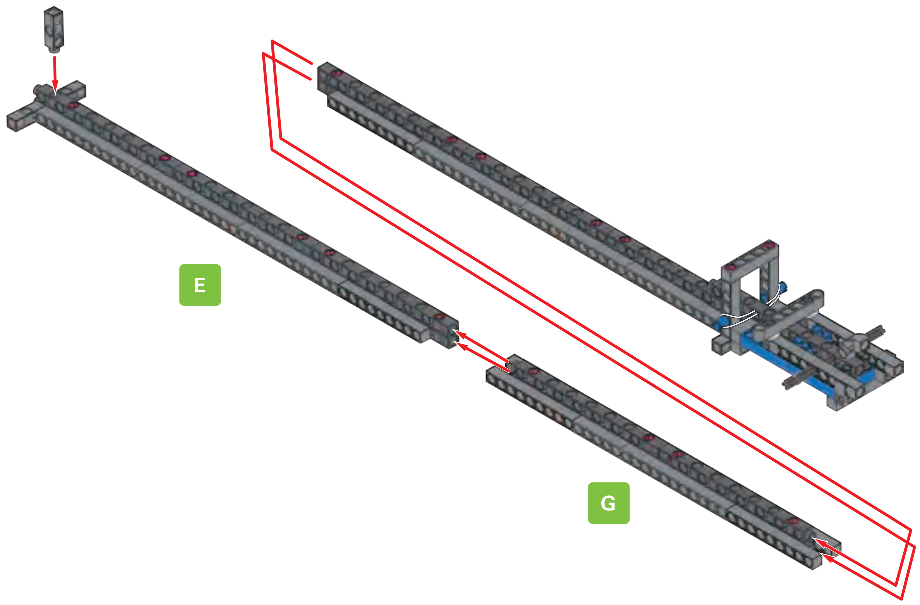




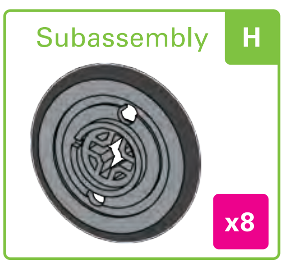


Assembly Steps for Activity 3: Collision Test Track with One Launcher Continued

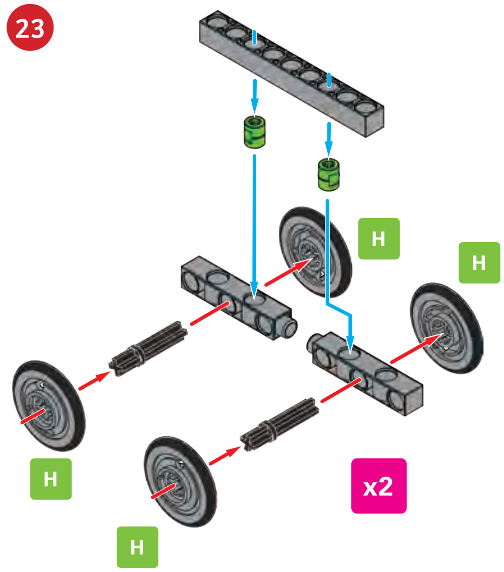
21



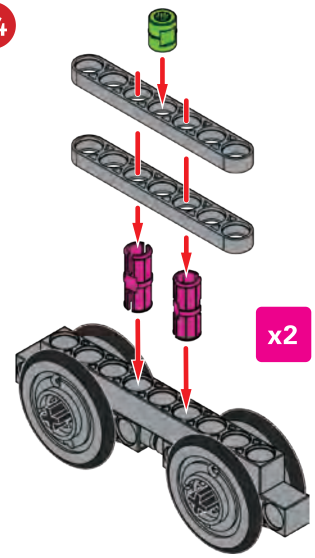
22



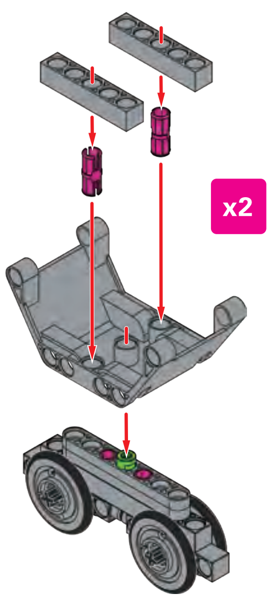
23

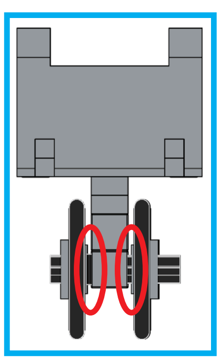


24

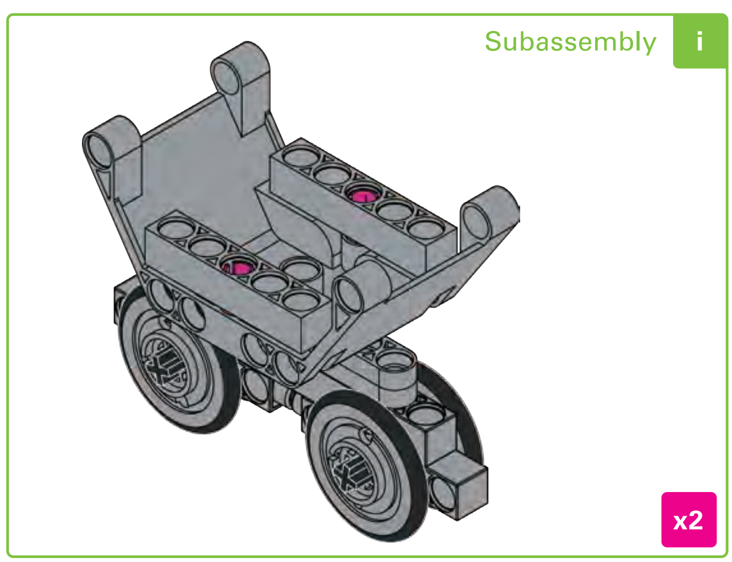


25



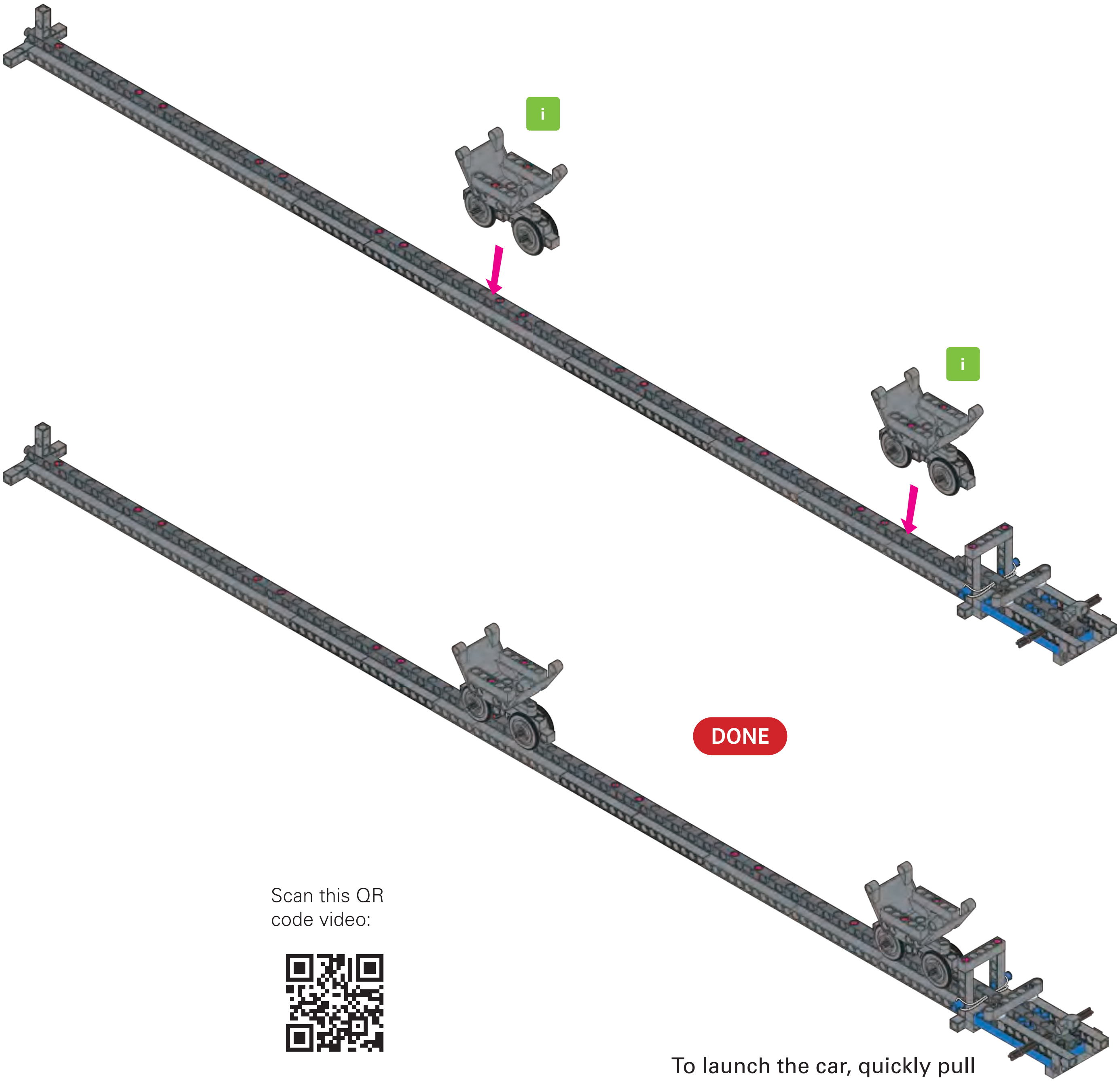


Leave a 1-mm gap between the wheels and the rods, so the wheels spin freely.



Assembly Steps for Activity 3: Collision Test Track with One Launcher Continued

26



Scan this QR code video:

To launch the car, quickly pull the axle out of the launcher while holding the track in place.

Activity 4

Collisions: Two Moving Cars

Through this activity, students expand their understanding of motion by investigating the forces involved when two moving objects collide.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Investigate forces and motions relating to collisions of two moving objects in various scenarios.
- Experiment with how velocity and mass (momentum) affect the motion of moving objects after a collision.
- Simulate how velocity and mass (momentum) affect the motion of moving objects after a collision.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-1 MS-PS2-2	MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Planning and Carrying Out Investigations • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. Connections to Nature of Science Scientific Knowledge is Based on Empirical Evidence • Science knowledge is based upon logical and conceptual connections between evidence and explanations.	Students recognize the variance between real world investigations and computer simulations. Students use observations as evidence to start to identify and predict trends due to varying components of a system.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Disciplinary Core Ideas	PS2.A: Forces and Motion • For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). PS2.A: Forces and Motion • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. • All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.	Students examine forces in collisions and consider Newton's third law. Students draw force diagrams to explain motion of different objects during collisions.
Crosscutting Concepts	Systems and System Models • Models can be used to represent systems and their interactions — such as inputs, processes and outputs — and energy and matter flows within systems. Stability and Change • Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	Students create a system model and observe the interaction of its components during changes to the system. Students use computer simulated models to observe collisions. Students observe stability and change related to collisions.

Materials Needed

- Assembly instructions for the collision test track with multiple launchers (located after the instructions for this activity)
- Parts for the collision test track with multiple launchers (one set per group)
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks*
- *Pencils*
- *Wet erase markers (one per group)*
- *Rulers (one per group)*
- *Access to Internet*
- *Access to computers (one per group or more)*

Notes for Teachers

Students should come into this activity with a basic understanding of force vector arrows that represent magnitude and direction of forces. This activity focuses on a specific type of collision between two moving objects (such as two moving cars). Collisions between a stationary and moving object are the focus of Activity 3. At this level, the focus is on changing motion and forces in one dimension at a time. Students should be able to observe and predict the motion of objects in various one dimensional collision scenarios.

Newton's Third Law and Collisions

When two moving objects collide, there are several variables at play that need to be considered to be able to predict the resulting motion of both objects — the speed and direction that each object is moving (velocity) and the mass of each object. For students to recognize trends in how each of these variables affect motion, it is critical to initially focus on one at a time. During this activity students will first focus on collisions between two objects of equal mass moving toward each other at equal speeds. Then students will think about motion resulting from the collision between two objects of equal mass but different speed moving in the same direction. Next, students focus on a scenario where one of the objects is moving faster than the other (varied velocities). Finally, students think about varying the masses of one of the objects.

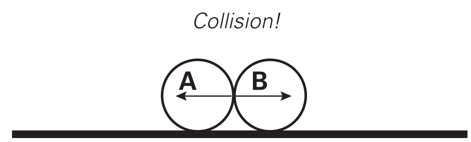


Figure 1

Any moving object has momentum (p), which is directly influenced by mass and velocity, both speed and direction ($p = mv$). Although students don't need to get into quantitative analysis of momentum, they can observe that the speed that one or both objects are moving, the direction one or both objects are moving, and the objects' masses can all have an affect on the resulting motion of both objects after collision.

A and B have the same mass. A is moving to the right and B is moving toward A at the equal and opposite speed (figure 2). The force of A on B and B on A will be equal and opposite at the moment of collision. What happens to A and B after the collision? The motion of A and B depends on the type of collision. Read below.

Figure 2

Elastic and Inelastic Collisions

In a perfectly elastic collision, when A collides with B, the force of A on B causes B to reverse direction and move in the opposite direction at the same speed as before. The force of B on A causes A to reverse direction and move in the opposite direction at the same speed as before (figure 3).

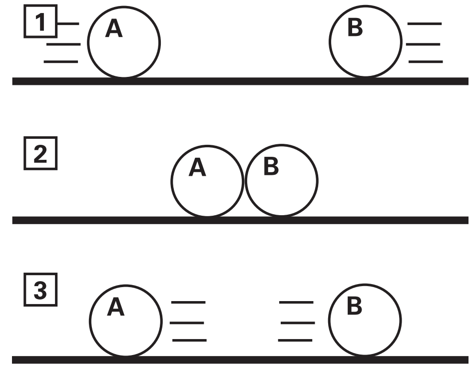


Figure 3

For a collision to be perfectly elastic, there must be no friction and no air resistance, circumstances not found outside a laboratory setting. However, a perfectly elastic collision can be simulated. To observe a perfectly elastic collision visit: https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html

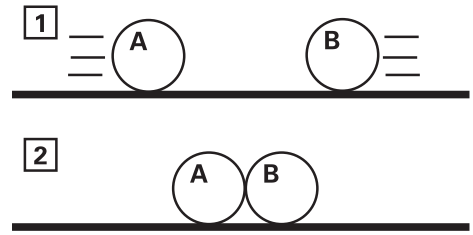


Figure 4

The opposite of a perfectly elastic collision is completely inelastic collision. In this type of collision A collides with B and both stop (figure 4).

In the real world, most collisions are inelastic, but not perfectly inelastic. This means both objects change motion after a collision. If object A and B are the same mass and are moving toward one another, they will move away from each other after the collision, but at a slower speed than they started. If masses of A and B are not the same, motion is affected.

Collisions Where Both Objects Are Moving in the Same Direction

If objects A and B are both moving in the same direction at the same speed, they will not collide (figure 5).

Figure 5

However, if object A is traveling at twice the speed of object B, it will catch up to B and the objects will collide. The resulting motion observed is that object A loses some speed but still keeps traveling in the same direction, while object B gains speed in that direction, and is now actually moving faster than object A (unless the collision is completely inelastic, in which case the objects move at the same speed) (figure 6).

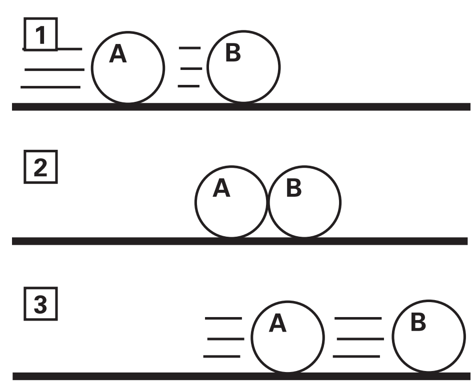


Figure 6

Because momentum is directly related to mass, as well as velocity ($p = mv$), mass is also a factor when it comes to the motion of two moving objects that collide. Students don't necessarily need to understand this quantitatively, but should be able to comprehend general trends related to collisions, mass, and motion. For example, if object A is moving toward object B, both objects are moving at the same speed, but object B is twice the mass of object A, then when the objects collide, they both continue to move in the direction that object B was moving, but B is moving slower while A is moving faster (figure 7).

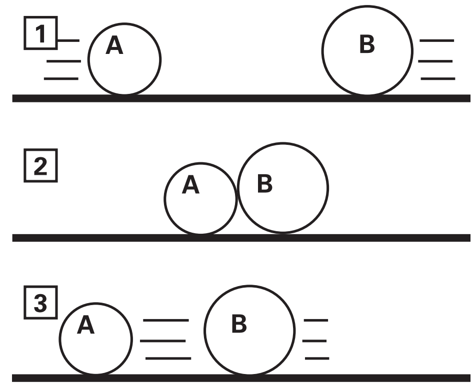


Figure 7

These are not easy concepts to visualize or predict qualitatively. The goal of this activity is largely to get students thinking about the fact that speed and direction of motion, as well as mass, affect both objects' motion after a collision, and to start to think about how each affects motion.

Activity Procedure

1. **Engage:** Show videos of bumper cars and pinball machines, or demonstrate collisions using rolling desk chairs.
2. **Explore:** Explain that today's class is all about crashes (collisions). Students are going to get to have some fun exploring how objects interact during a collision. Today's focus will be on how two moving cars interact when they collide (collisions between one moving and one stationary car are addressed in a separate activity).
3. Divide students into pairs or small groups (up to four students per group). Distribute the building materials and instructions. Monitor as students build the track, cars, and rubber band launchers (or if the models were used for Activity 3, students just need to add the additional launchers). Using tape, students should label the left hand car "1" and the right hand car "2".
4. When all groups are ready, ask students to place the two cars on the track and set it aside. Explain that students are going to make some predictions about the motion of the two cars in various scenarios and then observe what happens by testing those scenarios. Students should write each scenario in their science notebooks and then discuss with their groups to determine a prediction (group members may disagree). They should draw a sketch of the predicted motion and also explain in words what they think will happen.

Scenarios

- Two cars of equal mass that are moving toward each other collide at the same speed. Use the launchers on the left and right sides of the track.
- Two cars of equal mass that are moving in the same direction collide with each other. Car 1 was moving faster than car 2 before the collision. Use the left and middle launchers.
- Two cars of equal mass that are moving toward each other collide. Car 1 was moving faster

than car 2 before the collision. Use the left and right launchers.

- Two cars that are moving toward each other at the same speed collide. Car 1 has greater mass than car 2. Use the left and right launchers.

5. When students have finished predicting, give them ample time to explore the collision scenarios. Each launcher works the same as in Activity 3: An axle holds the launcher rod in place. To launch the car, quickly pull the axle out of the launcher while holding the track in place. The difference in Activity 4 is that you need at least two people working together to trigger the launchers at the same time, so both cars move at the same time. To achieve different speeds, pull the launcher rods back different amounts. To launch the cars in the same direction, use the middle launcher. The students may want to use video cameras to film the collisions and watch them in slow motion.

6. **Explain/Elaborate:** Gather the group to discuss what students observed in each situation. There may be some discrepancy in what students observed due to variation in materials and force used. In general, students may be able to identify trends in motion, such as:

   a. Speed of either or both cars affects motion after the collision

   b. Direction of motion of both cars affects their motion after the collision

   c. Mass of either or both cars affects their motion after the collision

7. Explain to students that they will be using a computer simulation to determine if trends that they observed match those in an environment where variables can be precisely controlled.

8. Set students up with computers (they may work in pairs or within their groups). Using this link (https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html), allow students to work through the scenarios from above and compare the results to those that they observed using the cars. Circulate and help students understand how to correctly manipulate the variables (including elastic/inelastic collision setting).

   When students are finished, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

9. **Evaluate:** Provide students with similar scenarios and have them explain what motion they would predict to observe after a collision individually in their science notebooks.

More Resources Related to Forces and Motion

Collision Cart Interactive	http://www.physicsclassroom.com/Physics-Interactives/Momentum-and-Collisions/Collision-Carts/Collision-Carts-Interactive	Good simulation to show completely elastic or completely inelastic collisions between stationary or moving cars.
PhET collision lab	https://phet.colorado.edu/sims/collision-lab/collision-lab_en.html	Introductory level is in one dimension. Elastic/inelastic collision spectrum. Mass and speed can be varied.
Football video	https://science360.gov/obj/video/d0e16d27-05d4-4511-9394-2758aa066981/science-nfl-football-newtons-third-law-motion	The science of football: Newton's Third Law of Motion

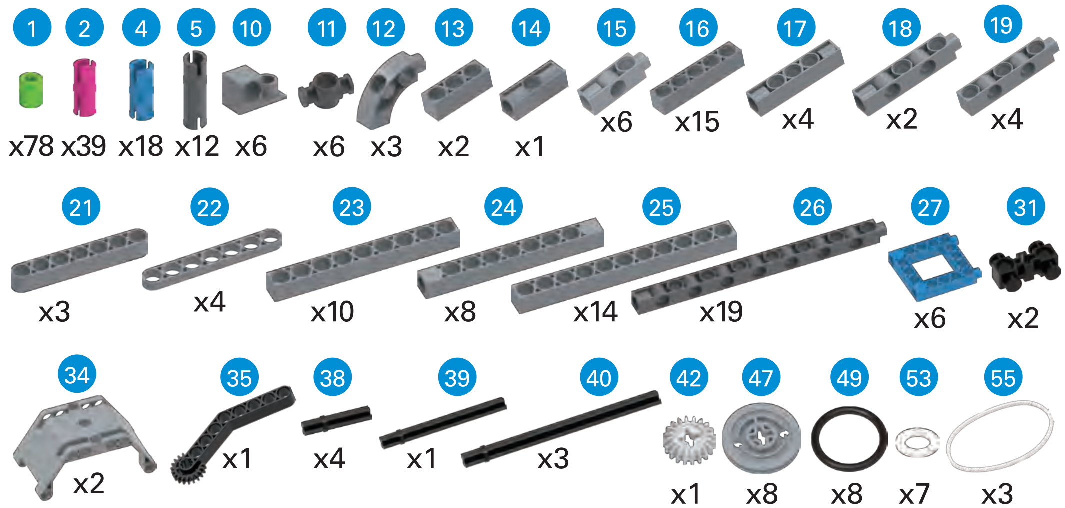
Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers

If you still have the models from Activity 3 assembled:

- Skip Steps 1–4, 14–17, and 21–24;
- Build Steps 5–13 and 18–20 only once, and
- Build Steps 25–40 as shown

to convert the models for Activity 4.

You will need:



1

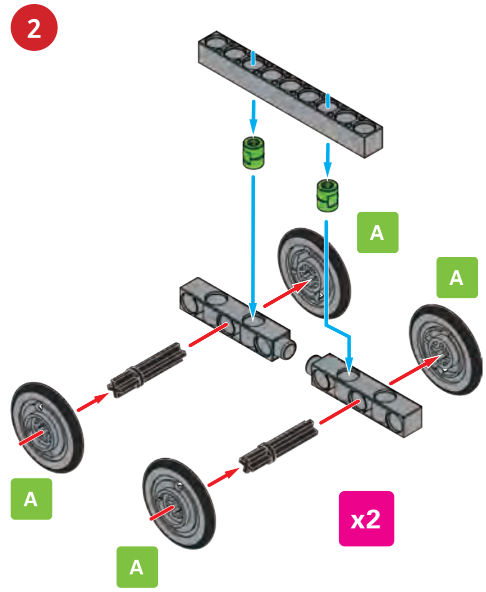
Skip Steps 1–4 if you still have the track cars built from Activity 3.

x8 Do this step 8 times.

Subassembly A

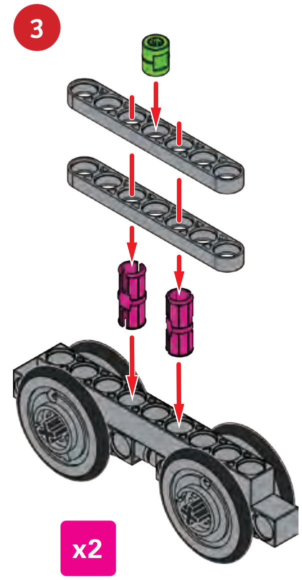
x8

2



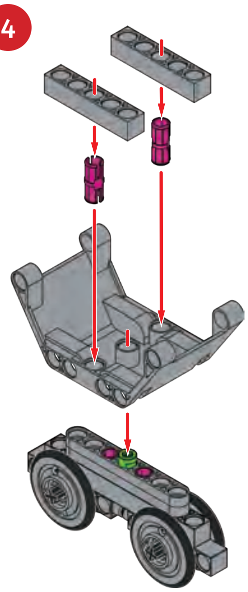
x2

3

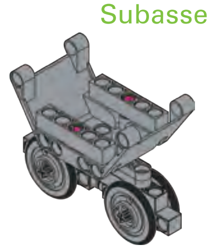


x2

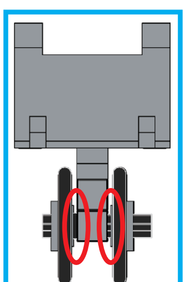
4



Subassembly B

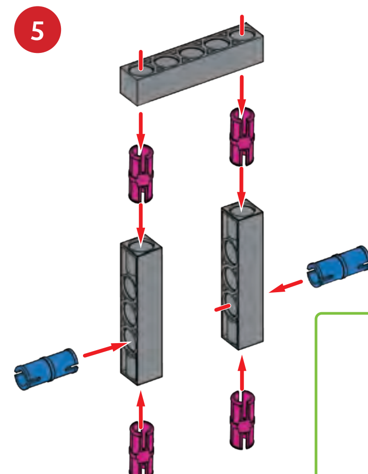


x2



Leave a 1-mm gap between the wheels and the rods, so the wheels spin freely.

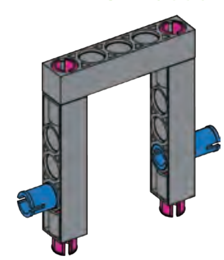
5



x2

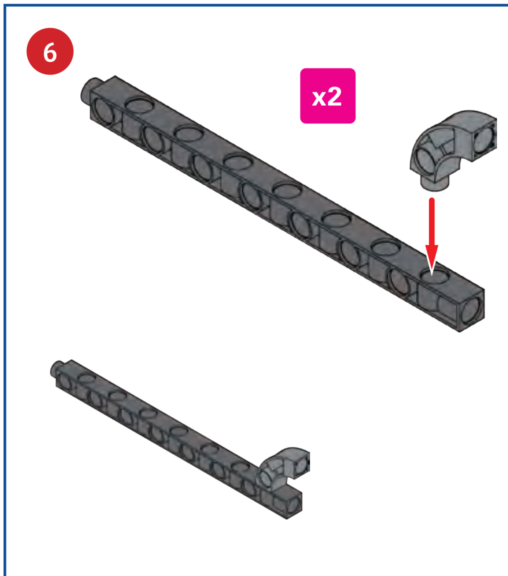
Build Steps 5–13 only once if you still have one launcher built from Activity 3.

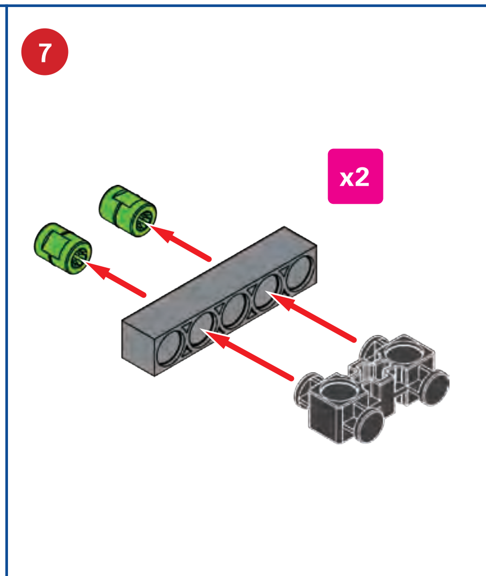
Subassembly C

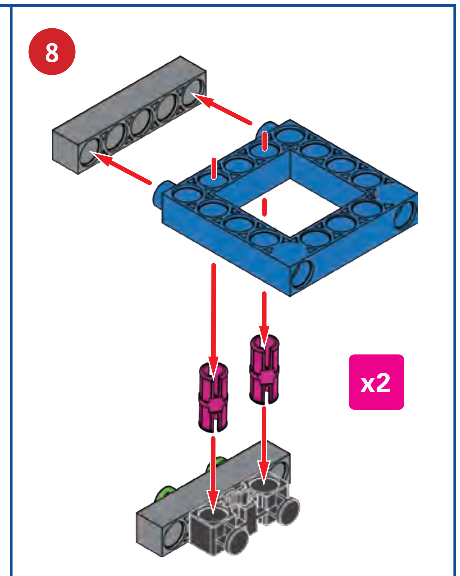


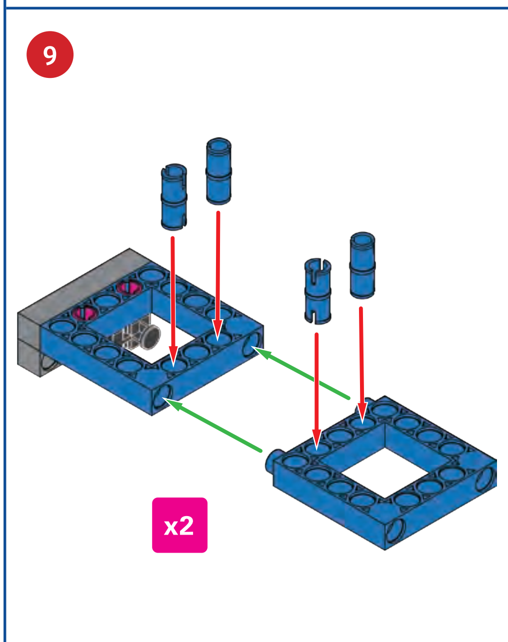
x2

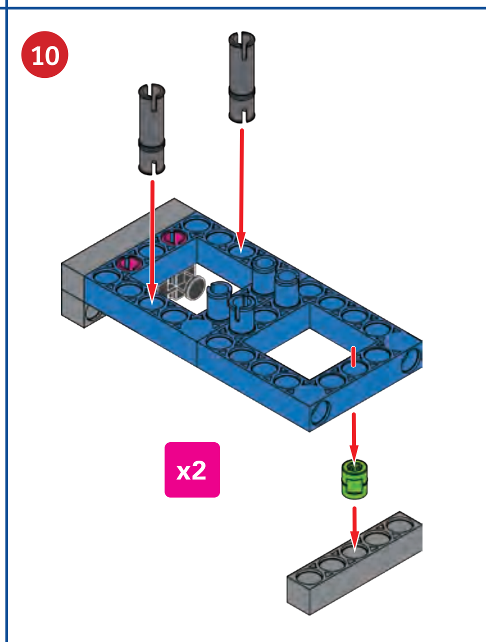
Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers Continued

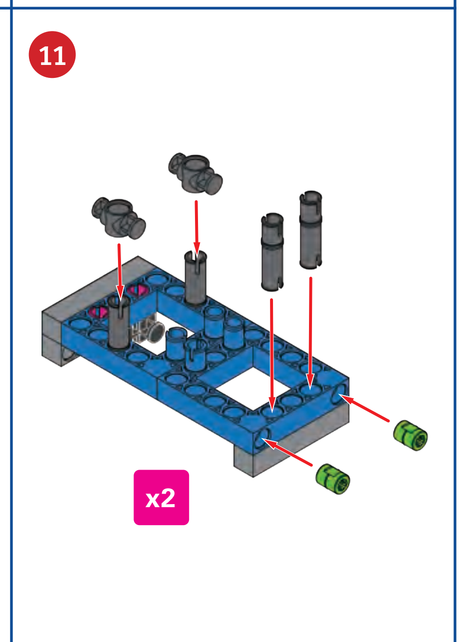


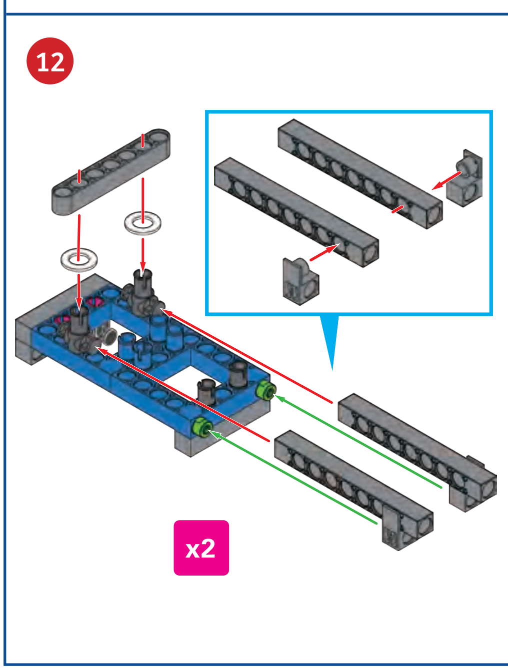


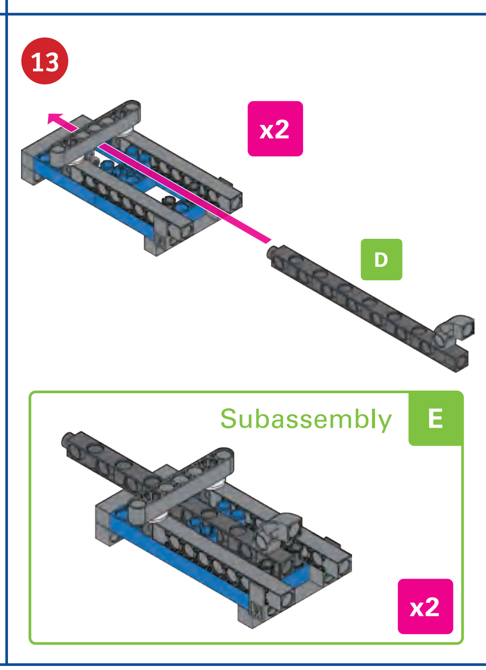


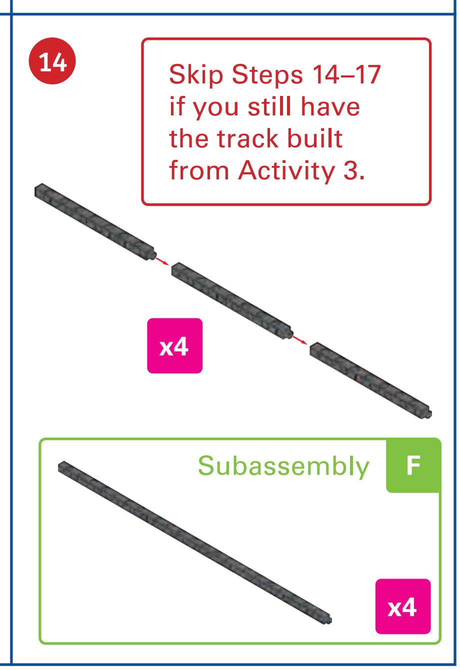






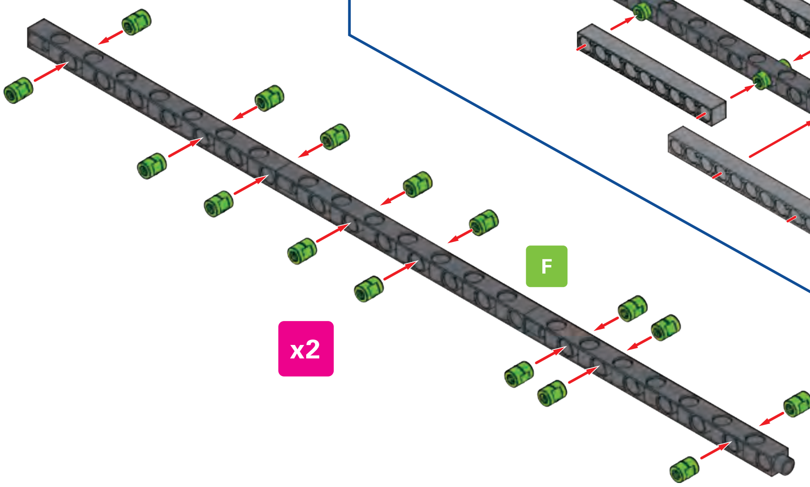




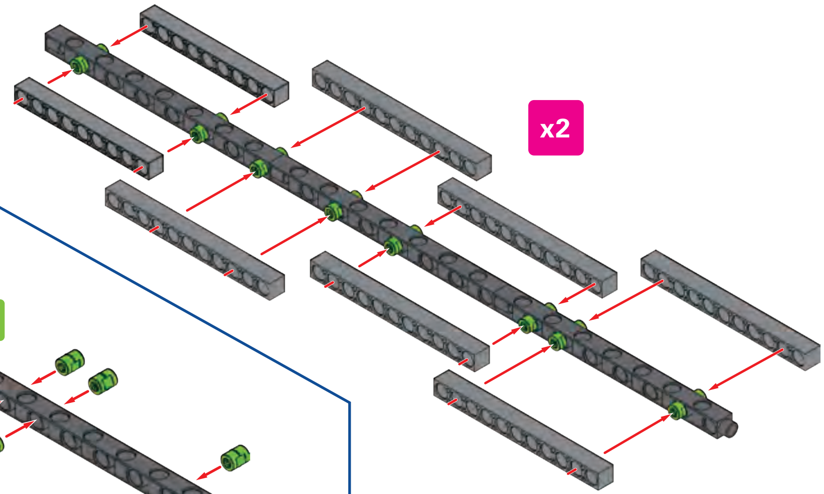


Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers Continued

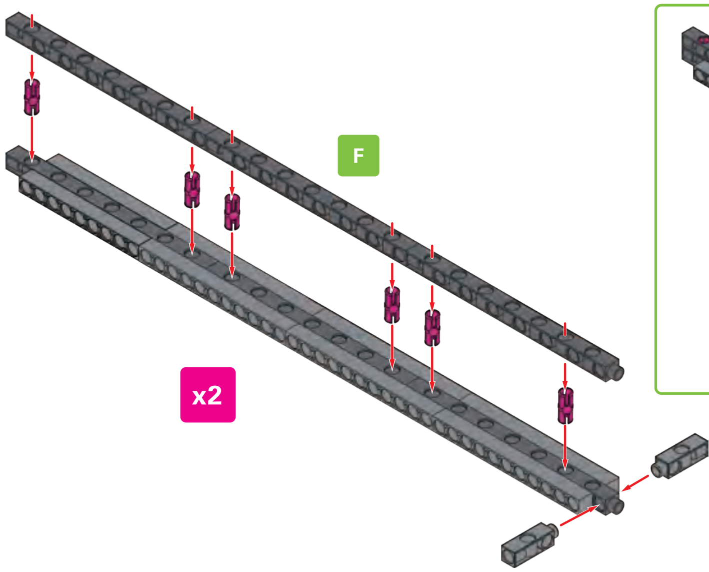
15



16

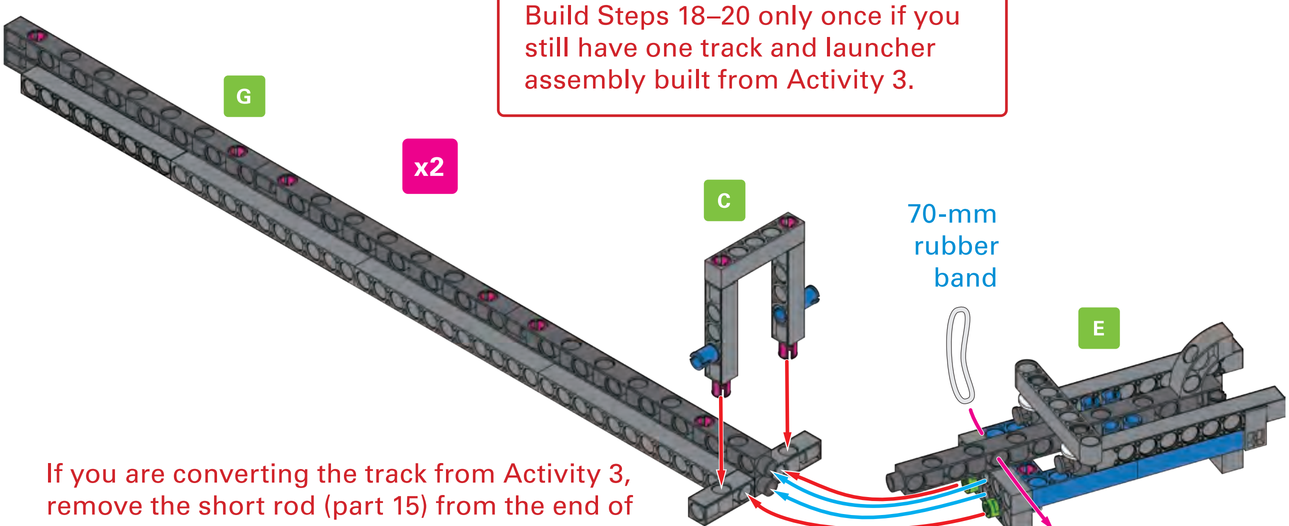


17



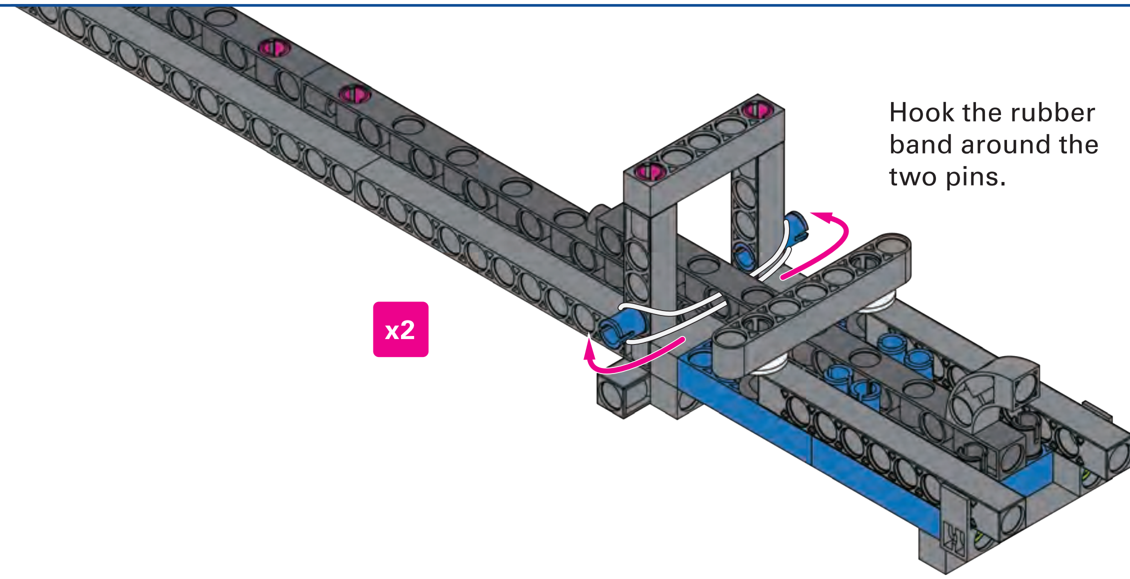
18

Build Steps 18–20 only once if you still have one track and launcher assembly built from Activity 3.



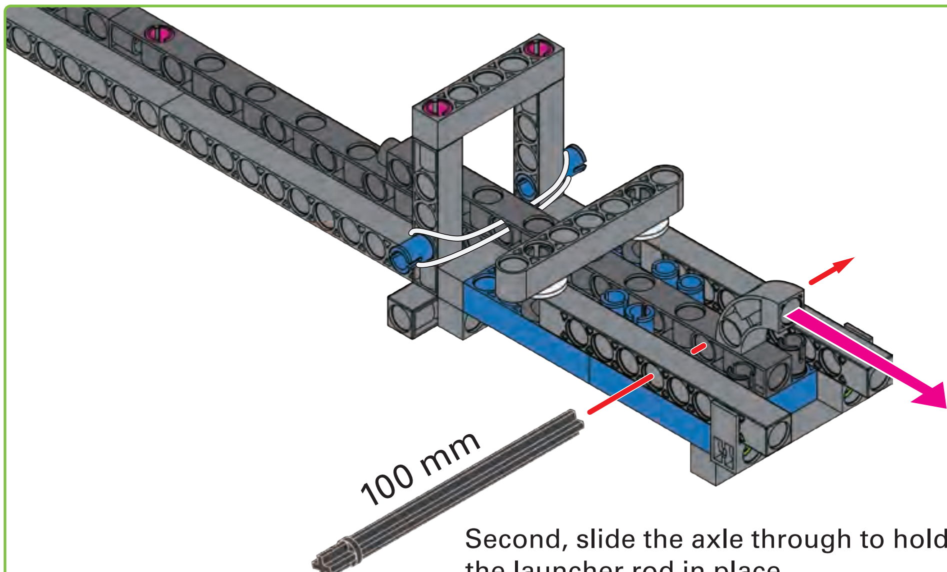
If you are converting the track from Activity 3, remove the short rod (part 15) from the end of the track before inserting subassembly C.

19



Hook the rubber band around the two pins.

20

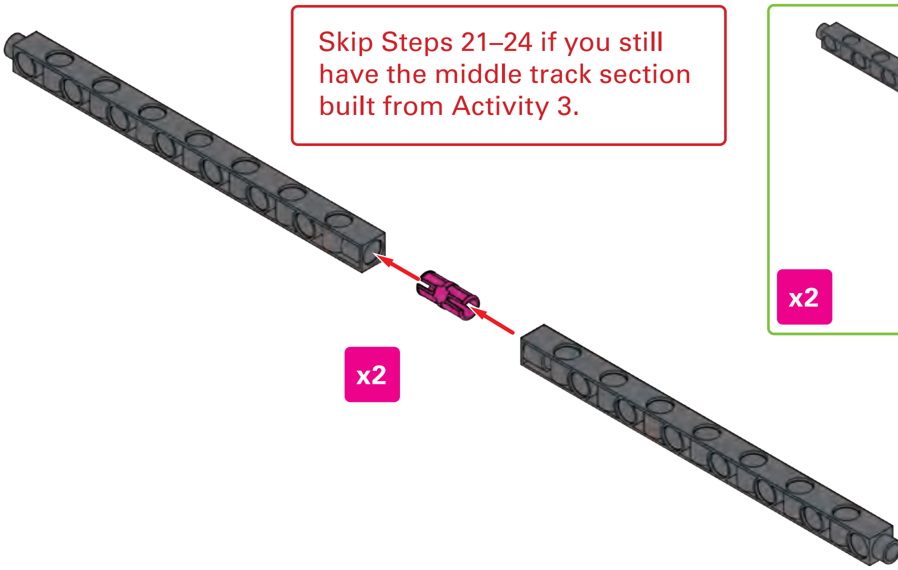


First, pull back the launcher rod.

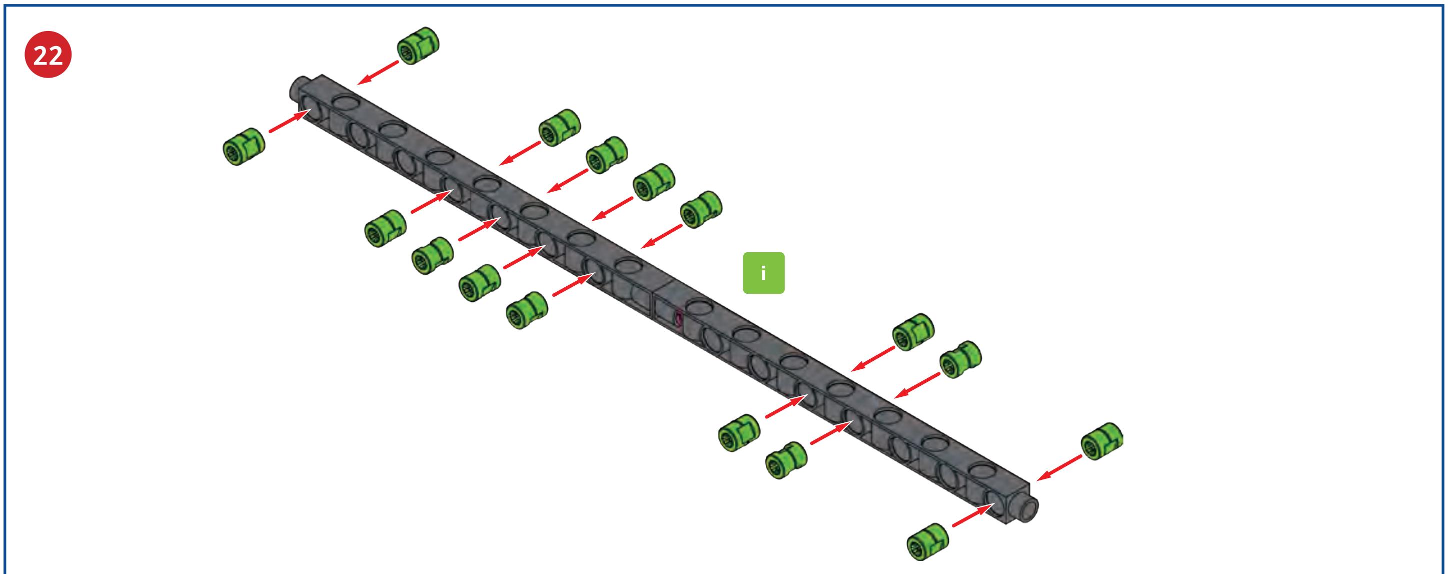
Second, slide the axle through to hold the launcher rod in place.

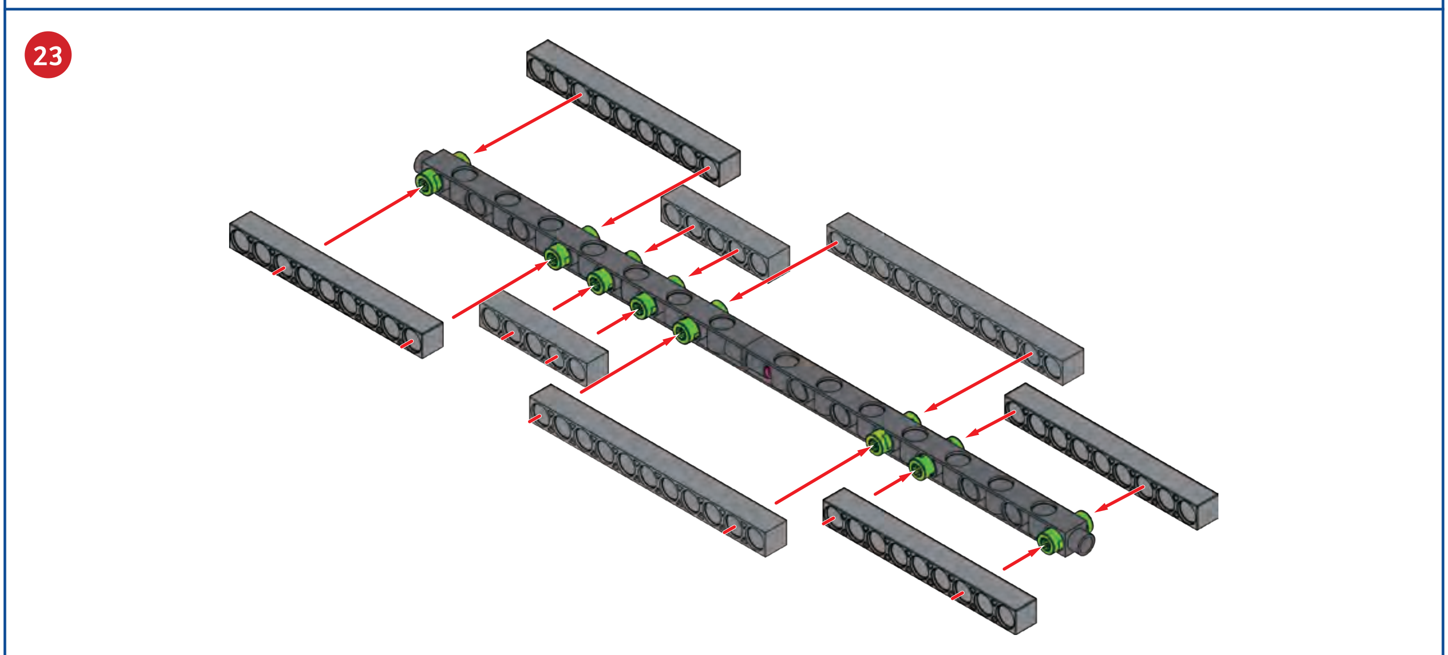
21

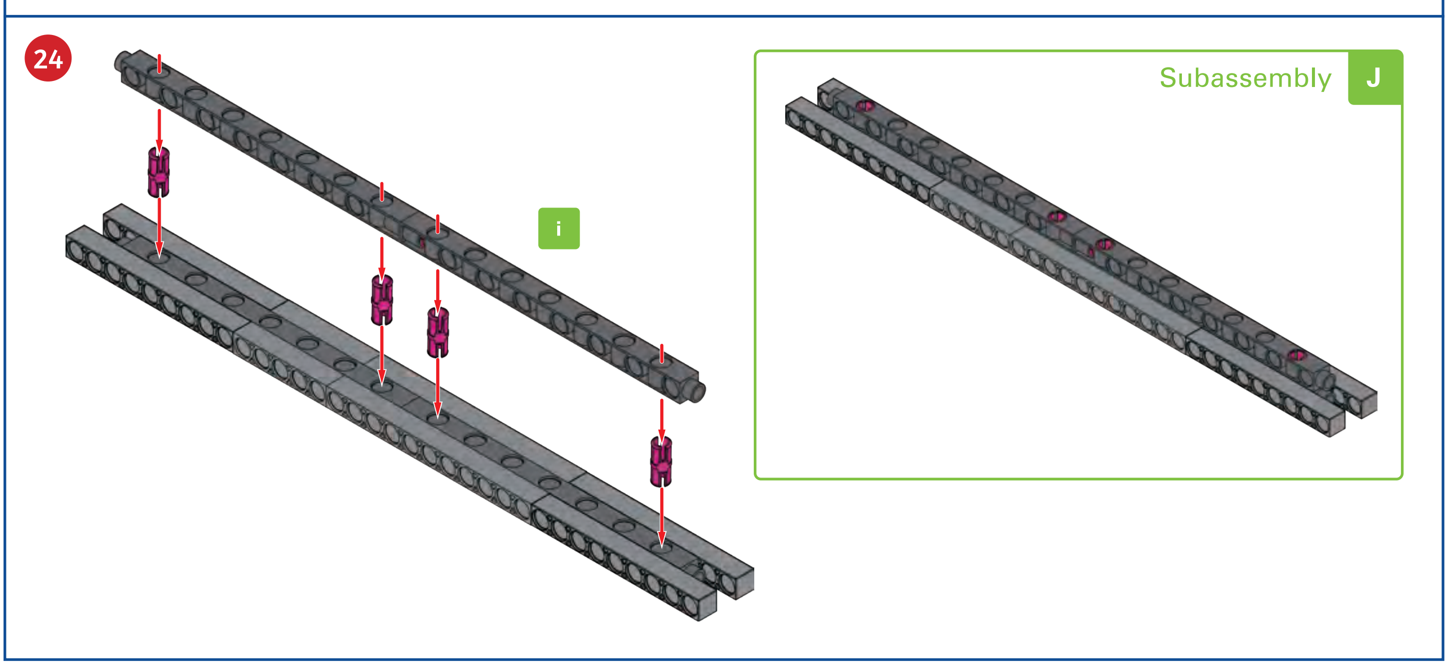
Skip Steps 21–24 if you still have the middle track section built from Activity 3.



Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers Continued

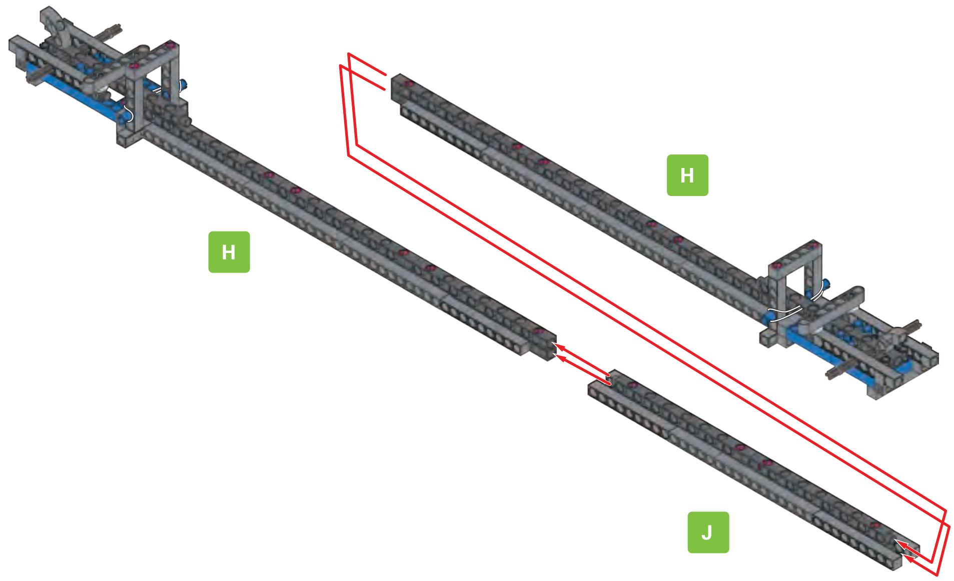




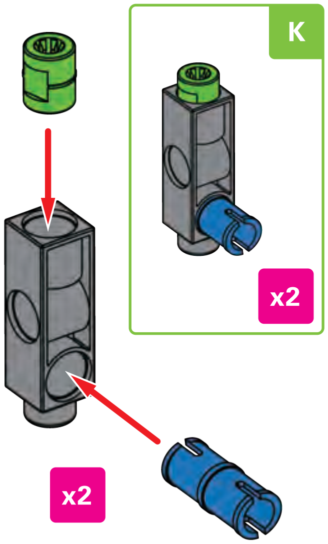


Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers Continued

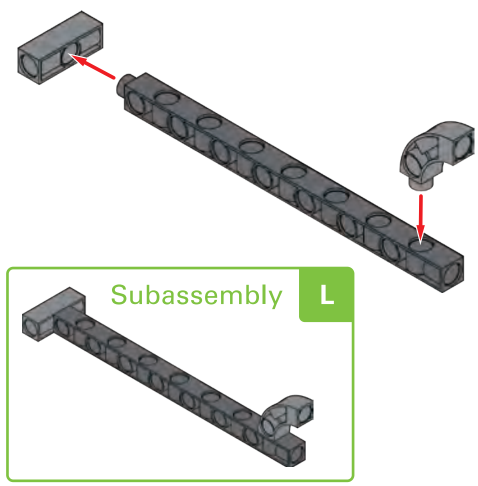
25



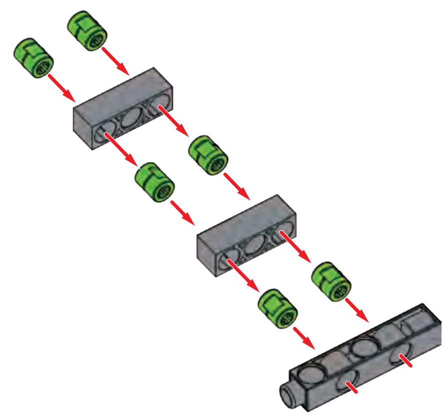
26



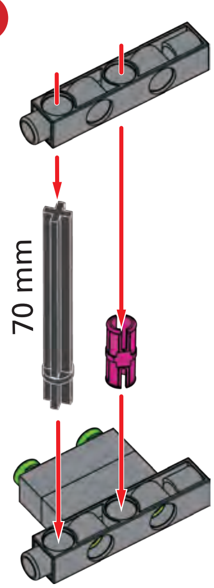
27



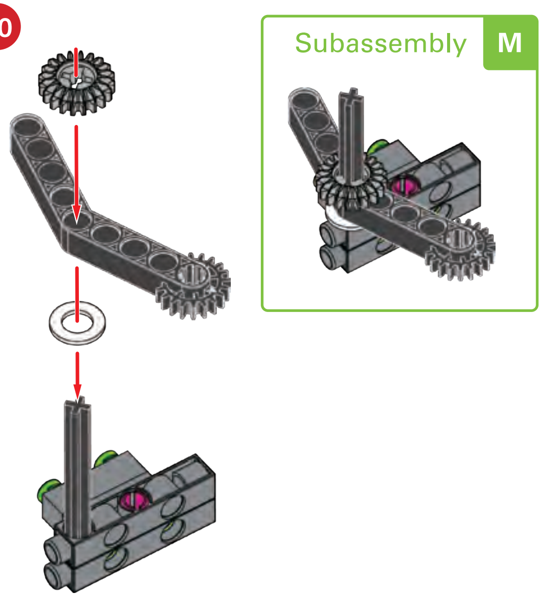
28



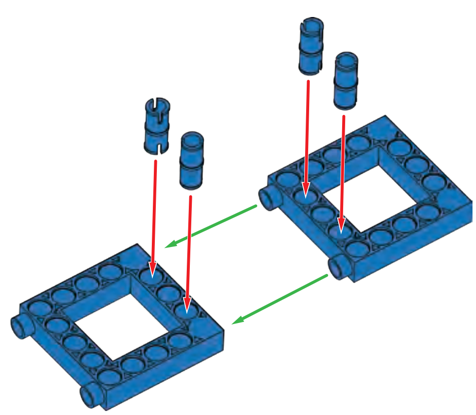
29



30

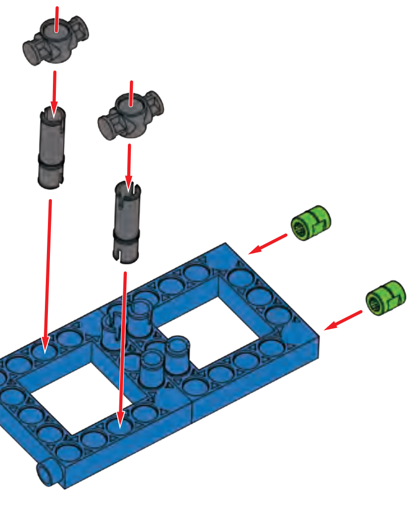


31

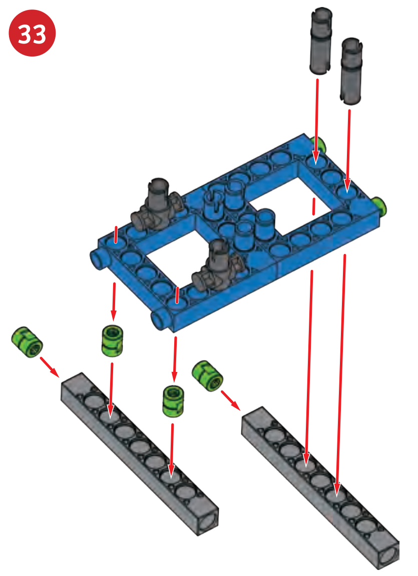


Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers Continued

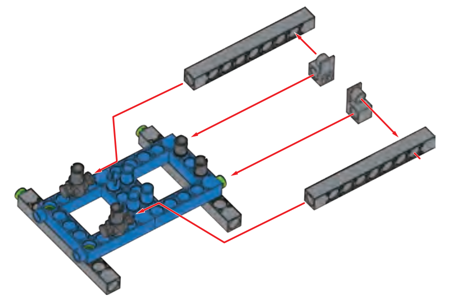
32



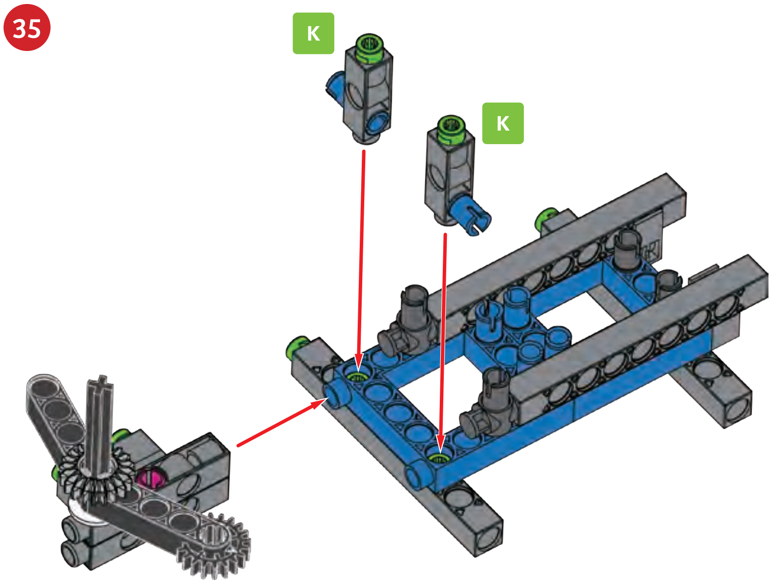
33



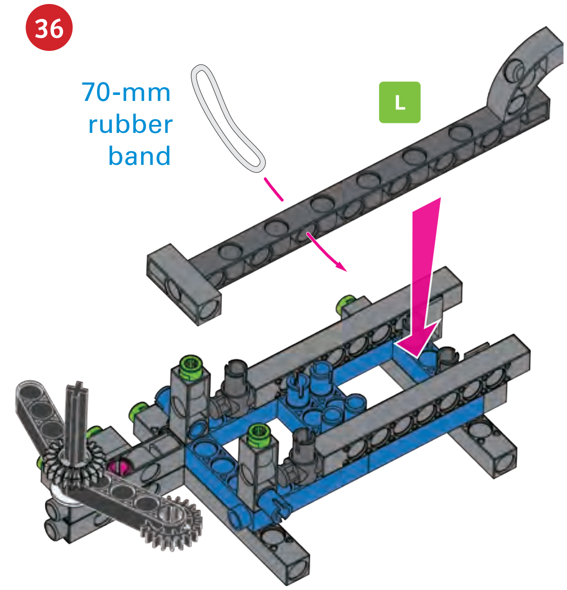
34



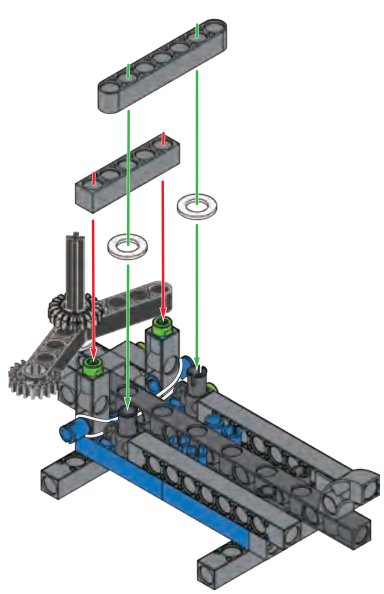
35



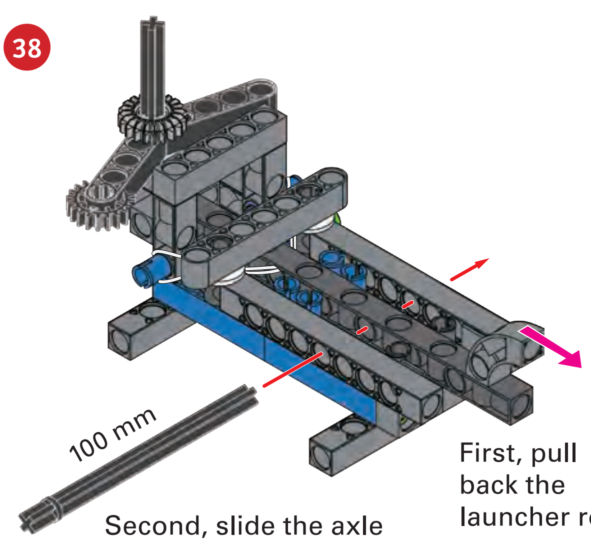
36



37

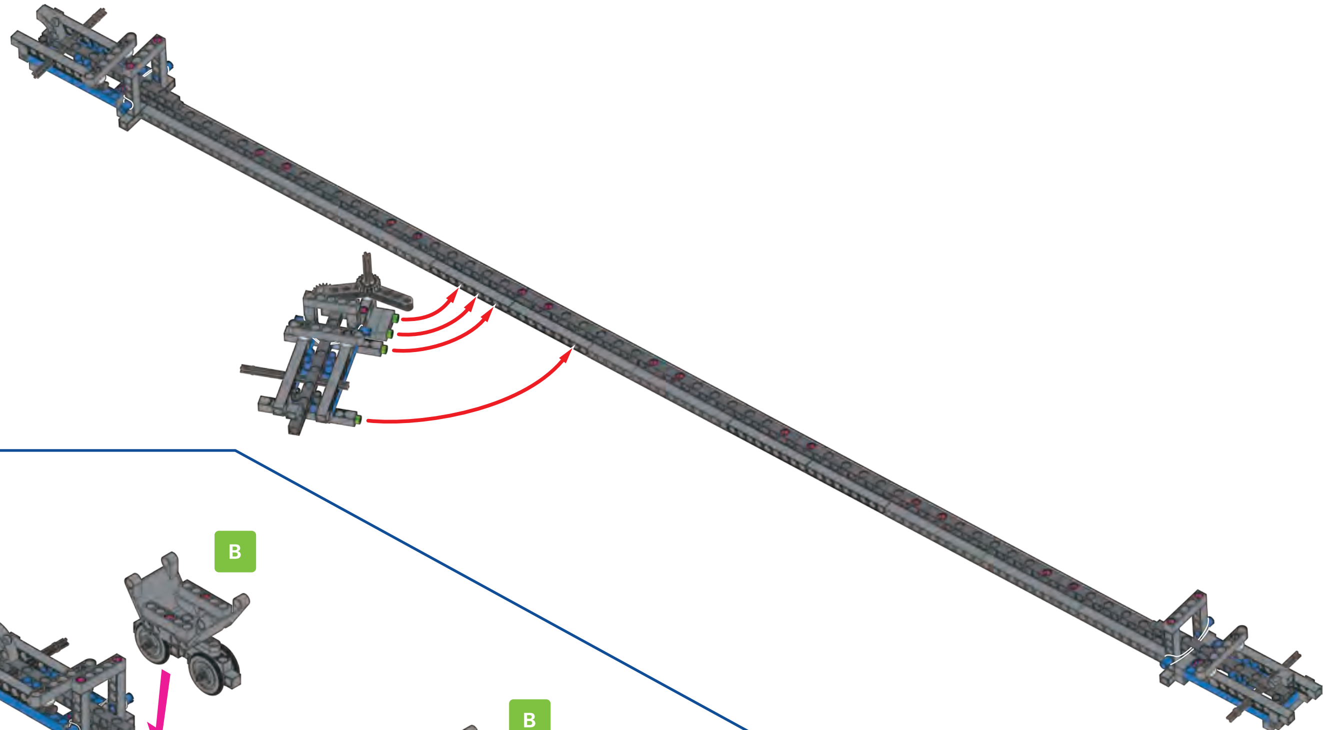


38

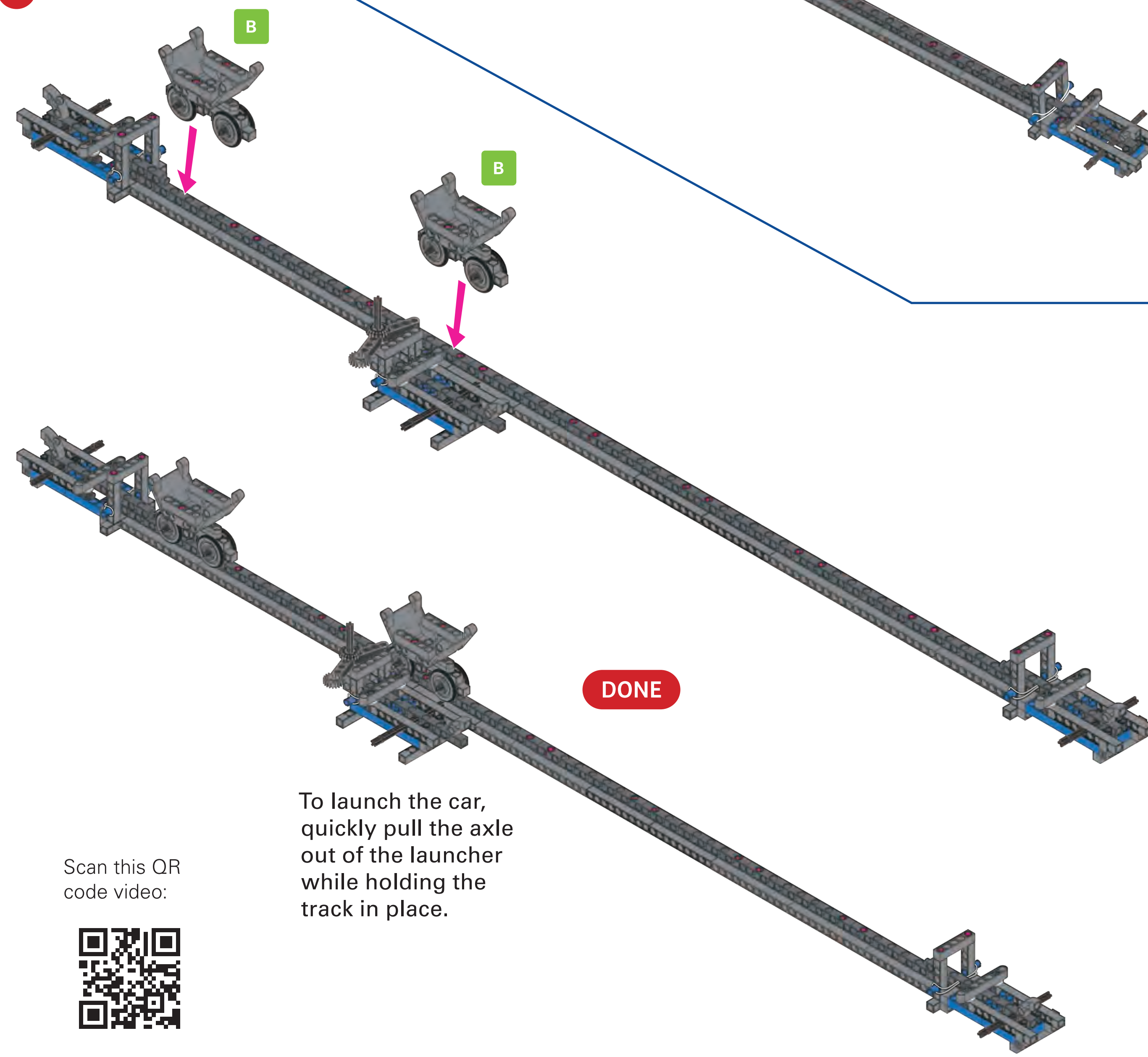


Assembly Steps for Activity 4: Collision Test Track with Multiple Launchers Continued

39



40



To launch the car, quickly pull the axle out of the launcher while holding the track in place.

Scan this QR code video:

Activity 5

Engineering Challenge: Newton's Third Law

In this activity, students use their knowledge of collisions to solve a problem.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Use steps in the engineering design process to work together and solve a problem using their knowledge of forces and motion.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-1 MS-PS2-2 MS-ETS1-2 MS-ETS1-3 MS-ETS1-4	MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Constructing Explanations and Designing Solutions • Apply scientific ideas or principles to design an object, tool, process or system.	Students use their understanding of motion related to collisions to solve a problem.
	Developing and Using Models • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.	Students build a model to test solution ideas.
	Analyzing and Interpreting Data • Analyze and interpret data to determine similarities and differences in findings.	Students share and compare solutions from different groups.
	Engaging in Argument from Evidence • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	Students evaluate solution ideas.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Disciplinary Core Ideas	PS2.A: Forces and Motion • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. • All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.	Students design a solution that involves principles related to objects' motions, including Newton's third law.
	PS2.A: Forces and Motion • For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law).	
	ETS1.B: Developing Possible Solutions • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.	Students participate in a process for evaluating solution ideas.
	ETS1.B: Developing Possible Solutions • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.	Students make changes to their original design idea as necessary throughout the testing process.
	ETS1.C: Optimizing the Design Solution • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process — that is, some of those characteristics may be incorporated into the new design.	Through sharing and class discussion students may find other solution that could make their idea better.
	ETS1.B: Developing Possible Solutions • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Models of all kinds are important for testing solutions.	Students test their ideas and then redesign as necessary. Students build and use a model to test their solutions.
	ETS1.C: Optimizing the Design Solution • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.	Students test, redesign and retest in an informal iterative cycle. They revisit redesign during class discussion.

Crosscutting Concepts	Systems and System Models • Models can be used to represent systems and their interactions — such as inputs, processes and outputs — and energy and matter flows within systems.	Students build and use a model to represent the system in which they are solving an engineering problem.
	Connections to Engineering, Technology, and Applications of Science Influence of Science, Engineering, and Technology on Society and the Natural World • The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.	Students discuss how collisions are used in real world solutions.
	Stability and Change • Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	Students use their knowledge of forces to use collisions to solve a problem.

Materials Needed

- Assembly instructions for the table hockey game and vector hockey models (located after the instructions for this activity)
- Parts for the table hockey game and vector hockey models (one set per group)
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks*
- *Pencils*
- Engineering challenge instructions (located after the instructions for this activity)

Prior to the Activity

Build one vector hockey model (one frame with launchers and disc) for demonstration purposes.

Activity Procedure

1. **Engage:** Divide students into pairs or groups of up to four. Instruct students to build the table hockey game model. Allow students a little time to play the game. If students are in a group of three or more, they will need to take turns. In this game, students lay the frame flat on a desk or table. One student stands behind each of the two goals, opposite each other. Each student holds a gray paddle by the handle. The object of the game is to hit the gray puck (pulley wheel) with the paddle to direct it away from your goal and into your opponent's goal.
2. When everyone has had a chance to play, gather the students. They will probably be excited. Try to reign them in by asking how their games went. Steer the conversation toward collisions. Did they use collisions in this game? What for?

When students are finished with this part of the activity, they should completely dismantle their table hockey game models (including removing all connectors) and return all of the components to the bins.

3. **Explore:** Explain to students that they are going work on solving a problem involving collisions (see the engineering challenge instructions after these instructions). Show students the materials prepared ahead of time. Discuss the problem and constraints as a class. Leave the vector hockey demo model set up where all students can see it.
4. Divide the students into small groups of up to four (but ideally two) students each. Give students the information about the problem and let them review it. Instruct students to work through steps 1–3 of the challenge instructions.
5. As each group is ready they should check in with the teacher (this serves as formative assessment). Provide them with the materials and instructions to build the frame and launchers. Students should then have time to work through step 4. Remind students that any changes they make to their original idea should be recorded (along with the results of the changes they make) in their science notebooks as they work.
6. **Explain:** When all groups have completed their explorations, bring the group together to complete step 5. Depending on the student's results, the teacher may need to provide additional explanation.
7. **Elaborate:** After all groups have presented their solutions to the problem, facilitate a discussion addressing the following questions:
    a. How did the sum of the forces acting upon the gray puck (pulley wheel) result in change of motion to solve the problem?
    b. How were Newton's third law, momentum, mass, speed, and/or direction involved in your solution?
    c. Was magnitude of force a factor in the solution?
    d. How might use of collisions be useful in the real world? Can you think of any technologies that use these ideas?
    e. Discuss aspects of the engineering design process.

    When students are finished with this part of the activity, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.
8. **Evaluate:** Ask each student to individually draw a sketch of their solution and associated forces in their science notebook for teacher review.

Extensions

- Present students with other engineering challenge problems with constraints and provide various parts for students to design solutions. Encourage students to follow the steps of the engineering design process when designing solutions.

Engineering Design Challenge

Identify the Need and Constraints

The Problem: Move the gray puck (pulley wheel) through the open corner of the frame.

The Constraints:

- The only things that can touch the gray puck are the gray paddles.
- The paddles may only strike the puck at right angles (90°) to the sides of the frame.
- You may move (launch) each paddle only once.
- You are limited to the materials provided.
- You must provide a diagram showing how your solution works. Use your science notebooks.
- You must be able to explain — using your knowledge of collisions — if and how velocity (speed and direction) and mass influence your design.

Develop Possible Solutions

Step 1: Each group member thinks of ideas to solve the problem and writes these ideas down or sketches them in their science notebooks. (~5 minutes)

Step 2: All ideas are then shared and discussed with the group. Group members practice courtesy by taking each idea under serious consideration, even if it clearly won't work. Discussion should be about the physics behind why an idea won't work, not about the merits of the idea or the person who came up with it. (~15 minutes)

Select a Promising Solution

Step 3: Collectively the group should decide upon one idea to test.

Build, Test, and Evaluate a Prototype

Step 4: Build and test the prototype. You may make changes to improve upon your design during this phase of the project. (You may test your design more than once if the problem is not solved within the given constraints on the first try, but each time you make changes they should be recorded. All of these changes should eventually lead to a solution that meets all constraints and solves the problem.)

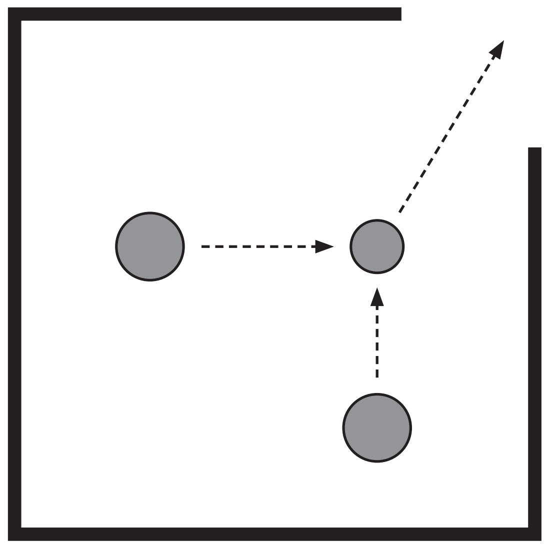
Step 5: Share your prototype with the class. As a class, discuss the positive and negative aspects of each group's design.

Redesign as Needed

Step 6: Discuss where the problem solving should go from here. Are there attributes from various designs that could be combined? Does one design clearly solve the problem better than the others? Do you have ideas for improvement?

Possible Solution

Two students release the gray paddles from the launchers at the same time using the appropriate amount of force so that they hit the gray puck at the same time and with enough force to send it through the opening.

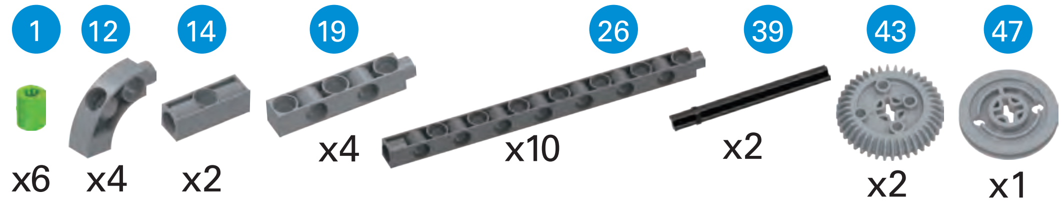


Additional Resources

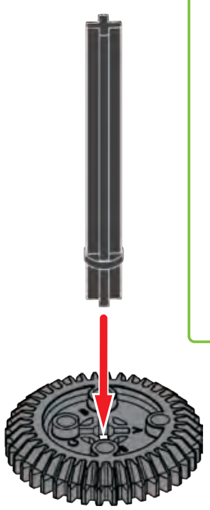
Bumper Ducks Game	https://ssec.si.edu/bumperducks	Starts out with deflection — collisions with a wall. Good for component vectors as levels increase. Using collisions to solve problems.

Assembly Steps for Activity 5, Part 1: Table Hockey Game

You will need:

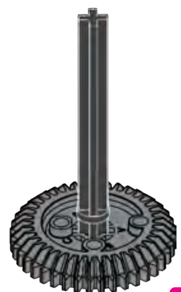


1



x2 Do this step 2 times.

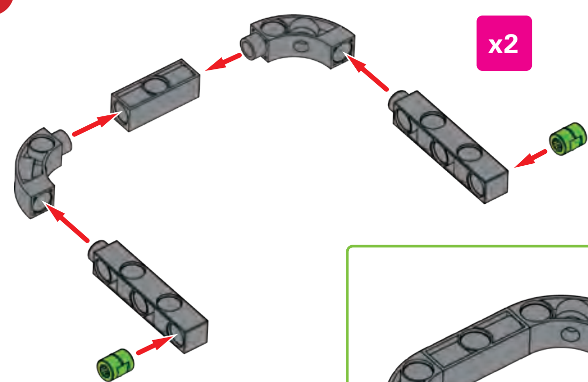
Subassembly **A**



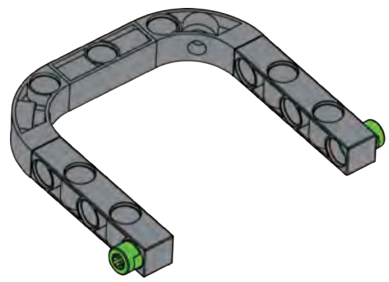
x2

2

x2



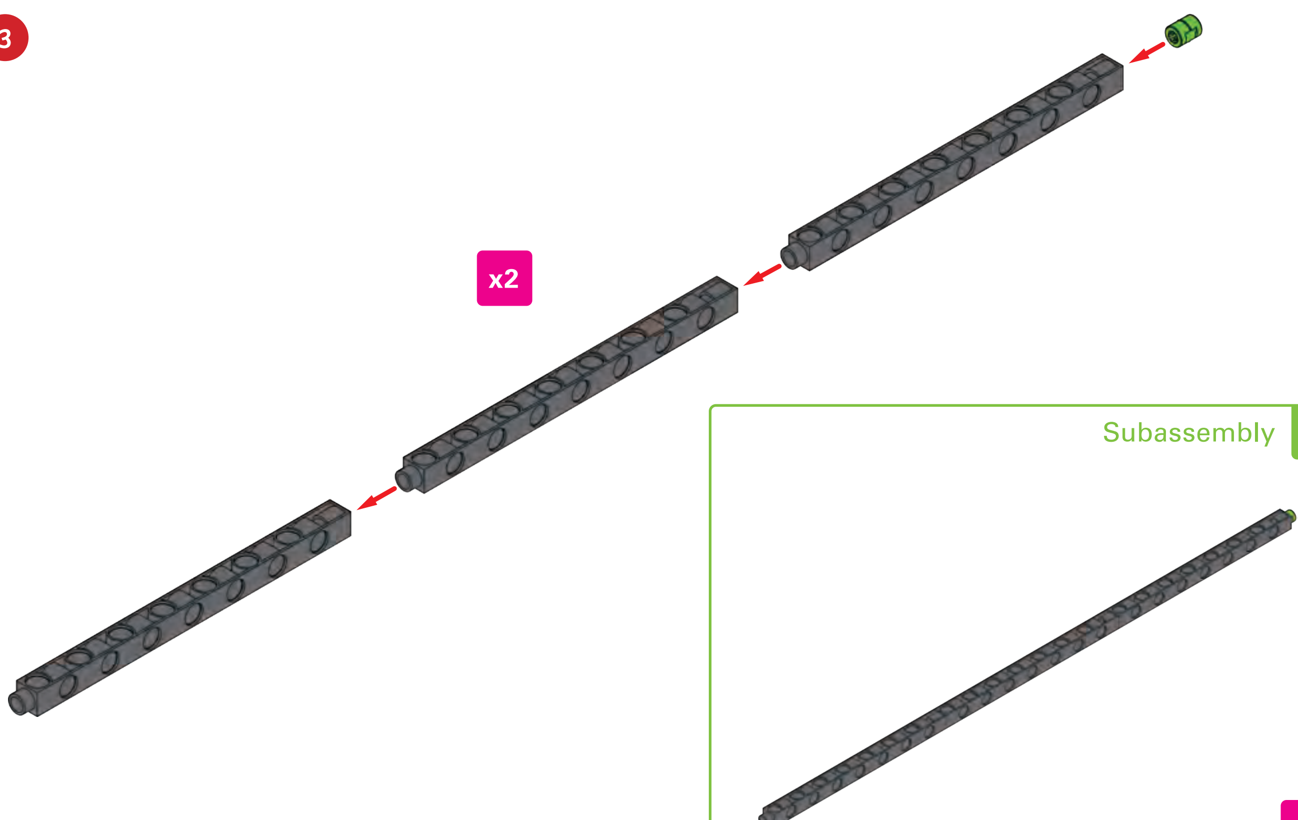
Subassembly **B**



x2

3

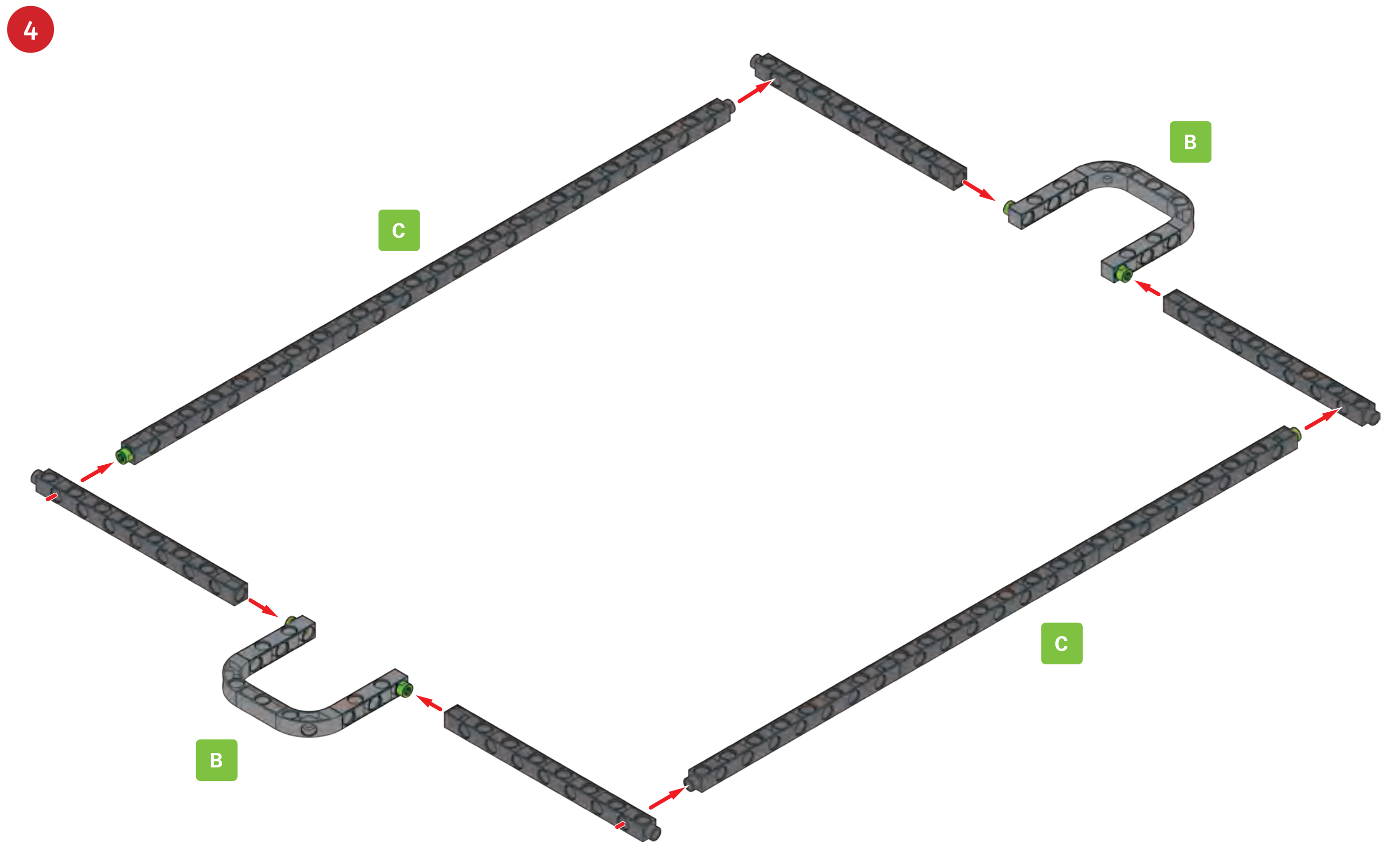
x2

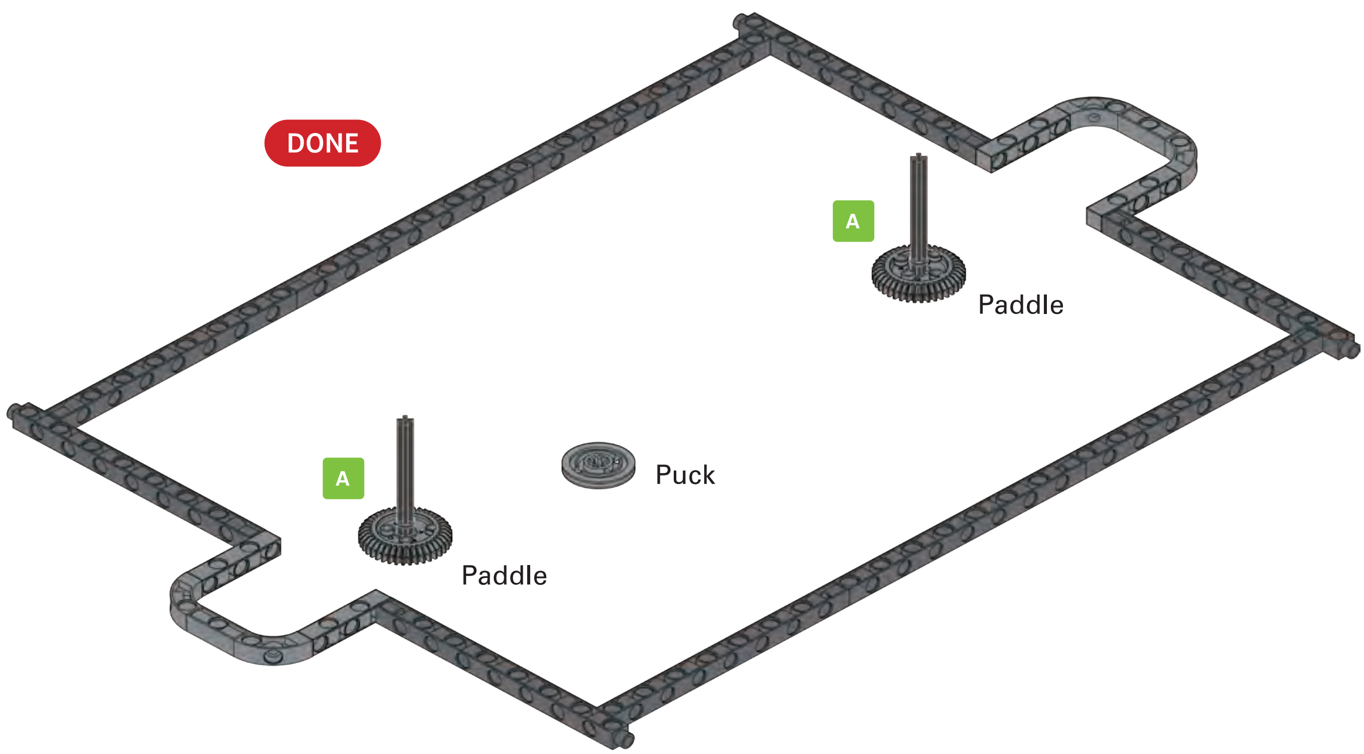


Subassembly **C**

x2

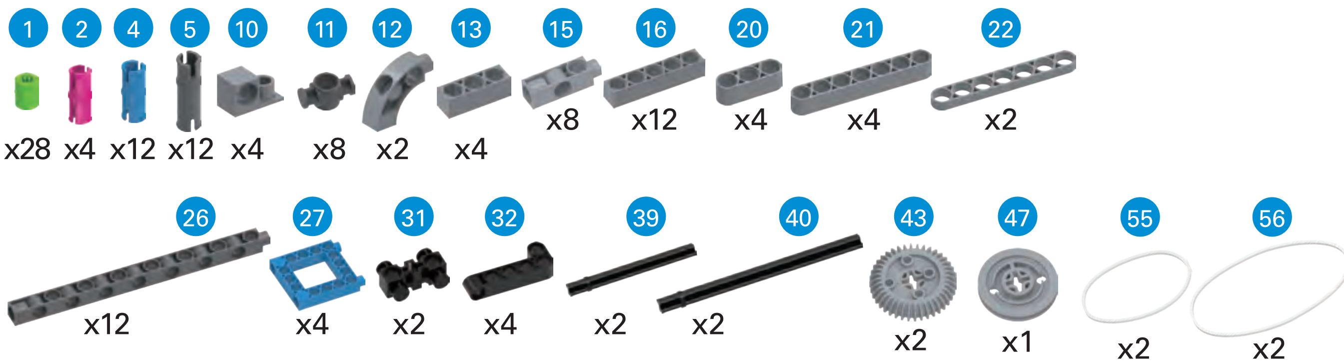
Assembly Steps for Activity 5, Part 1: Table Hockey Game Continued



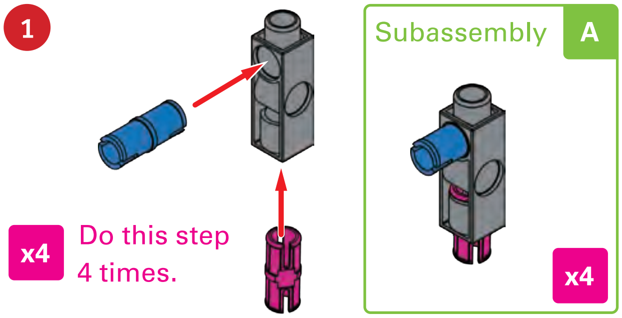


Assembly Steps for Activity 5, Part 2: Vector Hockey

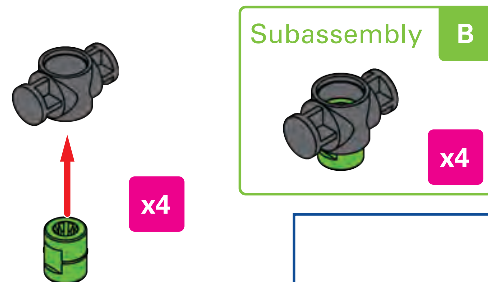
You will need:



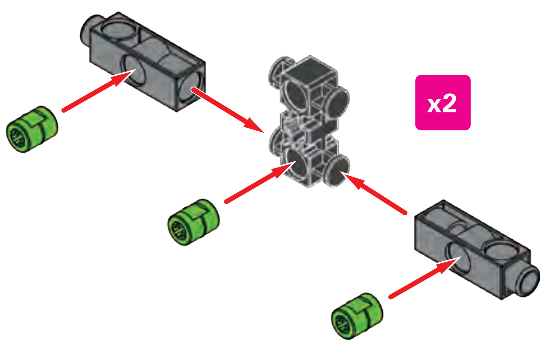
1



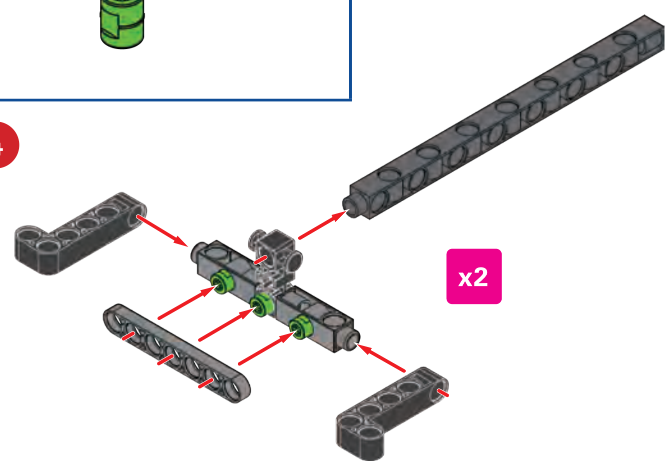
2



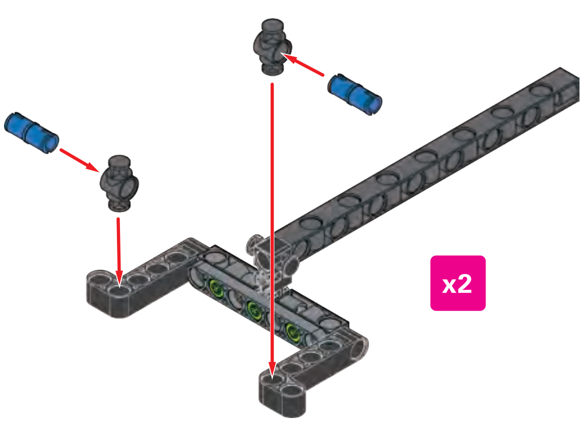
3



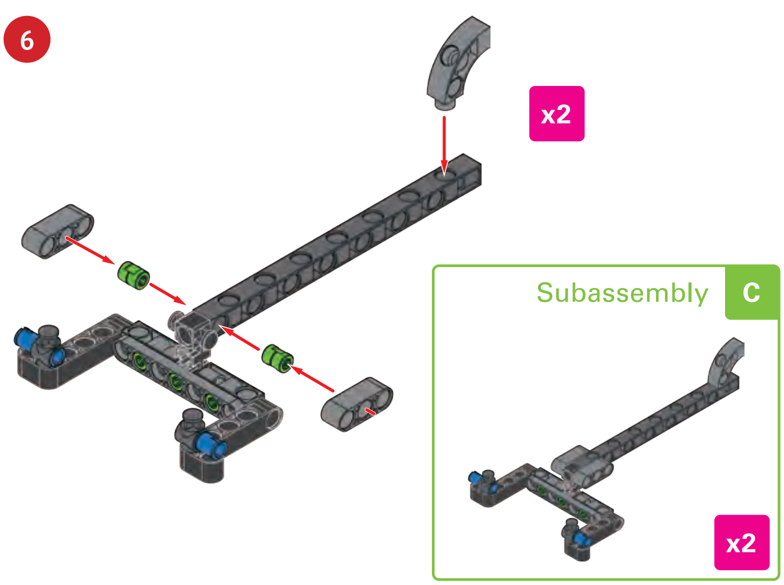
4



5

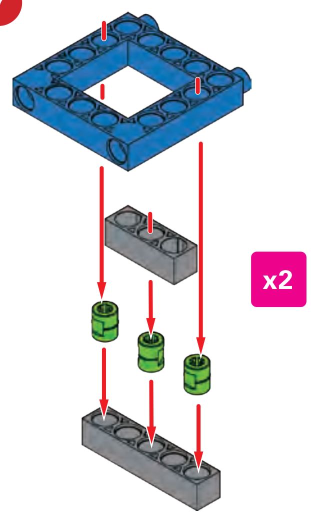


6

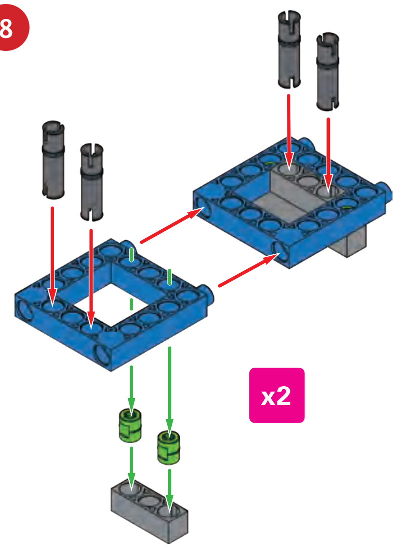


Assembly Steps for Activity 5, Part 2: Vector Hockey Continued

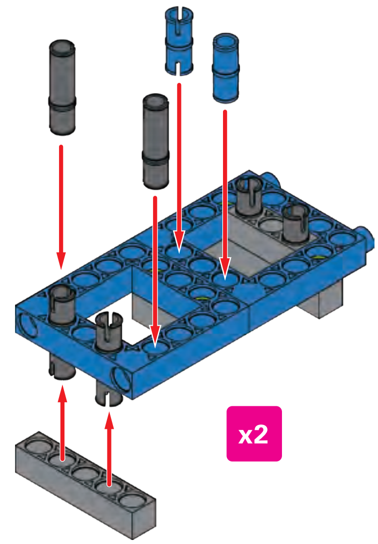
7



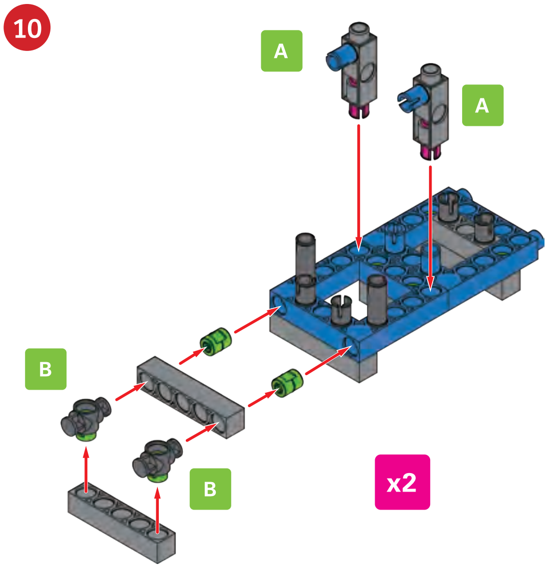
8



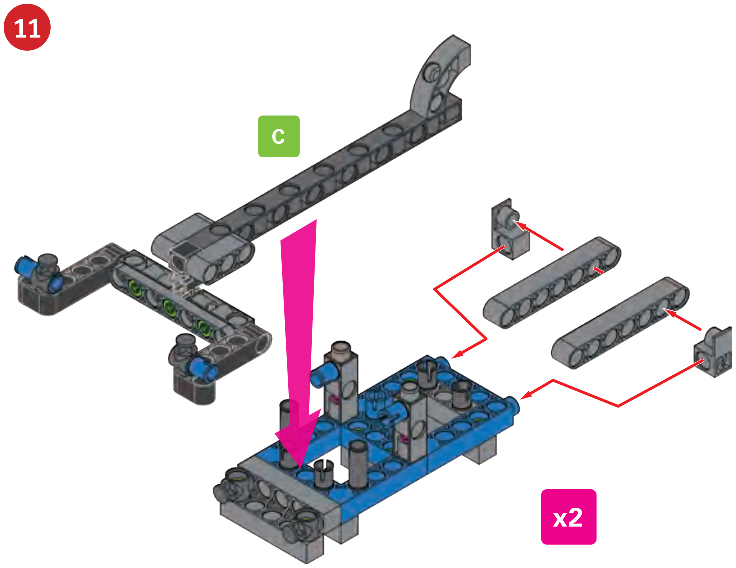
9



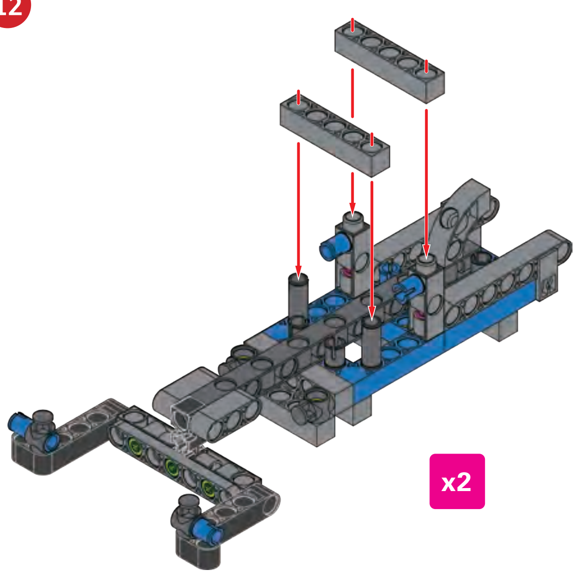
10



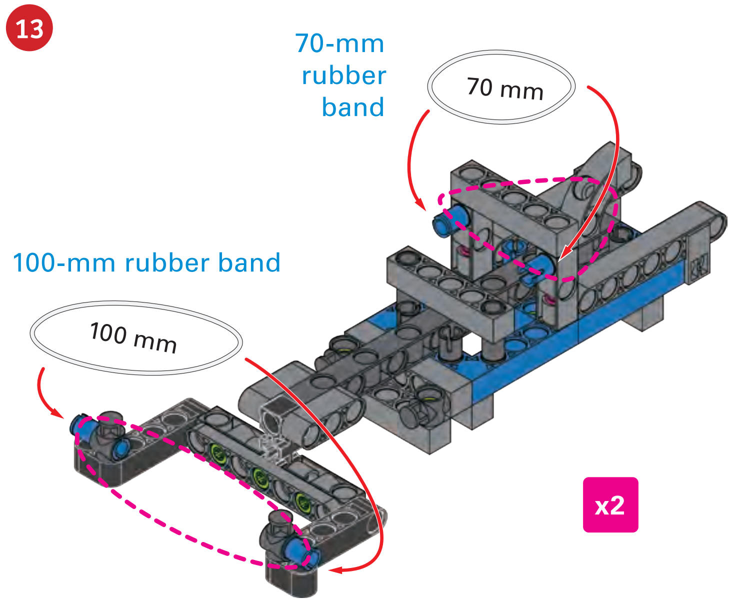
11



12

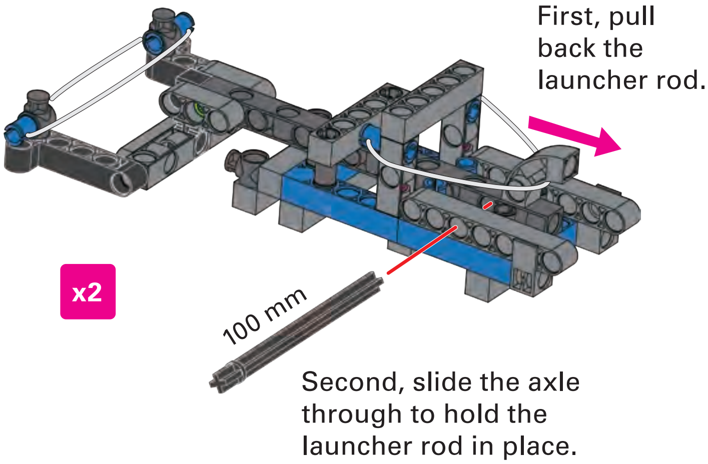


13

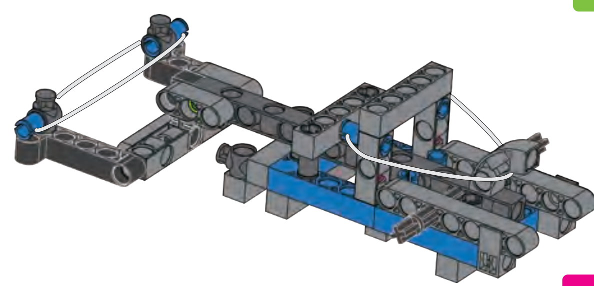


Assembly Steps for Activity 5, Part 2: Vector Hockey Continued

14

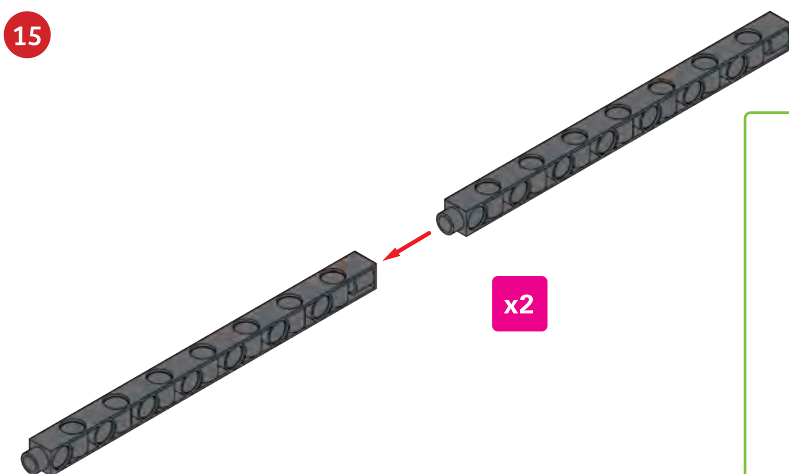


Subassembly **D**



x2

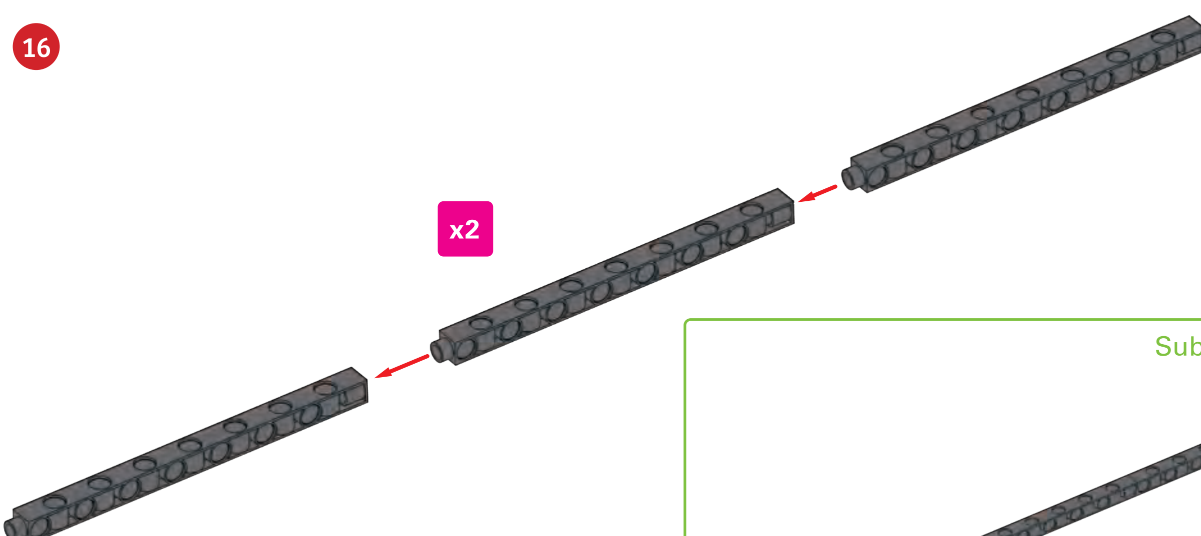
15



Subassembly **E**

x2

16

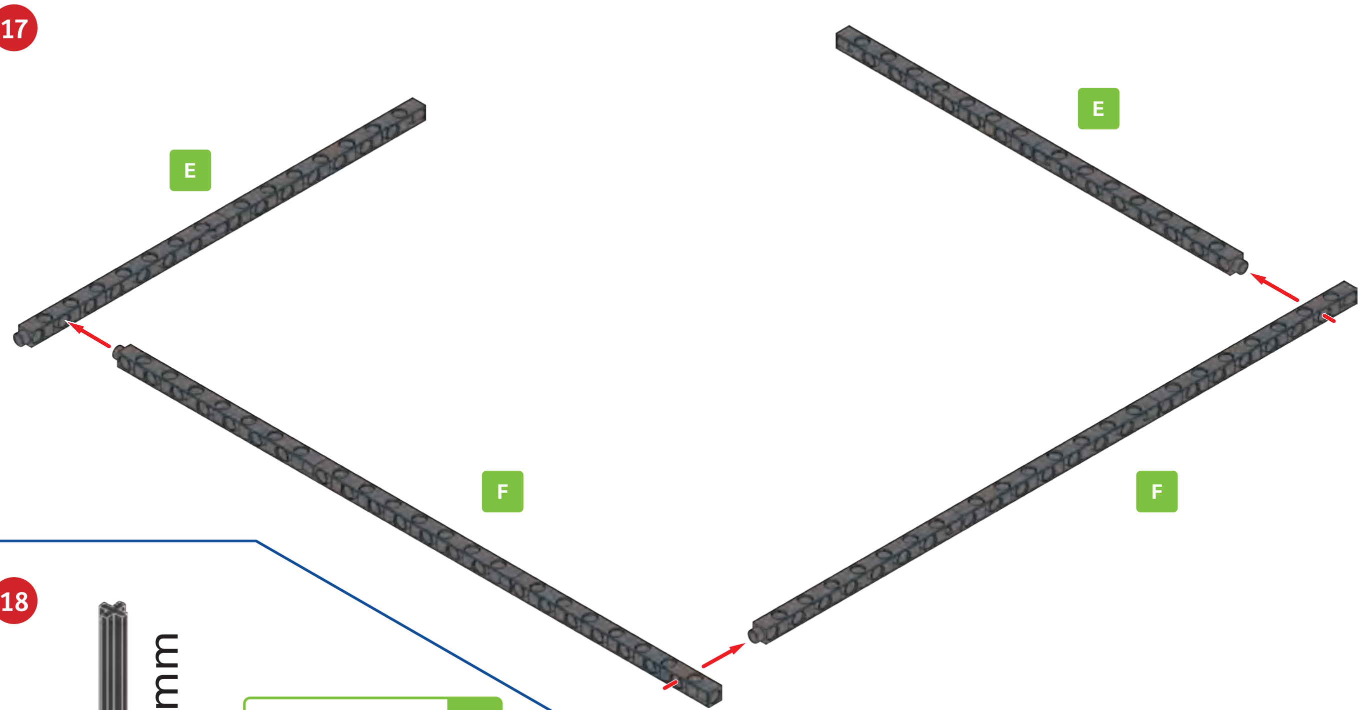


Subassembly **F**

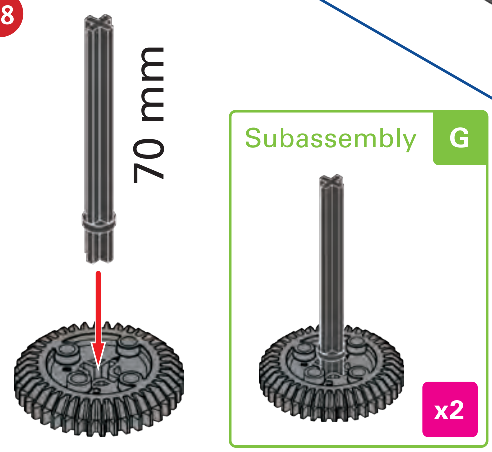
x2

Assembly Steps for Activity 5, Part 2: Vector Hockey Continued

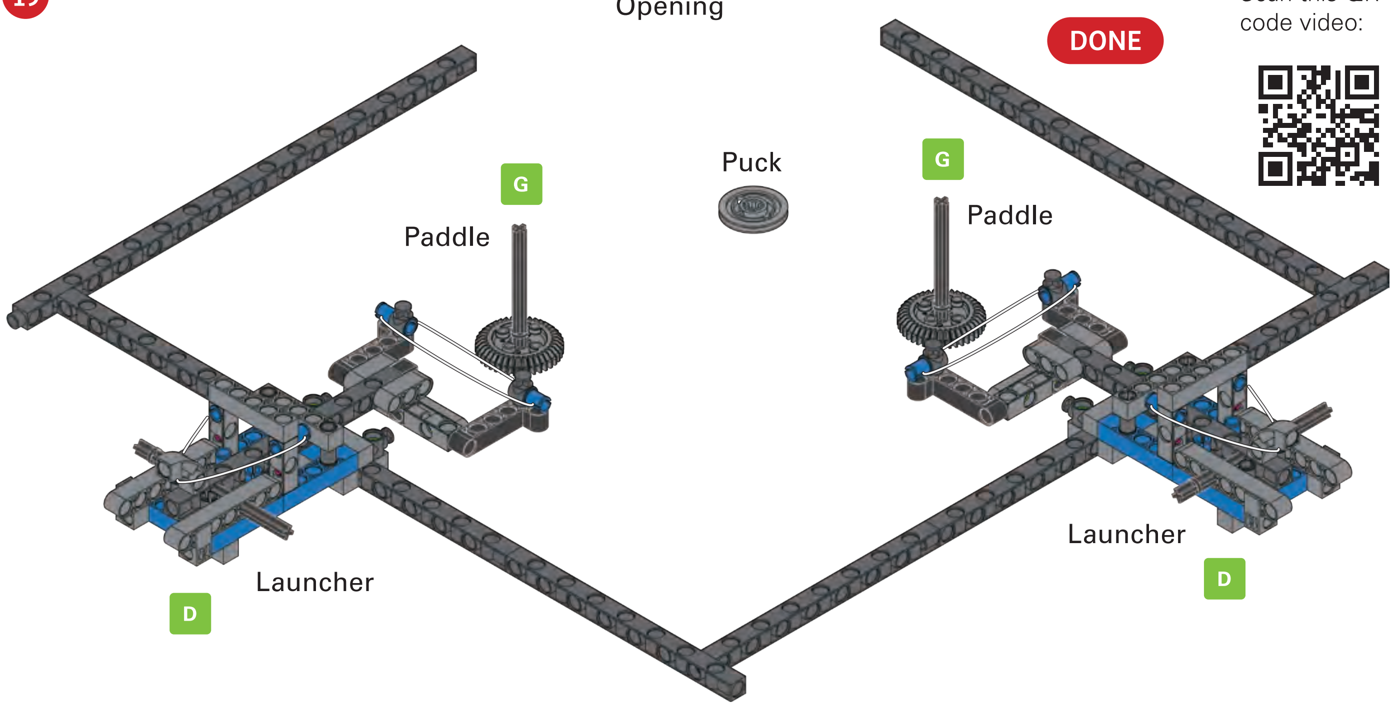
17



18



19



Scan this QR code video:

Activity 6

Magnetic Fields

Students visualize the non-contact force fields magnets produce.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Observe non-contact forces through exploration of magnets.
- Practice designing an investigation with teacher input.
- Determine what evidence of non-contact force looks like.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-5	MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Planning and Carrying Out Investigations • Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation.	Students determine what evidence of non-contact magnetic force looks like. Students design and conduct an investigation to provide evidence that fields exist between objects that are not in contact.
Disciplinary Core Ideas	PS2.B: Types of Interactions • Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).	Students map magnetic fields using magnets and iron filings.
Crosscutting Concepts	Cause and Effect • Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students think about cause and effect between objects that do or do not exert a non-contact force on other objects.

Materials Needed

- Assembly instructions for the magnetic field board and automatic magnetic field manipulator models (located after the instructions for this activity)
- Parts for the models, including magnets (one set per group)
- Paper clips
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks*
- *Pencils*
- *Additional magnets and paper clips to supplement (optional)*
- *AA battery (1 per group)*
- *Nonmagnetic materials such wood, metal, plastic, paper, etc.*
- *Rulers*

Notes for Teachers

Students will likely have had some experience with contact forces coming into this activity. In this activity, students will not only observe magnetic fields, but will also evaluate experimental design. This activity can serve as an introduction to experimental design, or an assessment of student understanding of experimental design. A great resource for learning more about experimental design can be found here: https://undsci.berkeley.edu/lessons/pdfs/student_worksheet.pdf

Activity Procedure

1. **Engage:** Begin by handing out magnets of various strength and paper clips to each student in the class (everyday magnets such as refrigerator magnets are fine). Give students a few minutes to interact with these materials. Ask them to record what they observe and any questions those observations inspire in their science notebooks.

2. Ask students to set their magnets and paper clips aside. Ask them what they observed. Likely they will have observed the paper clip being attracted to the magnet. They may have observed a stronger attraction with some magnets vs. others. They may have also interacted with each other and observed attraction and repulsion between magnets.

3. Ask the students if there are forces associated with magnets. Ask them to describe these forces. Ideally,

students will recognize that magnetic forces are not visible and act at a distance. Discuss non-contact vs. contact forces. Come up with a driving question that works for your class for their upcoming investigation. For example, "How can we explain how magnetic forces act at a distance?" Many students may have already heard of magnetic fields, but this activity focuses not just on magnetic fields, but how we know they exist (the evidence for magnetic fields).

4. **Explore:** Ask students to think about how we might provide evidence that magnetic fields exist. What evidence tells us that an object is magnetic? (The invisible field's effect on another object.) Discuss as a group. Ideas such as magnets attract metal, magnets move a compass needle, and others may come up. Students may or may not think about iron filings. You may decide to have students individually write in their student notebooks about what they think evidence of a magnetic field would look like before or after this conversation. A good resource to learn more about scientific evidence can be found here: https://undsci.berkeley.edu/article/whatisscience_06

5. Individually or as a group have students construct a claim/evidence/reasoning chart related to magnetic forces and fields. Start with the question and then have students come up with a statement for the claim. It may look something like this:
   How can we explain how magnetic forces act at a distance?

6. Students have discussed ideas for evidence. Now they will test those ideas. Divide students into small groups (up to four students per group). Provide the group with the building materials and instructions for the magnetic field board model and instruct them to build it. This will be the setup they will use for their experimental design.

7. Ask students to set the model aside where they can all see it. Provide each group with magnets, compass, and a variety of non-magnetized materials (such as wood, metal, plastic, and paper). Ask the students to work together to design an experiment using the magnetic field board that will provide evidence that force fields exist between objects exerting forces on each other even though the objects are

not in contact. Remind students that at this point they are designing the experiment, not performing it. Points of focus in their design could include:

a. Defining a driving question

b. Constructing a hypothesis

c. Identifying dependent, independent, and constant variables

d. Explaining the procedure they plan to follow

e. Describing what evidence will look like if observed

Students should write down and sketch their experimental design in their science notebooks to be reviewed by the teacher prior to continuing. This portion of the activity can be guided to the extent that the teacher sees fit.

8. At this point, the role of the teacher is to identify flaws in the students' understanding of experimental design and gently guide them toward best practices. Help students work through the points of focus above and determine if their experiment answers their question, proves or disproves their hypothesis, etc. Guide them back to their claim/evidence/reasoning charts to check their experimental focus. In some cases it may be more educational for teacher to allow students to run a flawed investigation so that they can learn from their mistakes! It is important to note that experiments should be reproducible. They should provide precise instructions. For example, it is not clear enough to say, "Hold the magnet close to the metal filings." Rather, something like, "The magnet should be positioned one inch above the metal filings," could be said.

9. Once approved, allow students to carry out their investigations. They should record results in their science notebooks as they see fit (or as the instructor has discussed with them based on their experimental design) and explain the evidence they found or did not find. They should complete their claim/evidence/reasoning chart or similarly report their findings. They should also include reflection about what they did, including what they would change if they were to investigate again.

10. **Explain:** Once all the groups have completed their investigations, discussion should take place between all of the students and the instructor around their experiments and what worked, what didn't, what evidence was observed, etc. Within this discussion the instructor can relate best practices for an experiment of this type. Students can also use this magnetic field simulation to visualize magnetic fields another way and solidify their understanding: https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets. This simulation could also be used for the Elaborate portion of this lesson.

Best Practices for Experimental Design

Driving Question: What evidence can be observed that fields exist between objects exerting forces on each other even though the objects are not in contact?

Testable Hypothesis: If … then … because …

For example: *If I move the magnet close to the metal filings, then they will move into a pattern because they are aligning with the invisible magnetic field.*

Variable 1 (independent variable): magnet/other materials (wood, metal, plastic, paper, etc.)
Variable 2 (dependent variable): iron filings
Constants: the remainder of the setup and the process

How the Experiment Works:

1. Build the test apparatus (magnetic field board).
2. Choose a method for testing (e.g., make observations of the metal filings when each material is placed four inches, two inches, one inch, and half an inch above the iron filings). Note: a compass may also be used to show evidence of magnetic fields.
3. Create a data table to organize observations.
4. Run experiment.
5. Analyze data.
6. Draw conclusions.

Note: Student descriptions of methods should go into more detail about what they plan to do.

11. **Elaborate:** To take both the concepts of magnetic fields and also experimental design further, students can investigate how different strengths of magnets affect the iron filings. They can apply what they have learned and design a second experiment to answer a new driving question.

    When students are finished with the activity, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

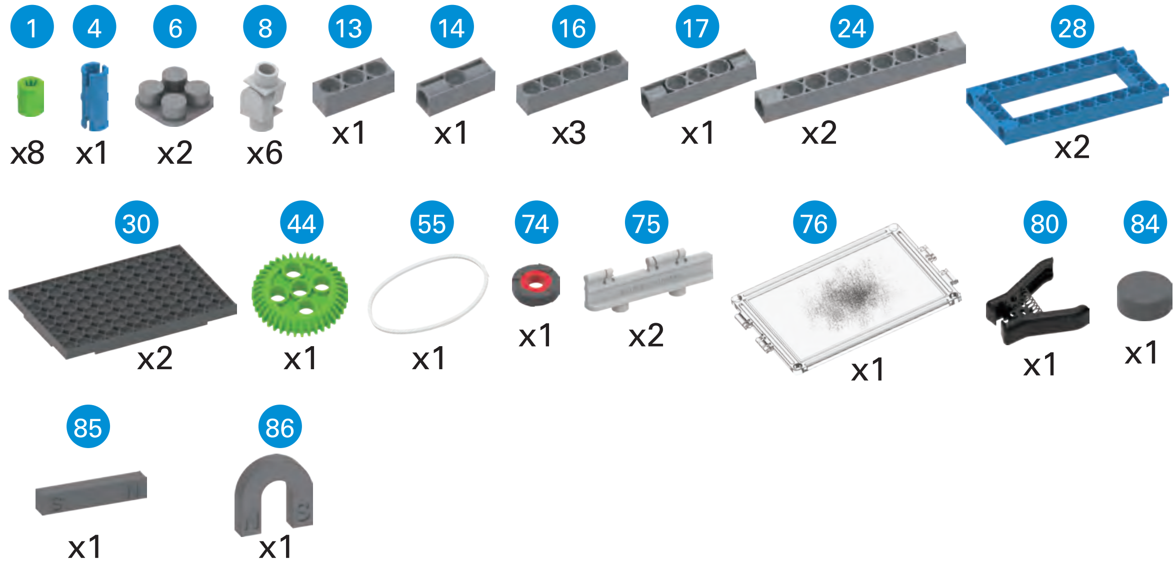
12. **Evaluate:** Students should individually in their science notebooks explain evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

Extensions

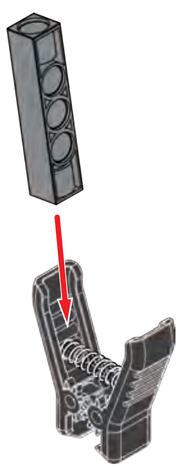
- Have students attempt to draw basic force diagrams for magnets thinking about Newton's laws.
- Have students build the automatic magnetic field manipulator model and design another experiment around this model.

Assembly Steps for Activity 6, Part 1: Magnetic Field Board

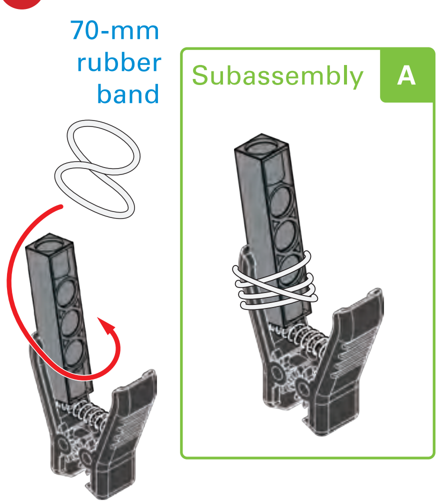
You will need:



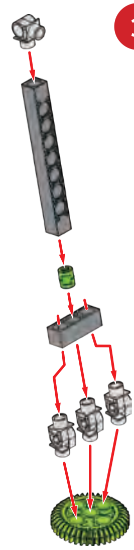
1



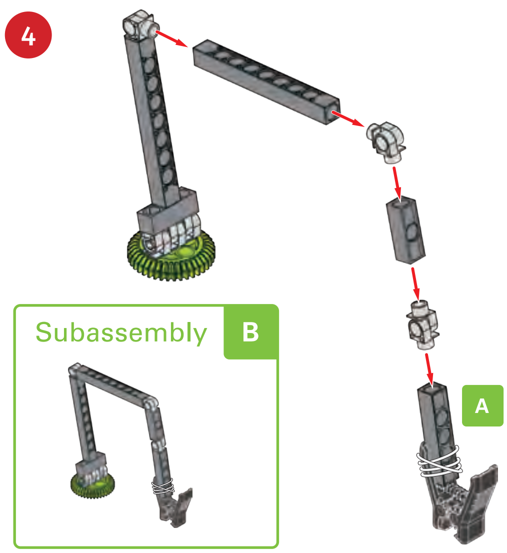
2



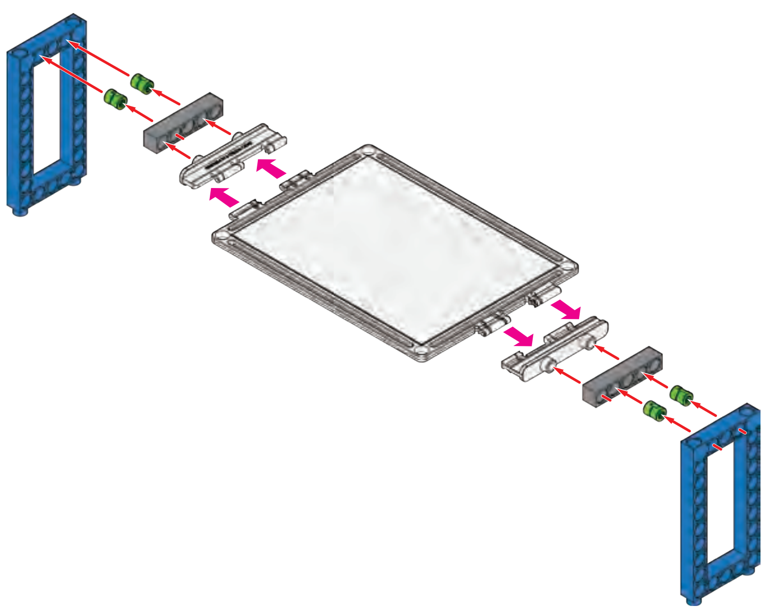
3



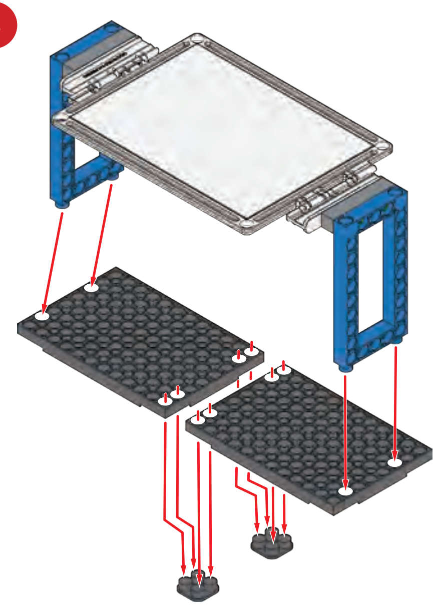
4



5

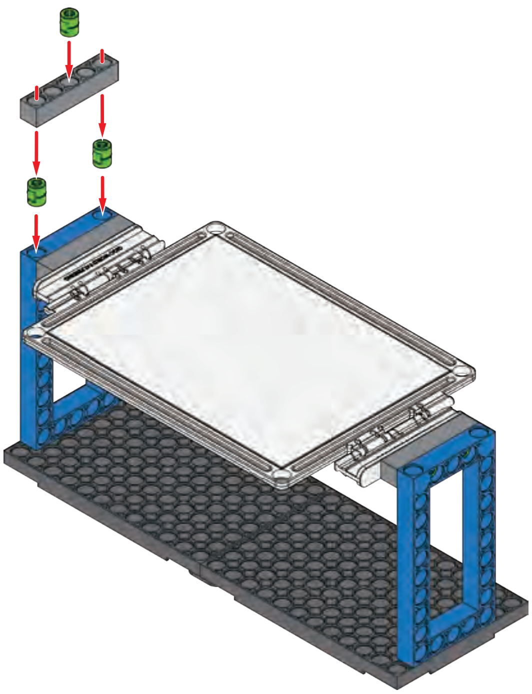


6

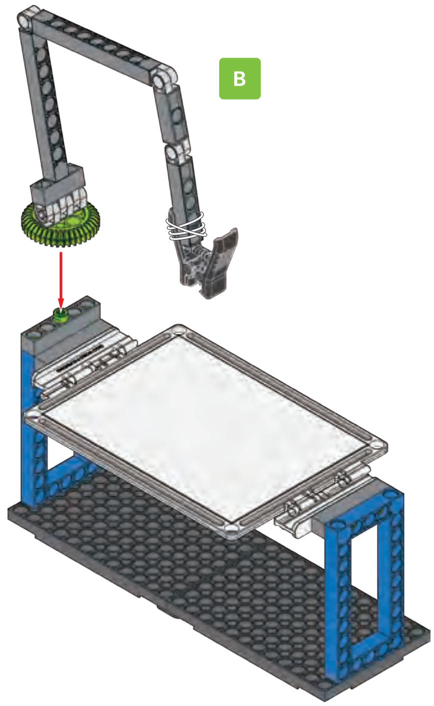


Assembly Steps for Activity 6, Part 1: Magnetic Field Board Continued

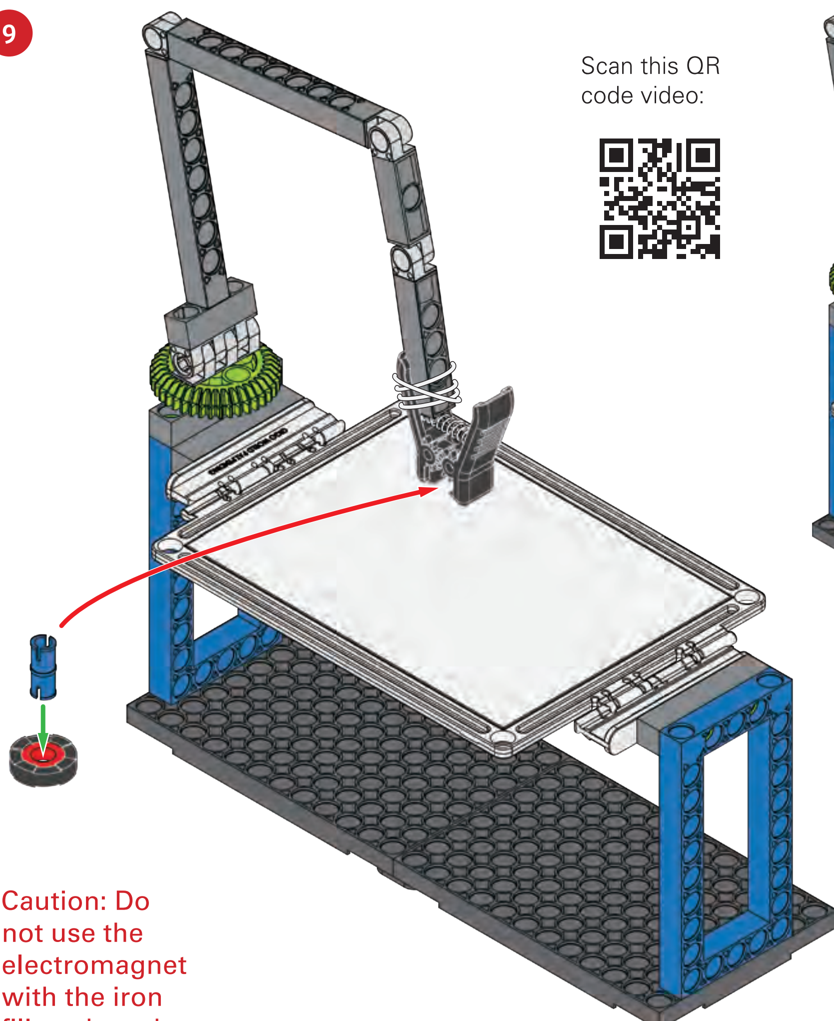
7



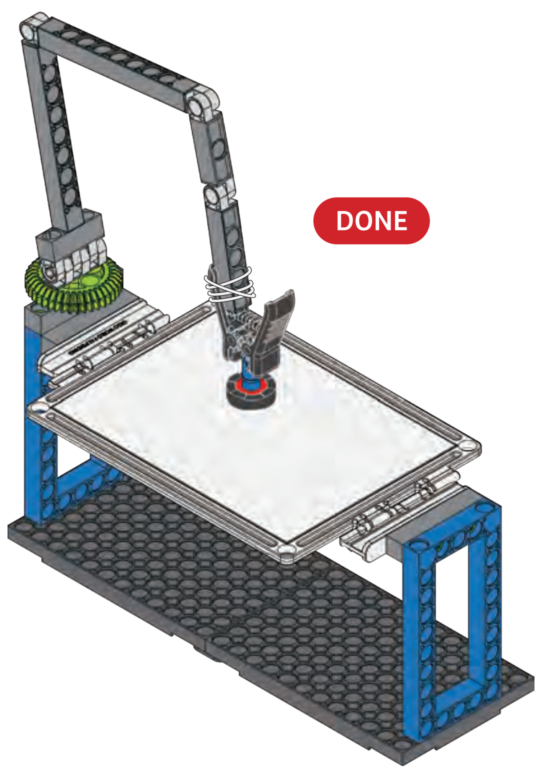
8



9



Scan this QR code video:



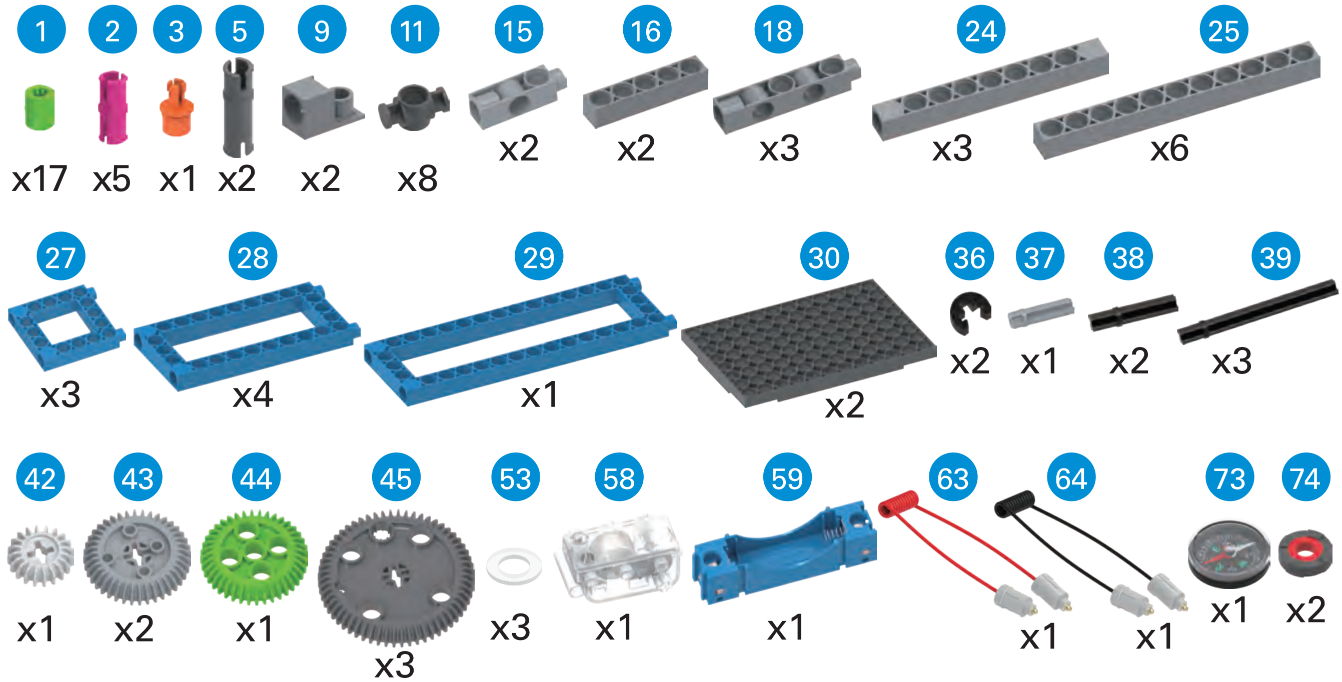
Caution: Do not use the electromagnet with the iron filings board.

Note: It is easier to see the iron filings if a piece of light colored paper is held or taped underneath.

Note: If the arm falls off too much during use, you can secure it with a longer pin.

Assembly Steps for Activity 6, Part 2: Automatic Magnetic Field Manipulator

You will need:



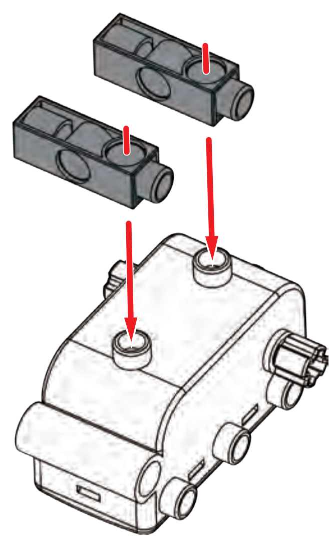
1

x2 Do this step 2 times.

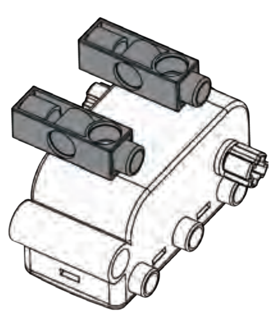
Subassembly **A**

x2

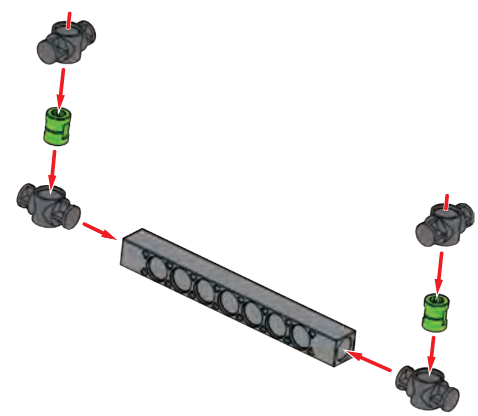
2



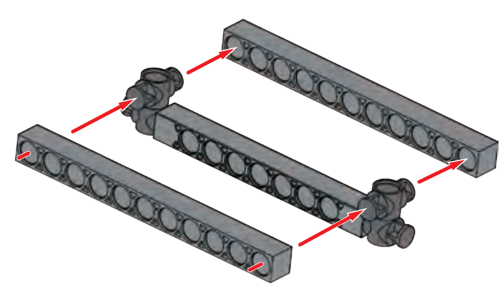
Subassembly **B**



3

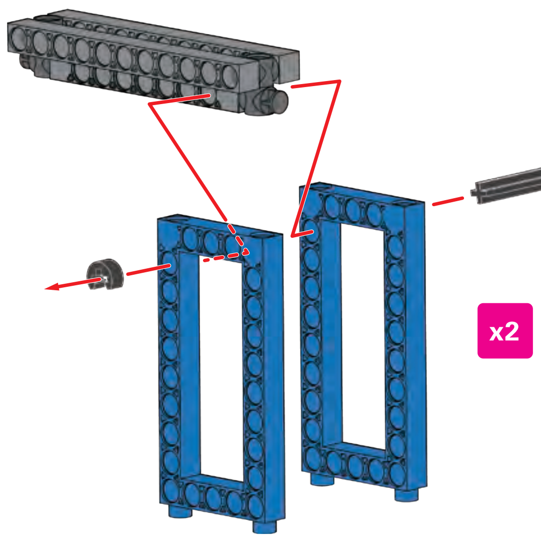


4

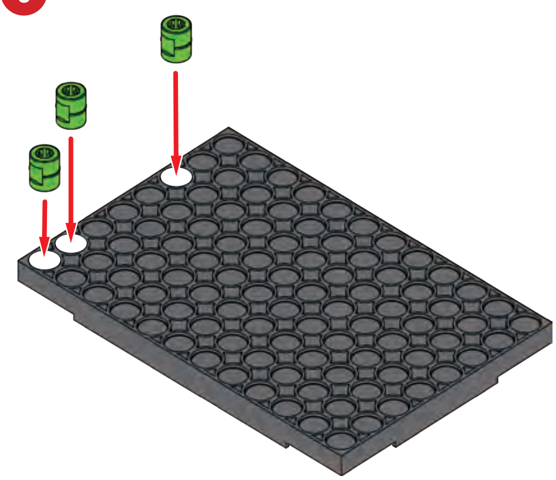


Assembly Steps for Activity 6, Part 2: Automatic Magnetic Field Manipulator Continued

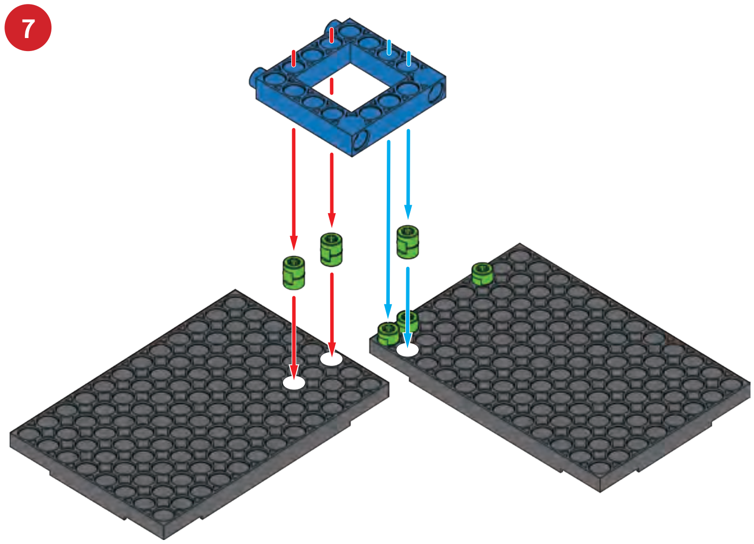
5



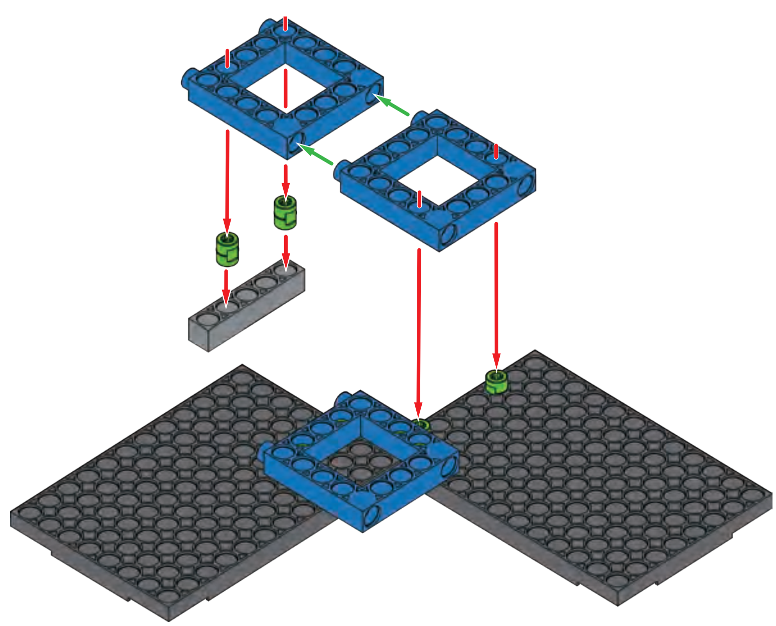
6



7

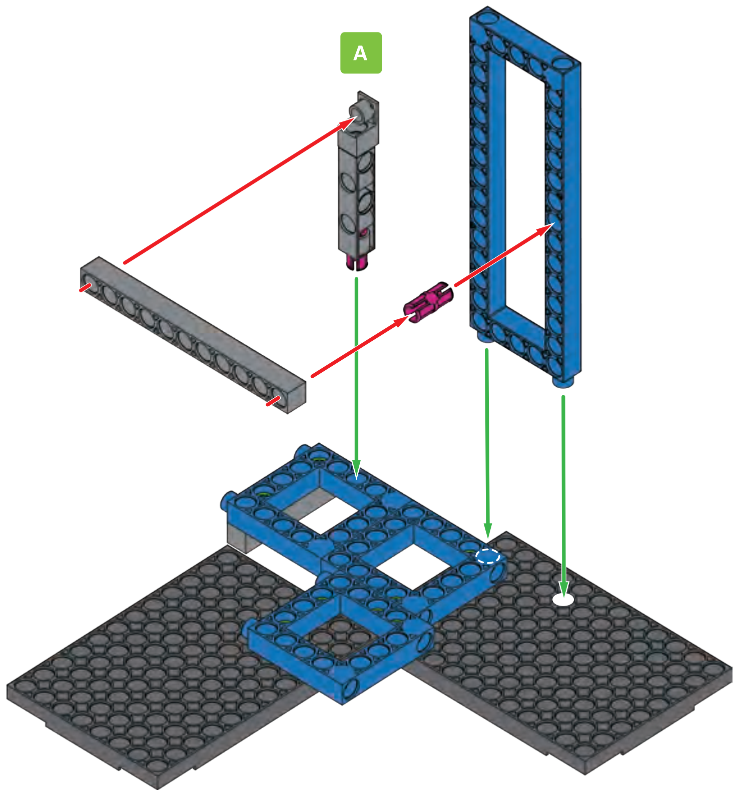


8

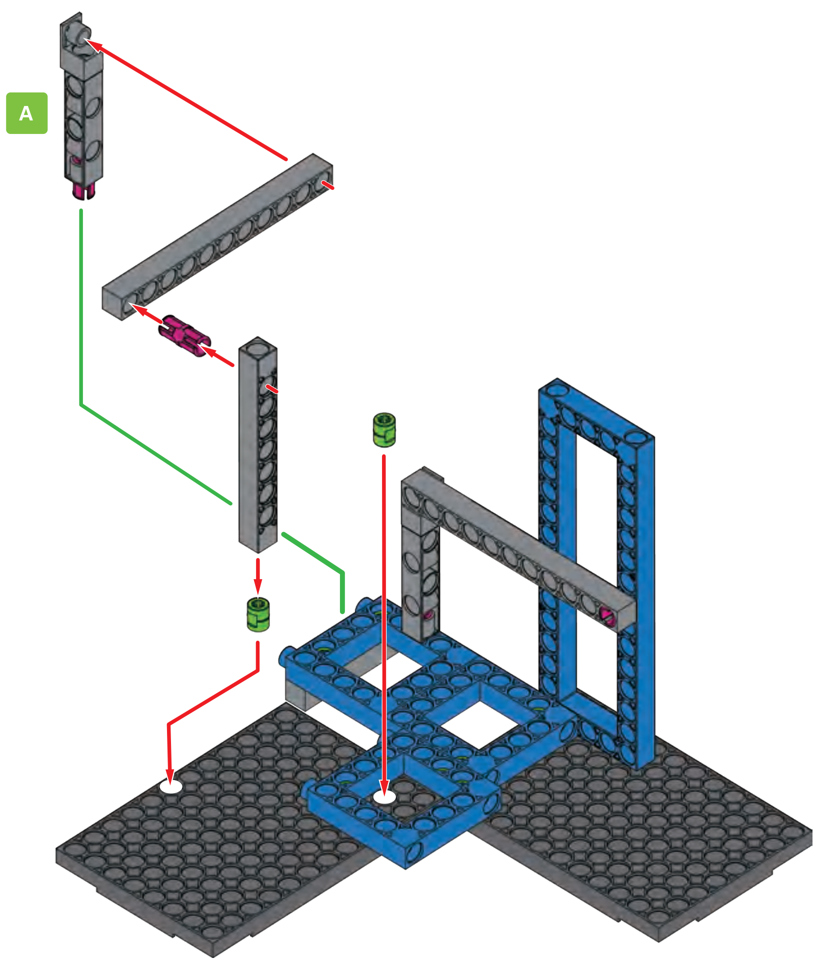


Assembly Steps for Activity 6, Part 2: Automatic Magnetic Field Manipulator Continued

9

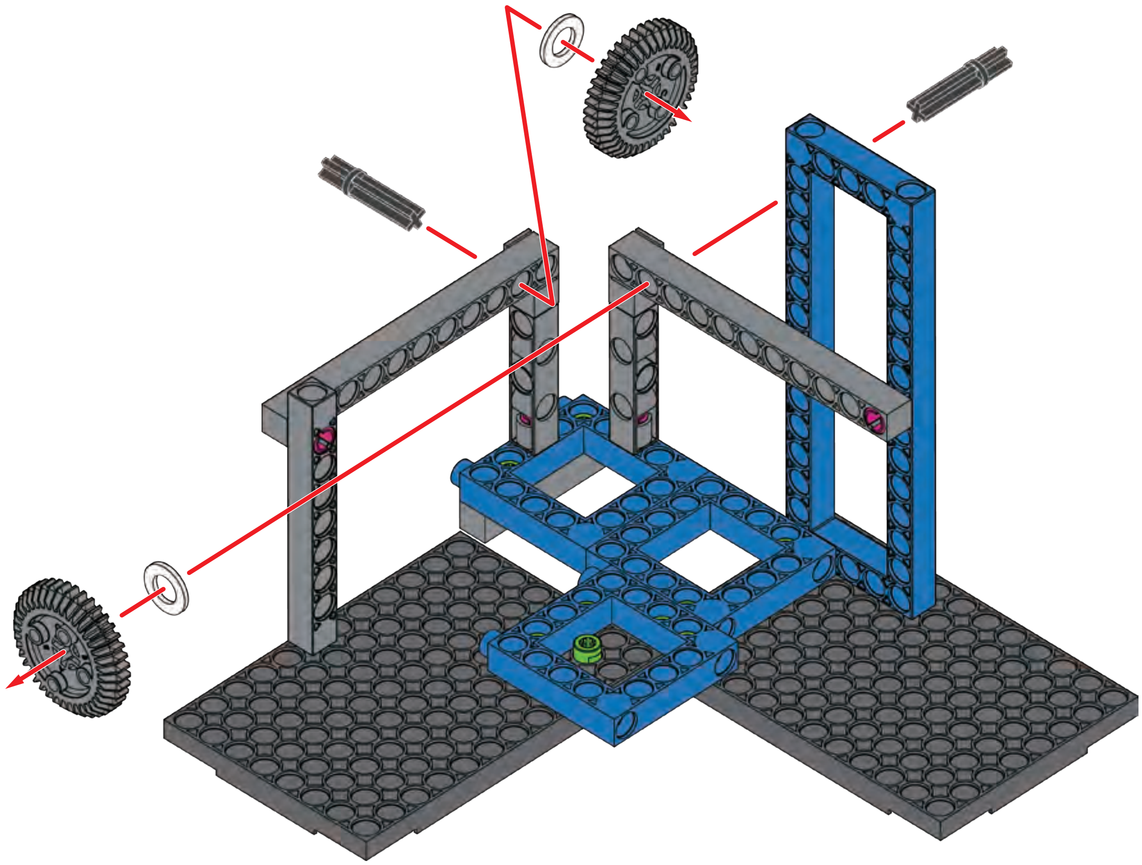


10

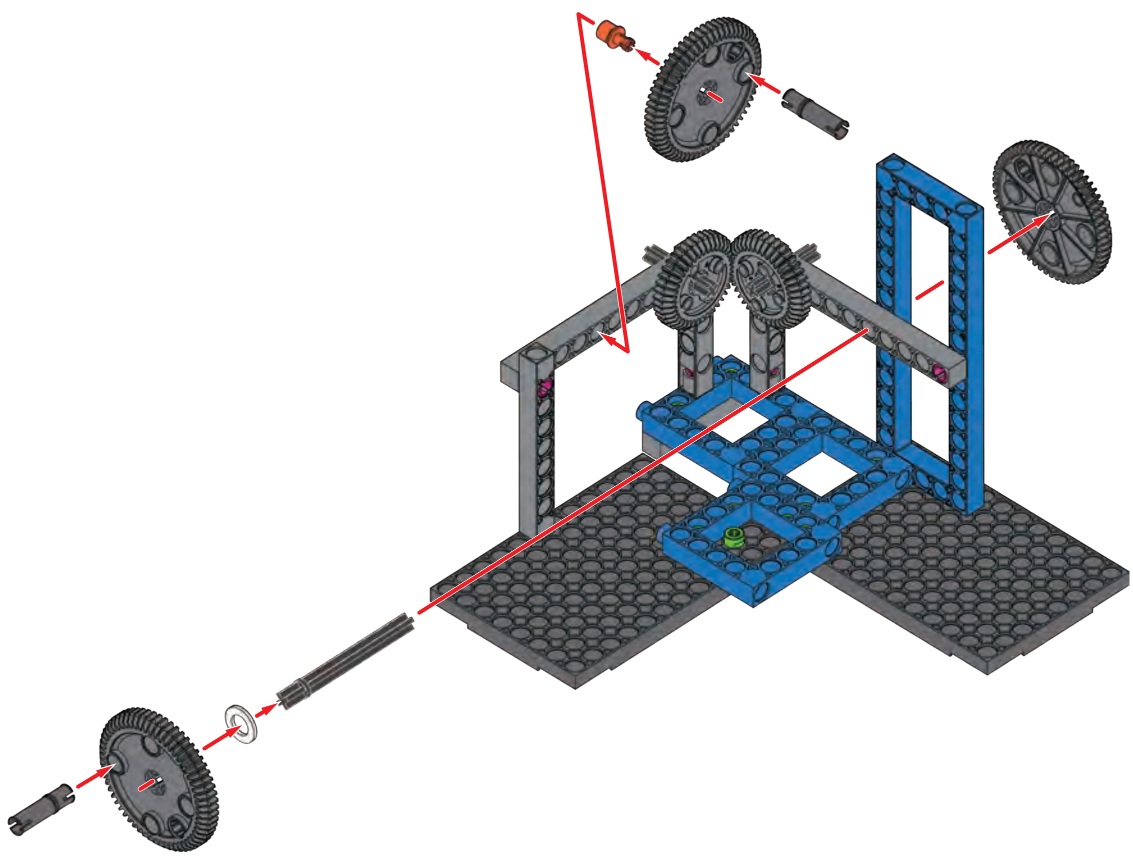


Assembly Steps for Activity 6, Part 2: Automatic Magnetic Field Manipulator Continued

11

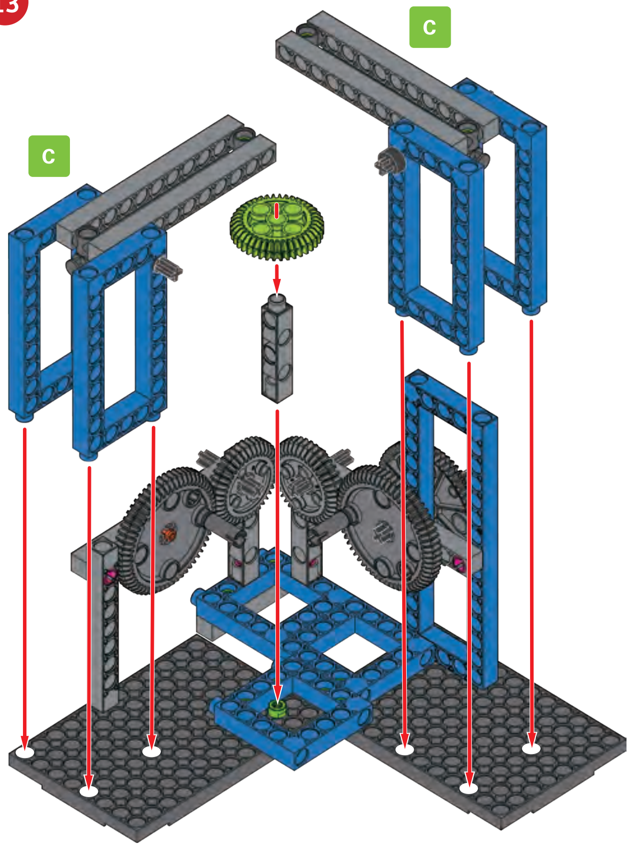


12

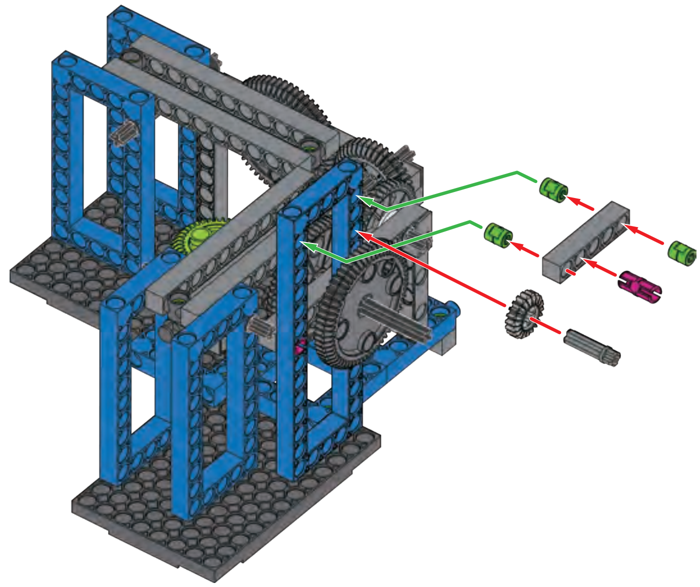


Assembly Steps for Activity 6, Part 2: Automatic Magnetic Field Manipulator Continued

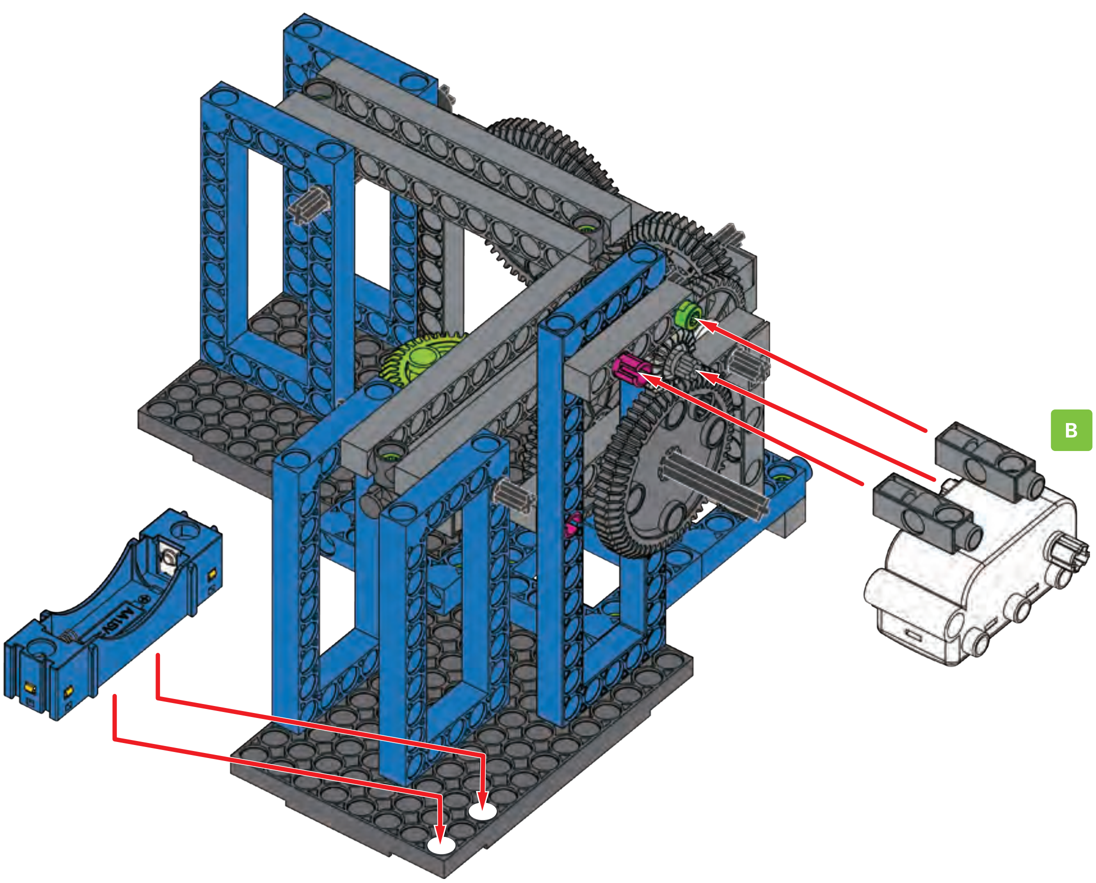
13



14

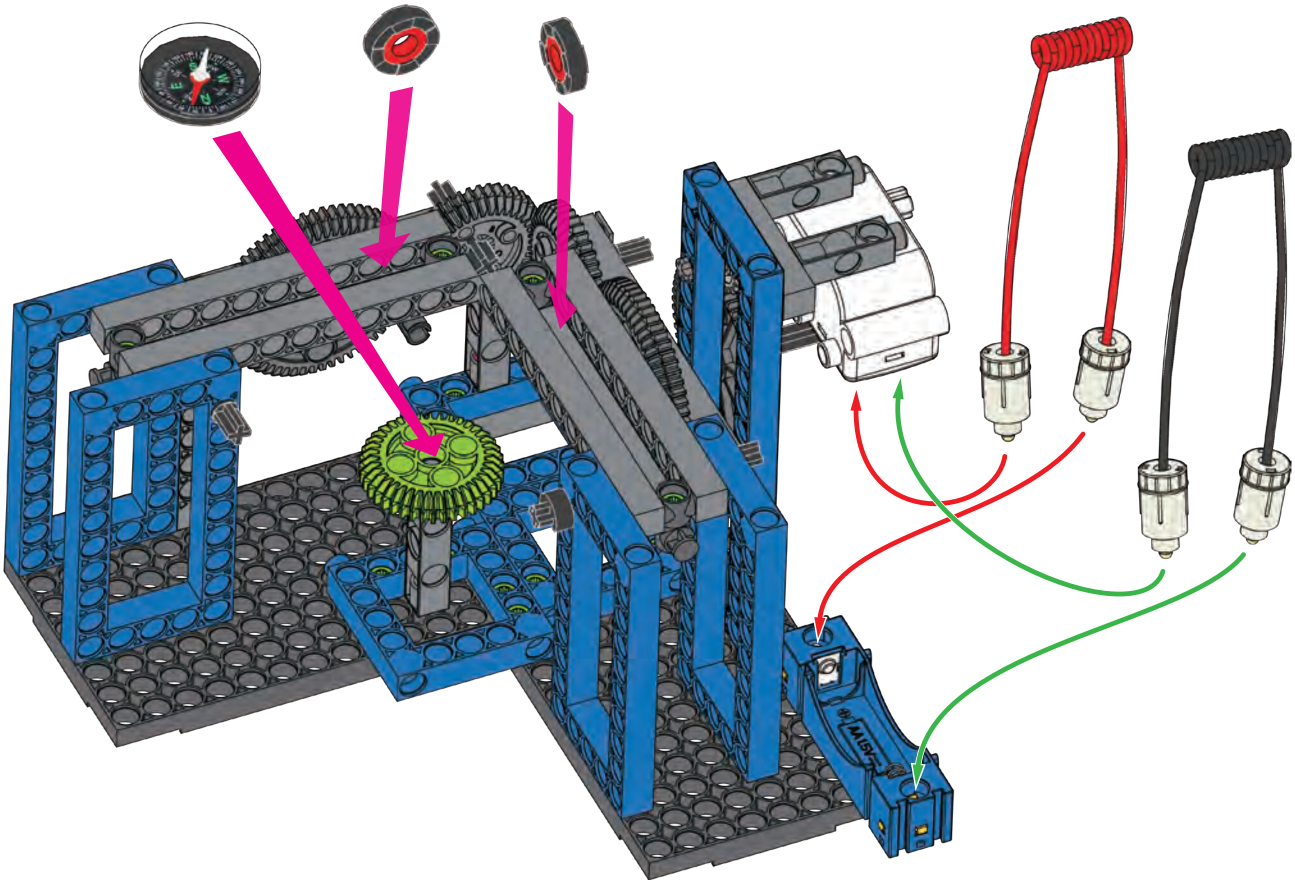


15

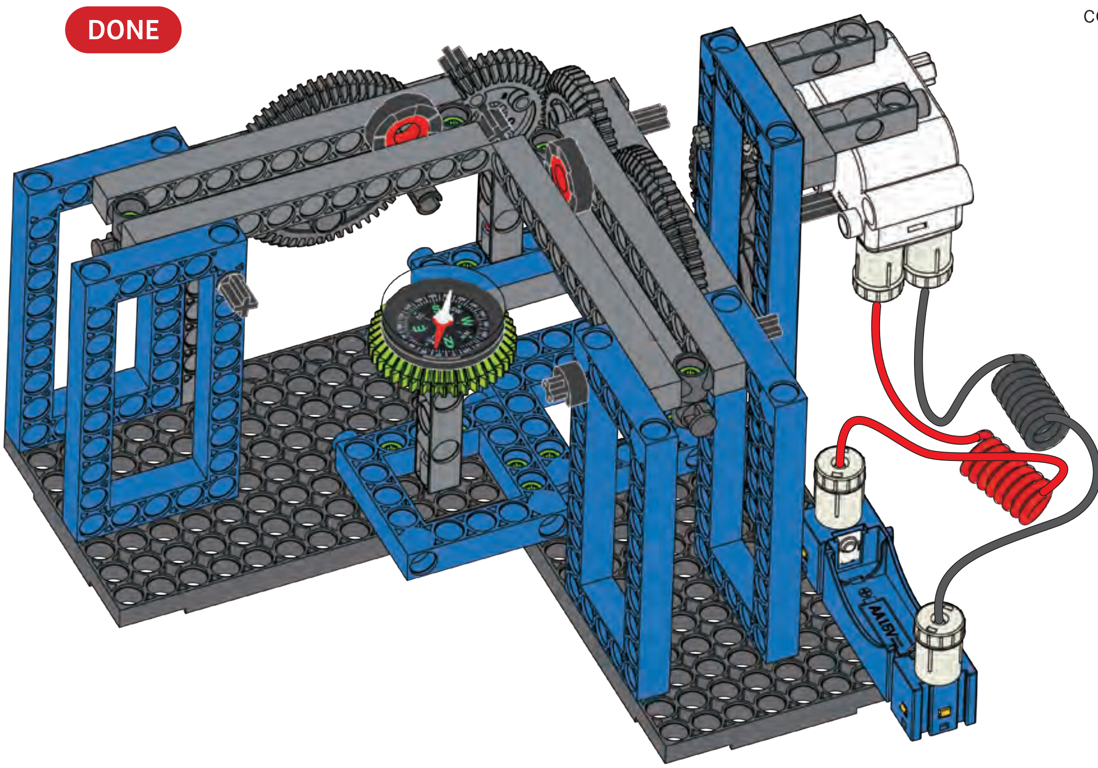


Assembly Steps for Activity 6, Part 2: Automatic Magnetic Field Manipulator Continued

16



DONE



Scan this QR code video:

Activity 7

Electric Fields

Students use the reaction of pith balls to a charged rod as evidence of an electric field.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Observe the effect of non-contact (static) electric forces on pith balls.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-5	MS-PS2-5. Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Planning and Carrying Out Investigations • Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation.	Students use pith balls to investigate electrical fields produced by static.
Disciplinary Core Ideas	PS2.B: Types of Interactions • Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object (a charged object, or a ball, respectively).	Students investigate static electric fields that act at a distance.
Crosscutting Concepts	Cause and Effect • Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students observe cause and effect relationships between objects and the static electrical forces acting upon them.

Materials Needed

- Assembly instructions for the pith balls experiment (located after the instructions for this activity)
- Parts for the models, including pith balls (polystyrene foam balls), rod, thread, and fleece cloth (one set per group)
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks*
- *Pencils*
- *Internet access*
- *Computers or other devices*

Notes for Teachers

Generally, the rod acquires additional electrons when rubbed on the fabric (which easily gives up electrons). The pith balls, which are neutral, should be repelled from the negatively charged rod.

Activity Procedure

1. **Engage:** Ask students how they would know if they were in the presence of an electric field. This may be a difficult question for students. They may discuss electric shocks and possibly hair standing on end, sparks, and other ideas.
2. **Explore:** Tell students that they are going to be building a simple device to detect the presence of an electric field. Divide the class into groups of up to four students each. Distribute the building materials. Allow students time to build the model.
3. Students should now draw a sketch of the initial state of the hanging pith balls for later comparison.
4. Instruct students to hold the rod at one end and rub the length of the rod several times using the fleece cloth. (You need at least 20 rubs to build up enough charge.)
5. Now instruct students to move the rod slowly toward the pith balls and observe what happens. The pith balls should move toward the rod. Instruct students to sketch what they observe in their science notebooks.
6. **Explain:** Discuss with the students. What do they think is happening? Are they observing evidence of a non-contact force? Instructors may choose the depth they wish to go into about the underlying positive and negative charges creating the forces. Good resources to aid in this explanation include:

   a. http://www.bbc.co.uk/schools/gcsebitesize/science/add_gateway_pre_2011/radiation/electrostaticssparksrev2.shtml

   b. https://phet.colorado.edu/en/simulation/balloons
7. **Elaborate:** Continue the explorations with one or both pith balls. What happens when the rod gets too near the pith ball? If it touches it? How do the pith balls interact with each other when

the rod is brought in between them?

8. Another option is to show this video to students: https://www.youtube.com/watch?v=Ngv2OIqFWXU

   Lead a discussion about what students observe. Is there evidence of a non-contact electrical force? How is this similar to what they observed with the pith balls? How is it different?

   When students are finished with the activity, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

9. **Evaluate:** Ask students to draw the following situations in their science notebooks, draw arrows representing the direction of the non-contact forces, and write an explanation about each. Collect the science notebooks and evaluate student understanding.

   For example, students may write that opposite charges attract. The rod exerts a rightward force on the ball and the ball a leftward force on the rod. The ball moves toward the rod since the rod is held stationary.

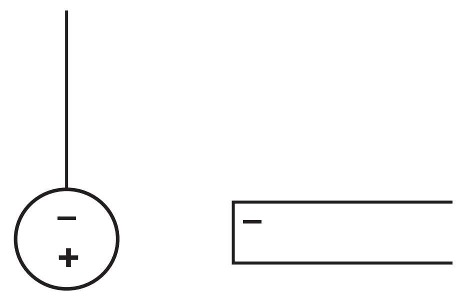


Figure 1

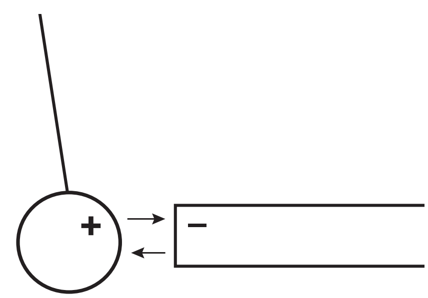
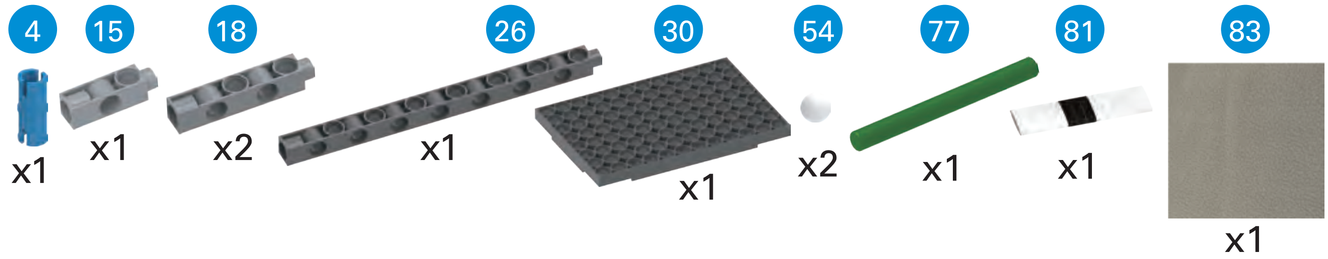
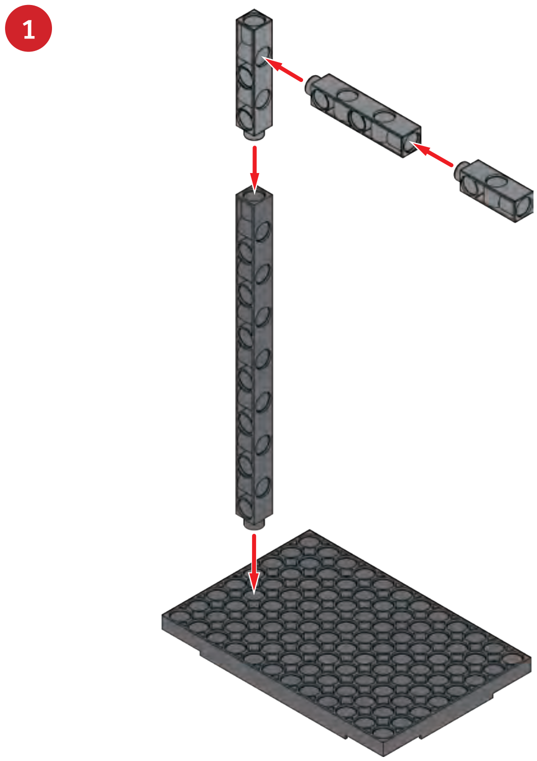


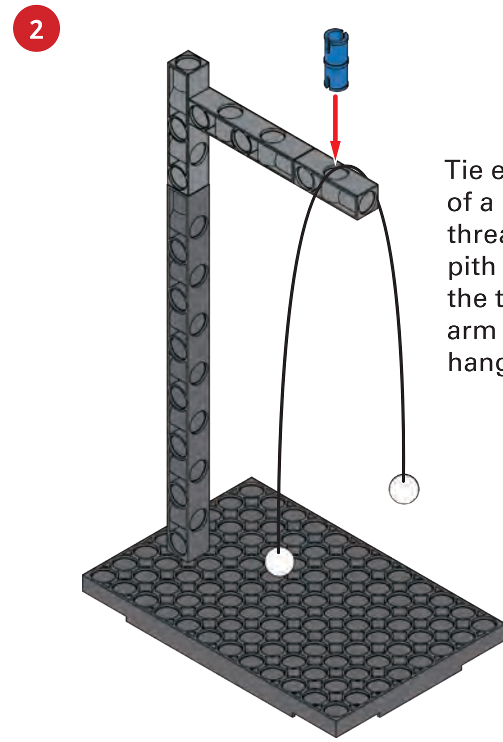
Figure 2

Assembly Steps for Activity 7: Pith Balls Experiment

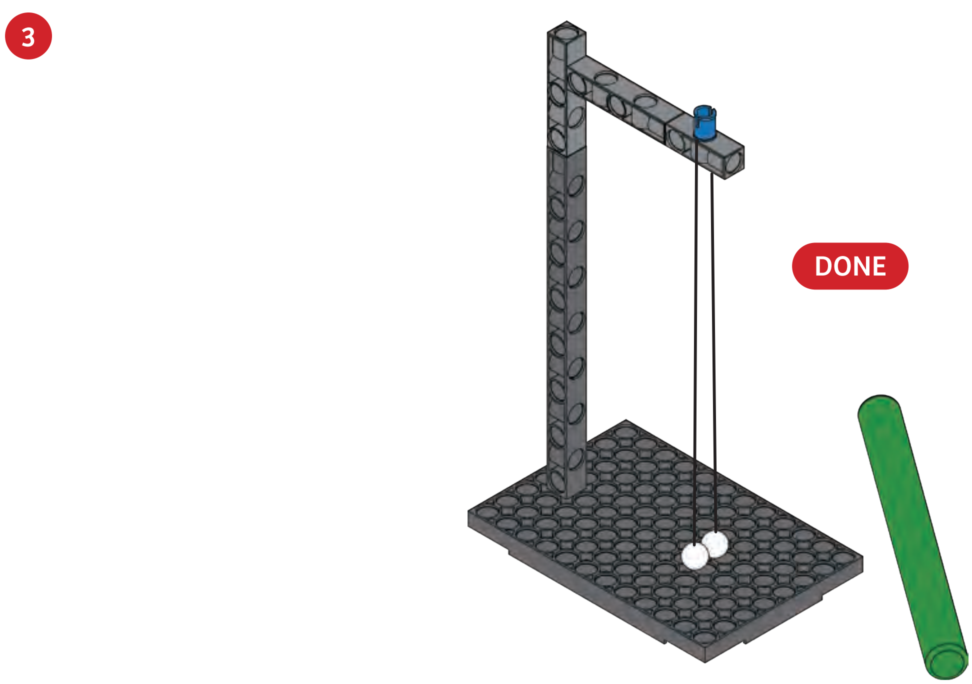
You will need:







Tie each end of a length of thread around a pith ball. Attach the thread to the arm so the balls hang freely.



Scan this QR code video:

Activity 8

Magnetic Forces

In this activity, students test and compare the strengths of different magnets.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Investigate how distance affects magnetic forces.
- Investigate how magnetic strength affects magnetic forces.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-3	MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Asking Questions and Defining Problems • Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.	Students work together as a group (with teacher guidance) to construct meaningful questions inspired by a real world challenge. Students investigate their questions using classroom materials.
Disciplinary Core Ideas	PS2.B: Types of Interactions • Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.	Students investigate magnetic forces (attraction and repulsion) and how magnetic forces depend on magnetic strengths, orientation and distance between interacting objects.
Crosscutting Concepts	Cause and Effect • Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students explore cause and effect relationships between magnets and magnetic objects.

Materials Needed

- Assembly instructions for the magnet car model (located after the instructions for this activity)
- Parts for the model (one set per group)
- Anchor pin levers to separate parts (1 per group)
- *Several different kinds of magnets with different strengths*
  - *o Neodymium magnets (strong)*
  - o Magnets from kit (medium strength)
  - *o Refrigerator magnets (weak)*

Activity Procedure

1. **Engage:** Write the following scenario on the board:

   a. An important key that opens Gina's safe is in the pocket of her jeans. She forgets it is there and it falls into the narrow crack between the wall and the washing machine while she is doing laundry. Because of the way the washing machine is wedged in, it's impossible to reach the key with her hand. How can Gina retrieve the key?

2. Ask students to take a few minutes to write one or more possible solutions to this problem in their science notebooks. Then discuss the class' ideas. Ideally, someone has come up with the idea of using a magnet to pick up the key. Discuss why this solution may or may not work (can you get the magnet close enough to the key? Is the magnet strong enough to hold the key?). You may even decide to set up a similar scenario and let students try to solve it.

3. **Explore:** What questions did the engage portion of this lesson inspire? Gently guide student discussion toward identifying questions about the strength and direction of magnetic force.

   Example questions:

   a. What factors influence the force of a magnetic field on another object? (However the question(s) is worded, it should lead students toward investigation of position of magnet (attraction vs. repulsion), distance between magnet and other object, and strength of magnet(s)).

   b. Can magnetic (non-contact) force cause motion?

c. How close does a magnet have to be to a magnetic object for that object to be attracted to it?

d. How powerful does a magnet need to be to attract/repel a magnetic object?

e. What factors affect the direction of the force between the magnet and the magnetic object?

4. Explain to students that they are going to build a car with a magnet on it and a stick with another magnet on it. It will then be up to them to work together (with teacher guidance) to design investigations that might help answer the questions you came up with as a class. Divide students into pairs or small groups of up to four. Distribute the building materials and instructions, and have the students build the magnet car and magnet stick. Allow students time to explore their questions using the car and stick. Example investigations are described below.

   a. Can magnetic (non-contact) force cause motion? Students move the stick near the magnet on the car and the car moves toward or away from the stick.

   b. What factors affect the direction of the force between magnets and magnetic objects? Students experiment with the direction of the magnet on both the car and the stick to cause the car to move toward and away from the stick.

   c. How close does a magnet have to be to a magnetic object for that object to be attracted to it? Students explore both quantitative and then qualitative answers to this question. First they will notice that the closer they move the stick to the car the stronger the force between them. Gently guide them to making measurements and recording data to provide evidence that magnetic strength increases as distance between the two magnets decreases.

   d. How powerful does a magnet need to be to attract/repel a magnetic object? Students explore increased magnetic strength by increasing the number of magnets on the car, the stick or both, and/or experimenting with different types of magnets. (Save questions related to the strength of magnets for the elaboration portion of the activity.)

5. **Explain:** After the students have had time to investigate, gather them to discuss what was observed. Work together to draw force diagrams related to each question.

   a. Students will have observed that the magnetic force caused the car to move.

   b. The closer the stick is moved to the car, the stronger the force (figure 1).

   c. When the magnets were oriented one direction, the attractive magnetic force caused the car to move toward the stick (figure 2).

   d. When one magnet was reversed, the repulsive magnetic force caused the car to be pushed away from the stick (figure 3).

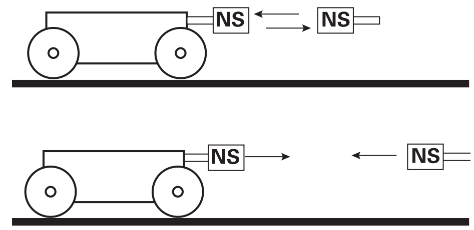


Figure 1

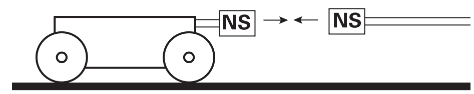


Figure 2

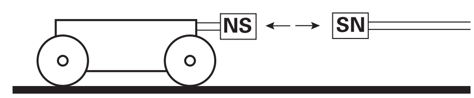


Figure 3

6. **Elaborate:** Through exploration and explanation, students should have a general understanding that non-contact magnetic forces can cause motion; they can be attractive or repulsive based on the orientation of the magnet; and that the strength of magnetic fields is influenced by distance. Now provide students with more of the same magnets and/or different strengths of magnets. Give them time to explore questions that arose initially related to magnetic strength. (e.g., How powerful does a magnet need to be to attract/repel a magnetic object?)

7. When students have had ample time to explore, regroup, and discuss magnetic strength (two magnets produce a stronger magnetic field than one magnet, different magnets have different strengths). Add force diagrams to the notebooks.

   When students are finished with the activity, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

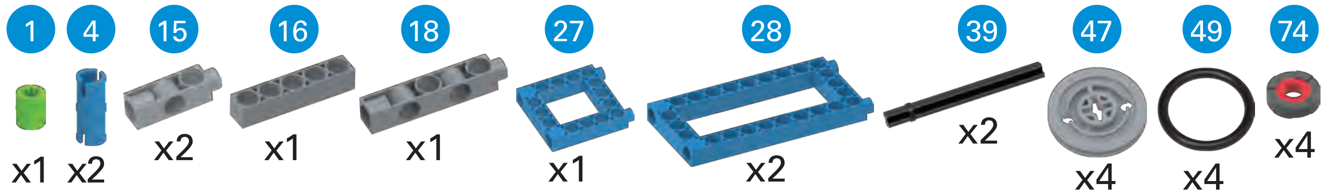
8. **Evaluate:** Return to the scenario from the beginning of the lesson. Ask students what Gina could have done if she was unable to retrieve her key with the first magnet she tried. (She could have moved the magnet closer to the key or used more than one or a stronger magnet — since the key is metal and not another magnet, orientation does not matter.)

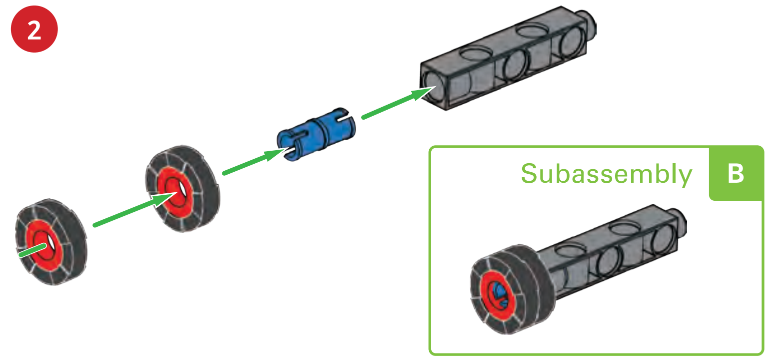
Extensions

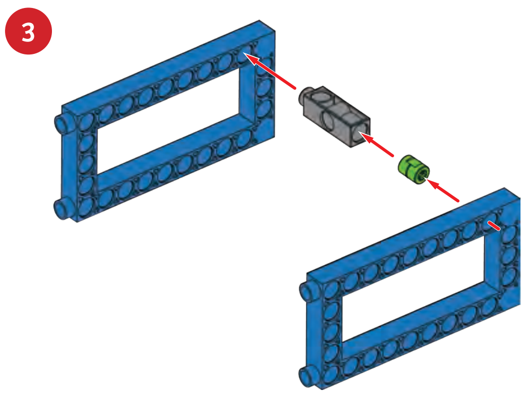
- Have students build the magnet maze model and use non-contact magnetic force to move a magnet through the maze.

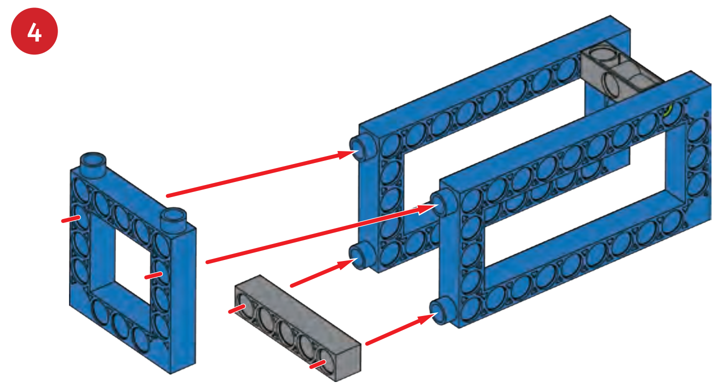
Assembly Steps for Activity 8, Part 1: Magnet Car

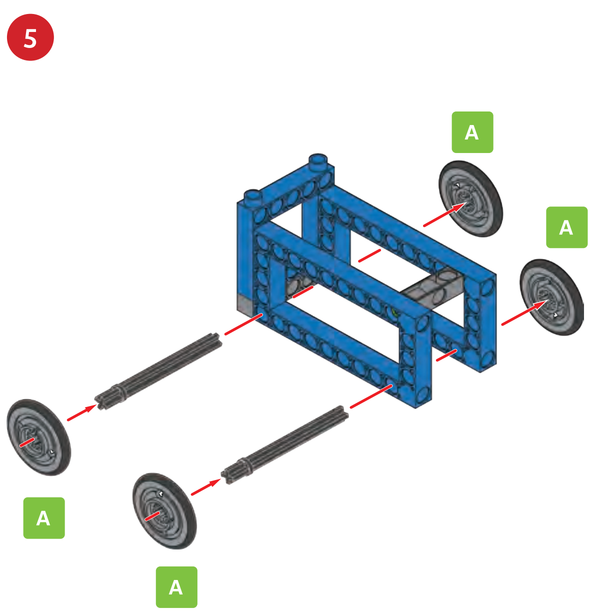
You will need:

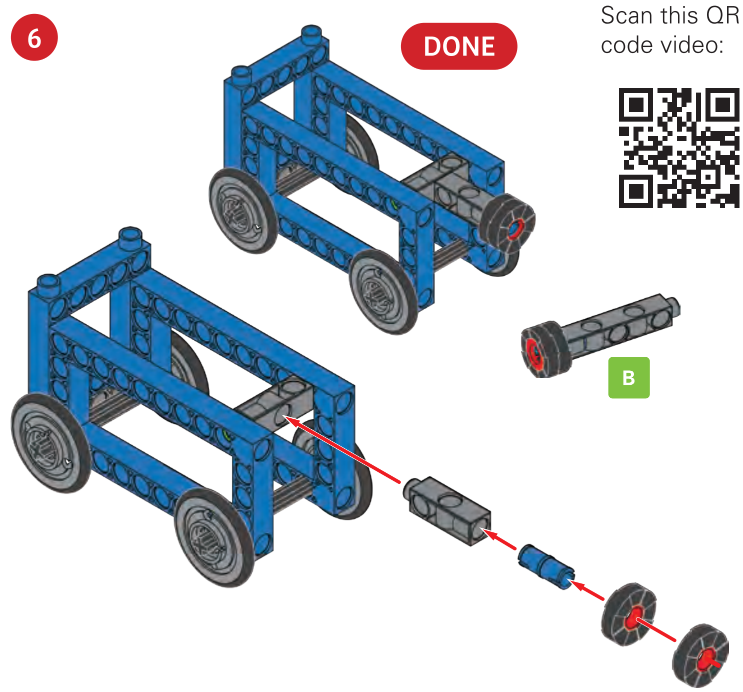








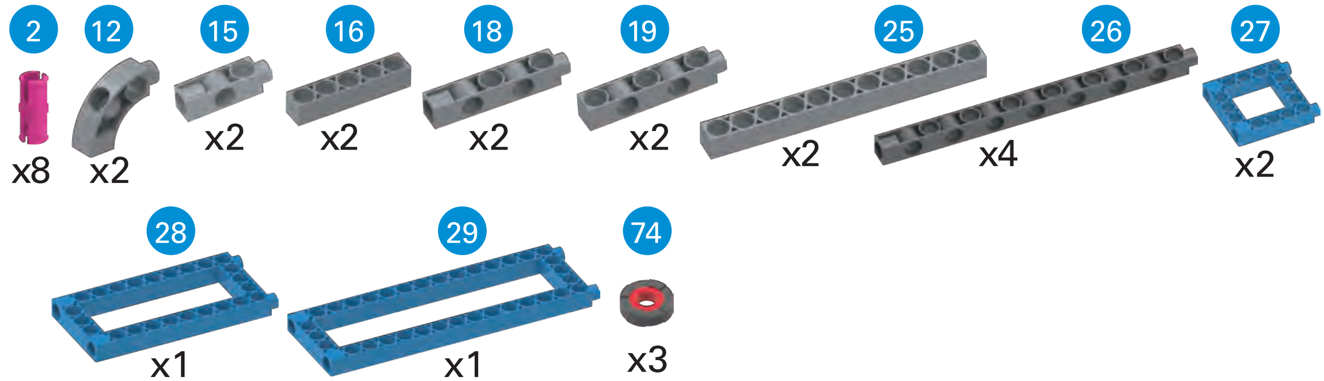




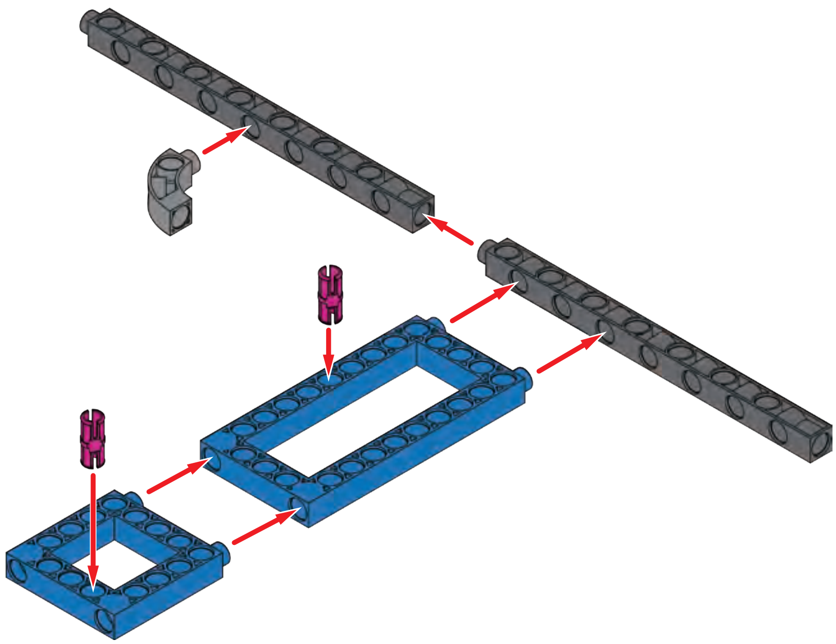
Scan this QR code video:

Assembly Steps for Activity 8, Part 2: Magnet Maze

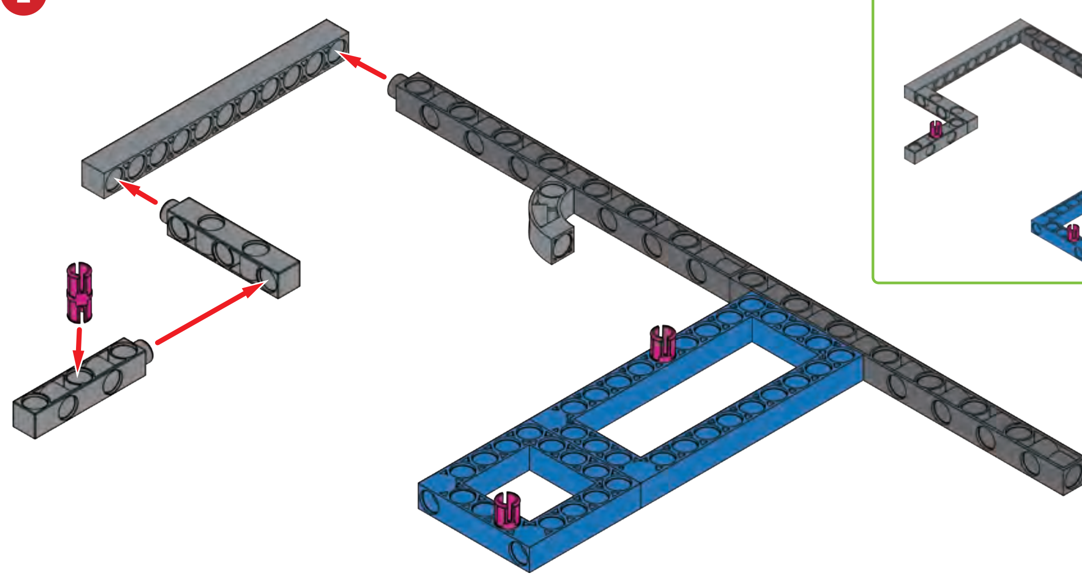
You will need:



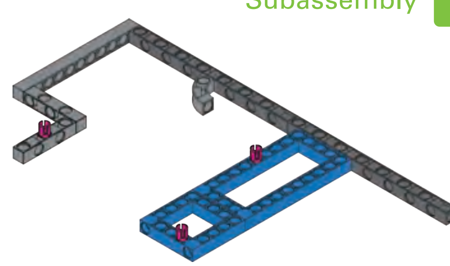
1



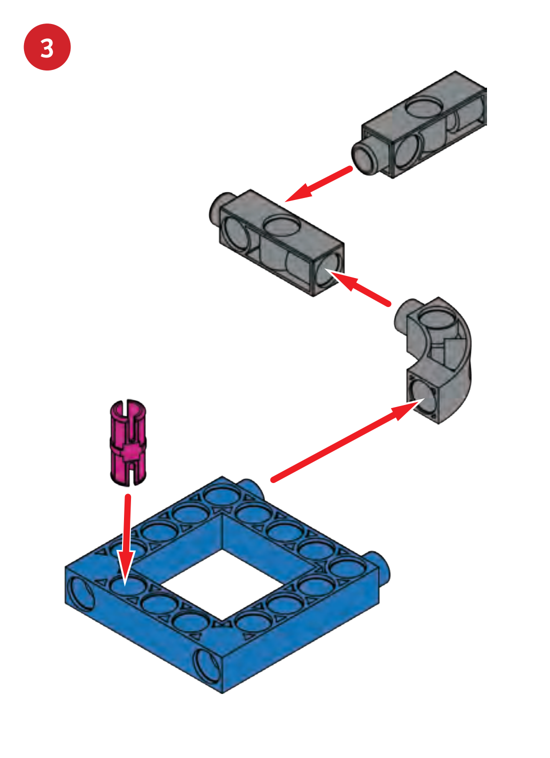
2

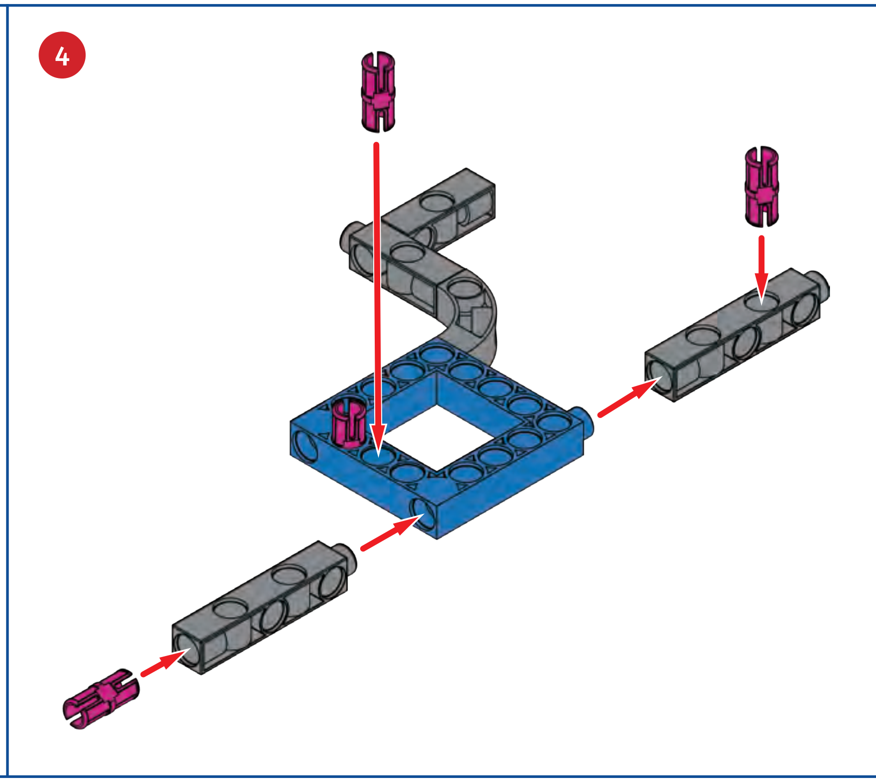


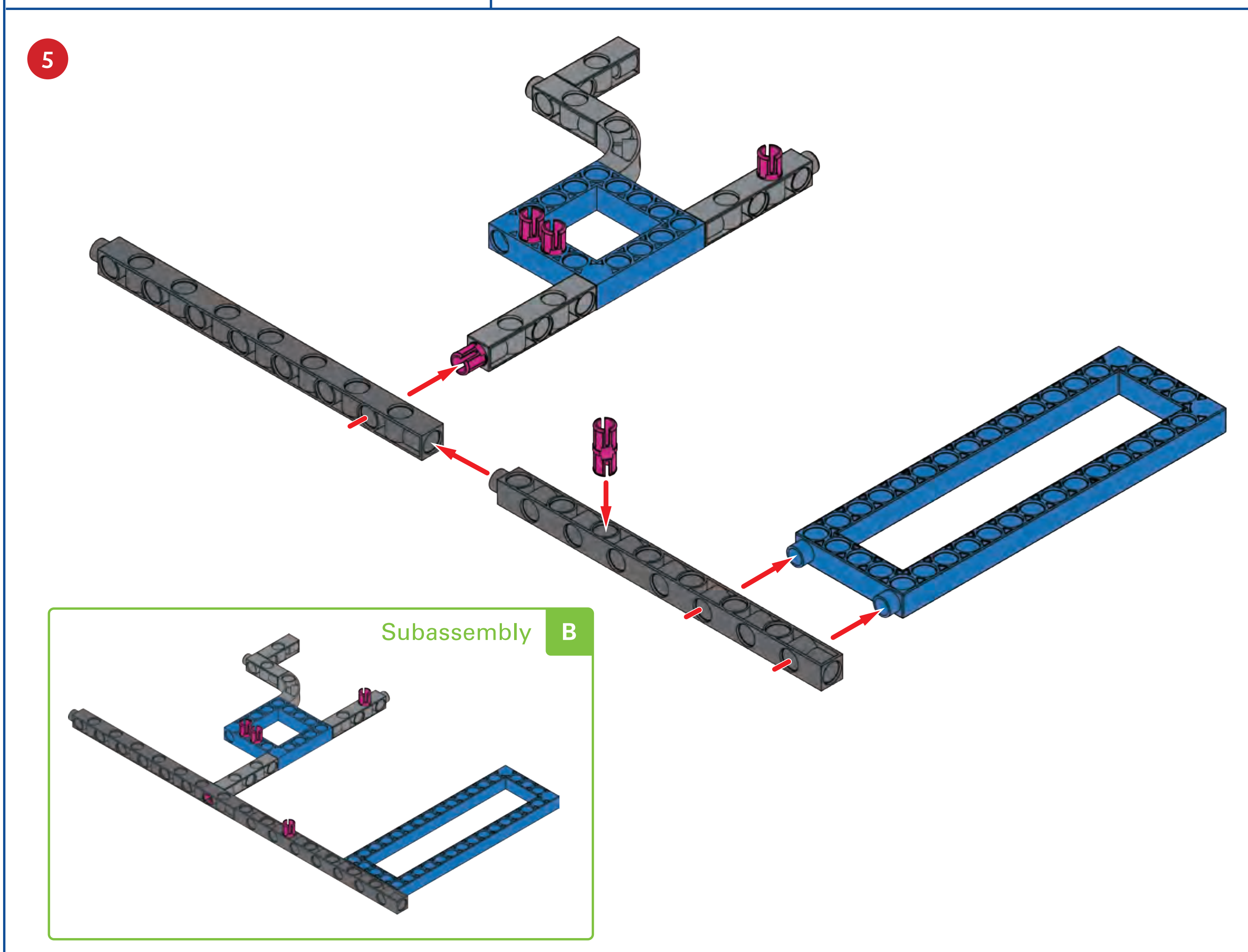
Subassembly **A**



Assembly Steps for Activity 8, Part 2: Magnet Maze Continued

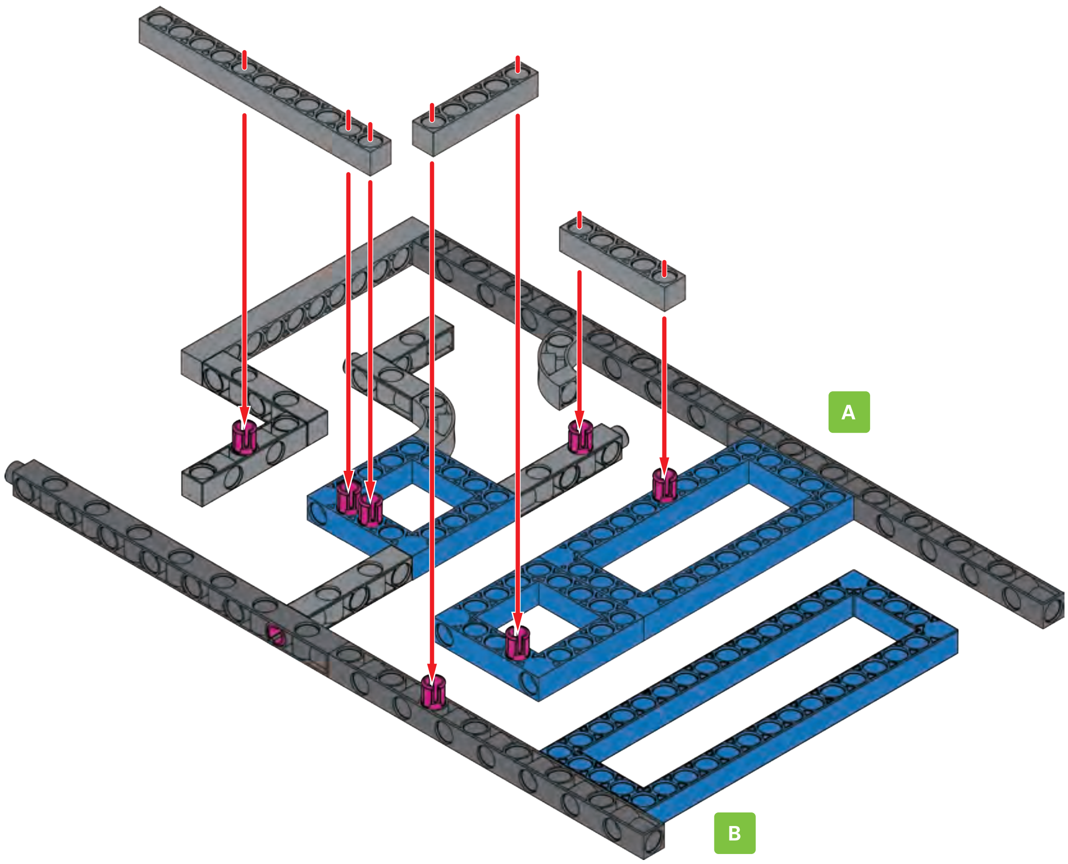


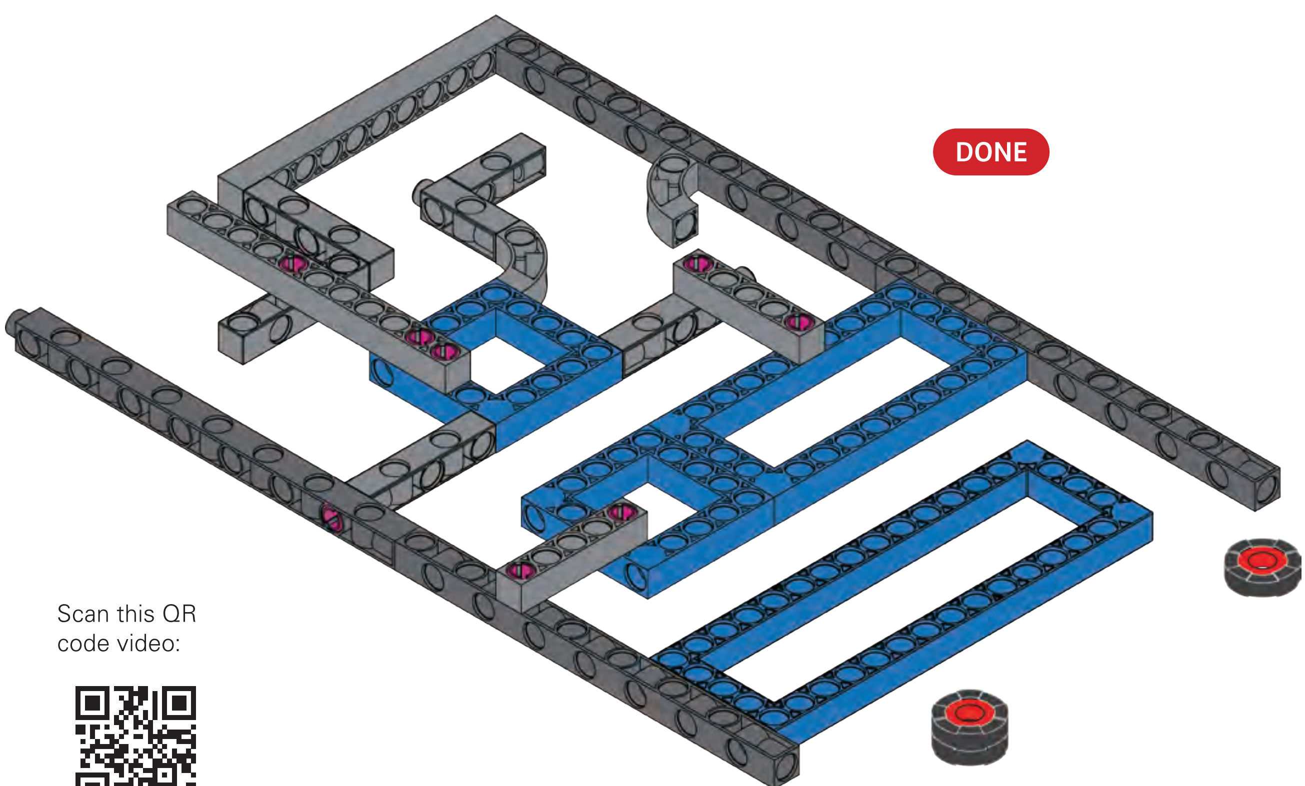




Assembly Steps for Activity 8, Part 2: Magnet Maze Continued

6





Scan this QR code video:

Activity 9

Electromagnetic Forces

With prior knowledge about magnetic and electric non-contact forces, students are introduced to the concept of electromagnetic non-contact forces.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Observe the magnetic properties of a spool of copper wire before and after current is flowing through it.
- Experiment with the direction of electric current and electromagnetic fields.
- Experiment with electromagnetic strength and magnetizing a nail.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-3	MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Asking Questions and Defining Problems • Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.	Students perform a classroom investigation related to electromagnets.
Disciplinary Core Ideas	PS2.B: Types of Interactions • Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.	Students experiment with how electromagnets are made and how they react when current is reversed.
Crosscutting Concepts	Cause and Effect • Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students observe cause and effect related to flow of current through a spool of wire and magnetic properties.

Materials Needed

- Assembly instructions for the electromagnetic force apparatus (located after the instructions for this activity)
- Parts for the model (one set per group)
- Anchor pin levers to separate parts (1 per group)
- Paper clips
- Metal rod
- *AA batteries (2 per group)*
- *Iron nail and other metal objects*
- *Science notebooks*
- *Pencils*

Activity Procedure

1. **Engage:** Show students the compass. Ask students if they know what a compass is. (Students will have used a compass in Activity 6, if completed). Students likely have some idea that a compass points north. They may or may not understand that the compass needle is a tiny suspended magnet that aligns with Earth's magnetic field (this simulation provides a great resource for visualizing magnetic fields: https://phet.colorado.edu/en/simulation/legacy/magnet-and-compass. Hold a magnet near the compass so the students can see how the needle moves as it is attracted and repelled from the magnet at different orientations. Then demonstrate for the class that if you hold a spool of wire up to compass there is no change, indicating no magnetic field. Pass these objects around so the students have a chance to try and observe for themselves.

2. **Explore:** Explain to students that there is a way to create a magnetic field around the coil of wire. Ask them if they have any ideas about how this might be done. They might think about wrapping the wire around a magnet, or similar. Divide students into pairs or small groups of up to four students. Provide the materials for them to build the electromagnetic force apparatus. Do not give them the batteries yet. Is the coil of wire magnetic yet? Students can test this using the compass. Some students may start to understand how the

spool of wire will be magnetized. Ask students (all, or those who have ideas) to individually explain their ideas in their science notebooks.

3. When all students have the apparatus built and have tested the spool with the compass, hand out the batteries to each group. Allow students to experiment with turning the current on and off and observing what happens to the compass. Does the wire have a magnetic field now? Encourage students to switch current direction and observe how the compass changes.

4. **Explain:** Students will likely be excited about what they have observed. Gather students and discuss what happened. Why does the spool have a magnetic field when electric current flows through it? Discuss electromagnets. A few great resources to help students understand electromagnets can be found below:

How does an electromagnet work?	https://www.youtube.com/watch?v=cxELqN7wjS0	Short video that does a good job explaining electromagnets
Magnets and electromagnets computer simulation	https://phet.colorado.edu/en/simulation/legacy/magnets-and-electromagnets	

5. **Elaborate:** Pass out the paper clips to the groups. Is the magnetic field around the coil strong enough to attract a paper clip? (No). Pass out the metal rods (or iron nails) to the groups. Instruct the students to insert the rod or nail into center of spool (or let them figure that out on their own). Let students explore:

   Is the nail magnetic on its own? (No.)

   Is it magnetic inside the spool with no electricity? (No.)

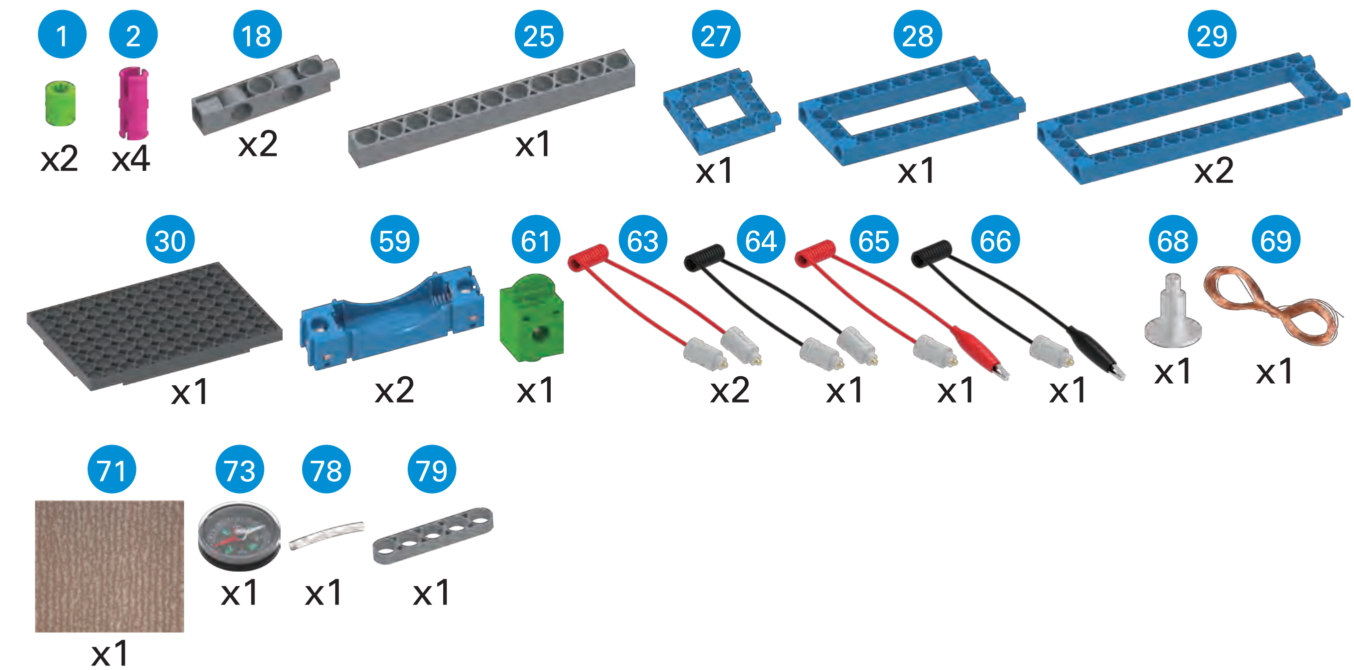
   Is it magnetic when the electricity is turned on? (Yes.)

   When students are finished with the activity, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

6. **Evaluate:** Have students individually sketch an electromagnet and explain how it works in their science notebooks. Collect and assess understanding.

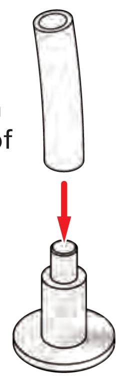
Assembly Steps for Activity 9: Electromagnetic Force Apparatus

You will need:

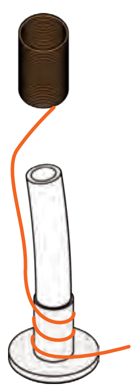


1

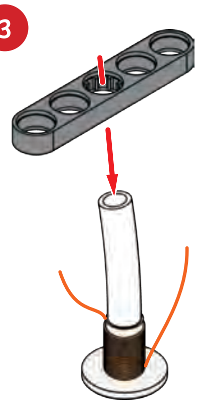
Cut a 30-mm piece of tube.



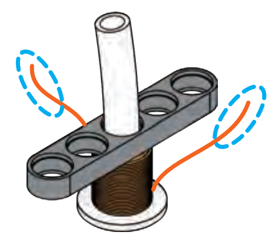
2



3

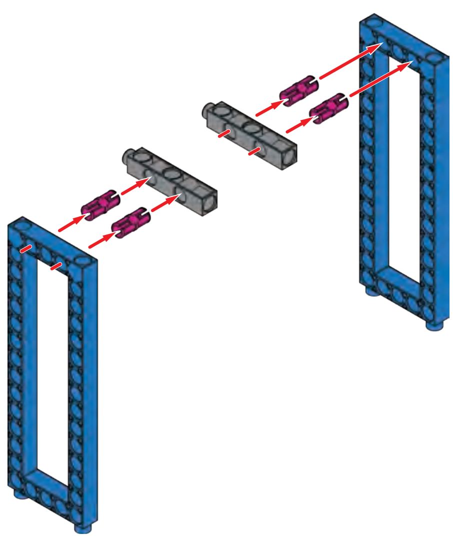


Subassembly A

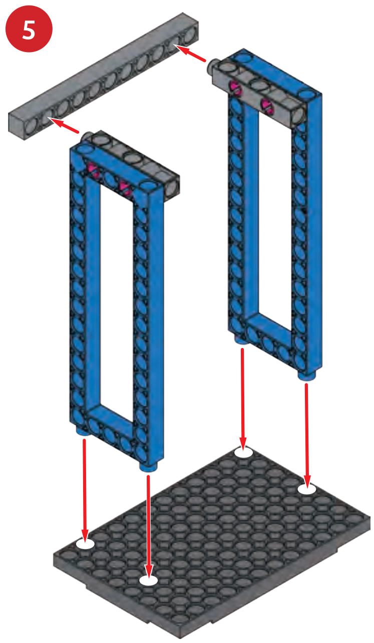


Use the sandpaper to rub the coating off the two ends of the wire.

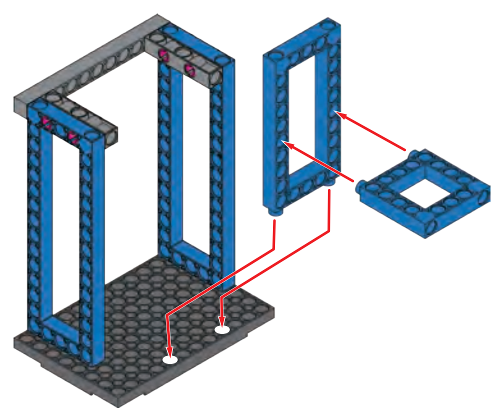
4



5

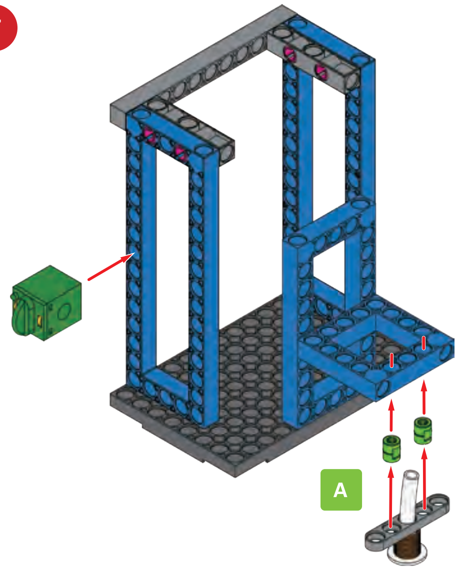


6

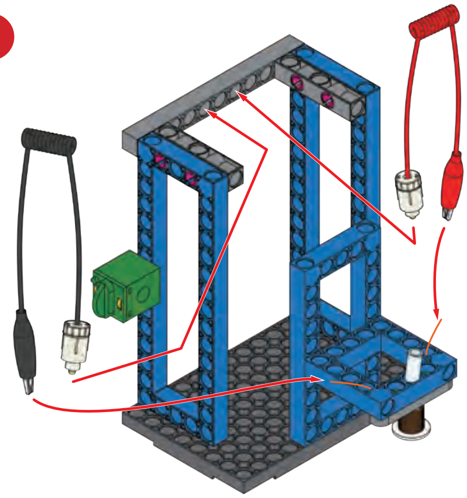


Assembly Steps for Activity 9: Electromagnetic Force Apparatus Continued

7

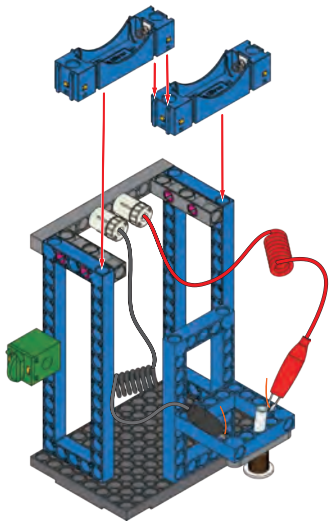


8

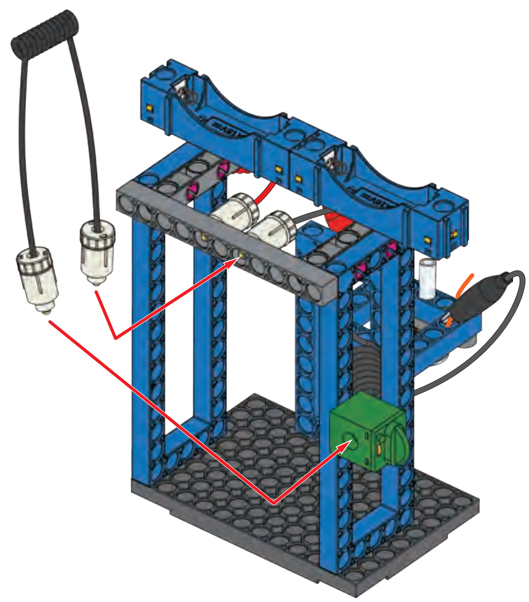


Make sure you have used the sandpaper to remove the coating from the two ends of the wire, so an electrical connection can be made.

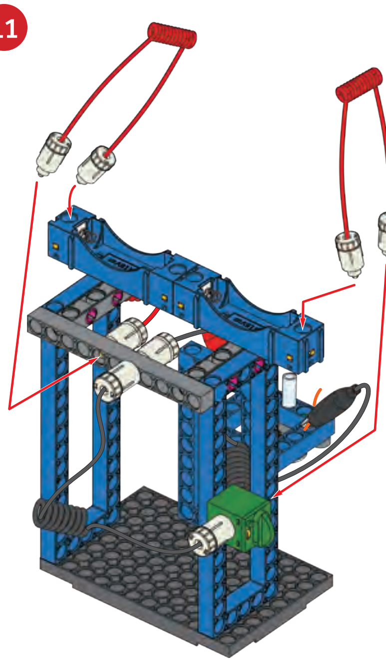
9



10

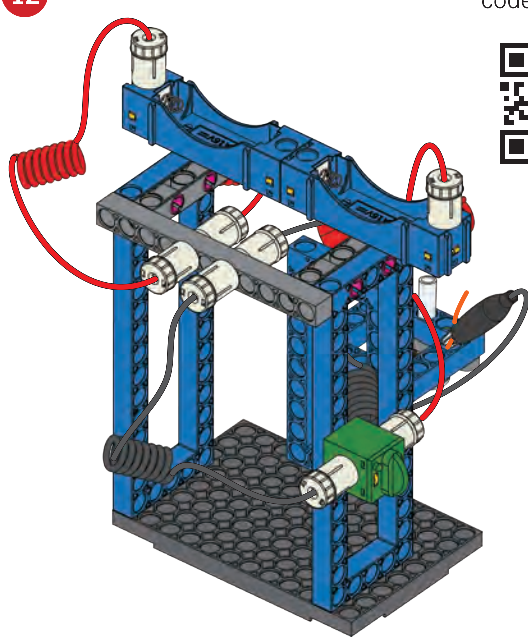


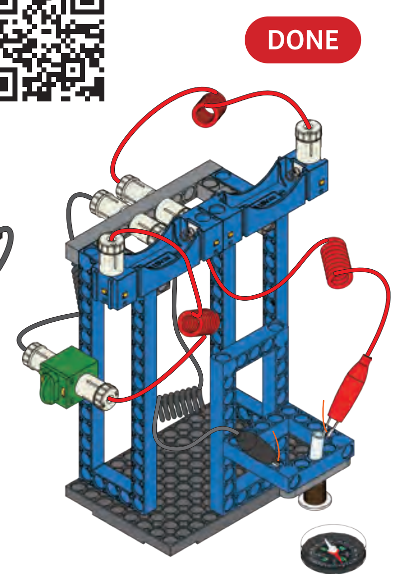
11



12

Scan this QR code video:





Activity 10

Engineering Challenge: Electromagnet Applications

Students use their knowledge of electromagnets to engineer solutions to problems.

Duration: One 45-50 minute classroom period

Age Group: Middle school

Objectives:

Students will:

- Observe practical uses for electromagnets in society.
- Build a model using an application of electromagnets.
- Describe how their model of an application of an electromagnet operates.
- Follow steps of the engineering design process to create their own practical application for electromagnets in society.

NGSS Addressed

Standards	Performance Expectations
MS-PS2-3 MS-ETS1-1 MS-ETS1-2 MS-ETS1-4	MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices	Asking Questions and Defining Problems • Ask questions that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when appropriate, frame a hypothesis based on observations and scientific principles.	

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Science and Engineering Practices Continued	• Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.	Students work to define a problem that can be solved through the development of a tool based on defined constraints.
	Engaging in Argument from Evidence • Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	Students propose and evaluate design solution and choose one to pursue.
	Developing and Using Models • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.	Students create a model to test their ideas for a solution to a problem.
Disciplinary Core Ideas	PS2.B: Types of Interactions • Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.	Students use their knowledge of electromagnetic forces to solve a problem.
	ETS1.A: Defining and Delimiting Engineering Problems • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.	Students work within specified criteria when solving a problem. Their solution must involve electromagnets which limits potential solutions.
	ETS1.B: Developing Possible Solutions • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.	Students follow a step by step process to design a solution to an engineering problem involving electromagnets.
	ETS1.B: Developing Possible Solutions • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.	Students develop a solution and then test it, improving it based upon their observations.
	• Models of all kinds are important for testing solutions.	Students build a model to use for testing their solution.
	ETS1.C: Optimizing the Design Solution • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution	Students test, modify and test again through an iterative process. They keep track of changes made through this process.

Dimensions	Name and NGSS Code/Citation	Specific Connections to Activity
Crosscutting Concepts	Cause and Effect • Cause and effect relationships may be used to predict phenomena in natural or designed systems.	Students understand how cause and effect using electromagnets can be used to solve problems in society.
	Influence of Science, Engineering, and Technology on Society and the Natural World • All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment.	
	• The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.	Students observe use of electromagnets to solve societal problems. Students define a problem in society that could be solved by using electromagnets.

Materials Needed

- Assembly instructions for the electromagnetic crane and the electromagnetic switch models (located after the instructions for this activity)
- Parts for the models (one set per group; each group will be building one of the two models)
- Anchor pin levers to separate parts (1 per group)
- *Science notebooks*
- *Pencils*
- *2 AA batteries (2 per group)*

Notes for Teachers

Now that students understand how an electromagnet works, challenge students to think about how an electromagnet could be used to benefit society (e.g., magnetic crane in a junkyard, automatic door).

Prior to the Activity

Assign one or more students who finish an assignment early on a day prior to this activity to build the two demo models following the assembly instructions located after the instructions for this activity.

Activity Procedure

1. **Engage:** Show students videos of electromagnet applications. For example, electromagnetic crane picking up scrap metal video: https://www.youtube.com/watch?v=XBWy9gzGGd4

2. **Explore:** Explain that students are going to create some examples of useful products that incorporate electromagnets. Divide the students into pairs or groups of up to four. Pass out the instructions and building materials for the electromagnetic crane (easier) and the electromagnetic switch (more difficult). Instructors may want to choose which build the group gets based on their ability to stay focused and follow directions. Allow students ample time to build their models.

3. **Explain:** Once students have had ample time to complete and test out their models, explain that they will now share that model with the group. You may want to combine groups with the same model and allow them time to work together. The goal is for the group to explain how their model works and what it is used for.

   When students are finished with the activity, they should completely dismantle their models (including removing all connectors) and return all of the components to the bins.

4. **Elaborate:** Now that students have an idea about some of the things electromagnets can be used for, it is their turn to design their own product. Students should work in groups and work through the steps of the engineering design process to complete this challenge (see next page).

5. **Evaluate:** Assign students to individually draw what was happening inside the crane in the video from the Engage portion of the lesson in their science notebooks. Collect their notebooks to assess.

Electromagnet Engineering Design Challenge

Identify the Need and Constraints

The Problem: Design a device that incorporates an electromagnet to complete a task or solve a problem.

The Constraints:

- The majority of your device should be built using the building materials from this kit. Other materials need to be approved by the teacher.
- Your device must incorporate the properties of an electromagnet.
- You must provide a diagram showing how your solution works.
- You must be able to explain — using your knowledge of electromagnets — how your device works to complete a task or solve a problem.

Develop Possible Solutions

Step 1: Group members work together to come up with a problem that needs to be solved in society that the properties of an electromagnet could be used to solve. Students should have their problem idea approved by the teacher prior to continuing. (~15-20 minutes) Note: the teacher could also come up with the problems and give them to the students.

Step 2: Each group member thinks of ideas to solve the problem and writes these ideas down and sketches them in their science notebook. (~10 minutes)

Step 3: All ideas are then shared and discussed with the group. Group members practice courtesy by taking each idea under serious consideration, even if it clearly won't work. Discussion should be about the physics behind why an idea won't work, not about the merits of the idea or the person who came up with it. (~15 minutes)

Select a Promising Solution

Step 4: Collectively, the group should decide upon one idea to test.

Build, Test, and Evaluate a Prototype

Step 5: Build and test the prototype. You may make changes to improve upon your design during this phase of the project. (You may test your design more than once if the problem is not solved within the given restraints on the first try, but each time you make changes they should be recorded. All of these changes should eventually lead to a solution meeting all constraints and solving the problem.)

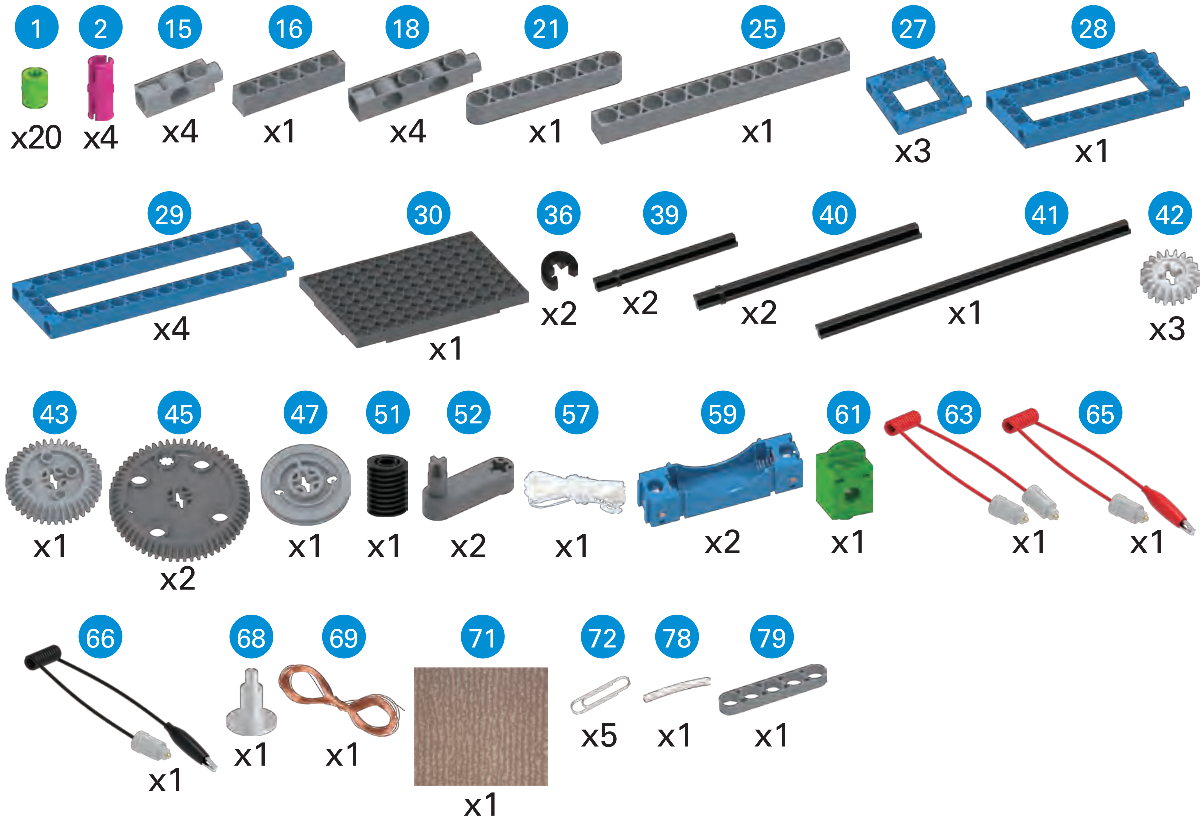
Step 6: Share your prototype with the class. As a class, discuss the positive and negative aspects of each group's design.

Redesign as Needed

Step 7: Discuss where problem solving should go from here. Do you have ideas for improvement?

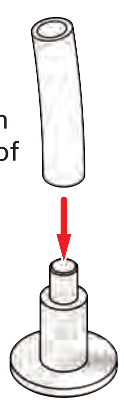
Assembly Steps for Activity 10, Part 1: Electromagnetic Crane

You will need:

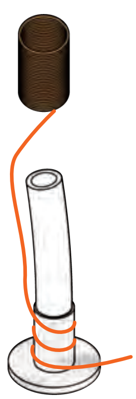


1

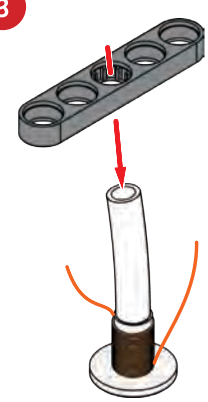
Cut a 30-mm piece of tube.



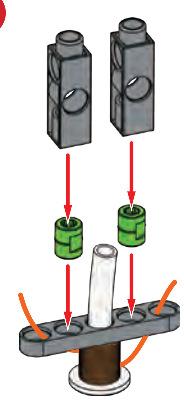
2



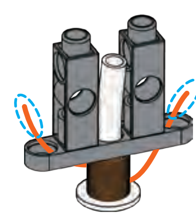
3



4

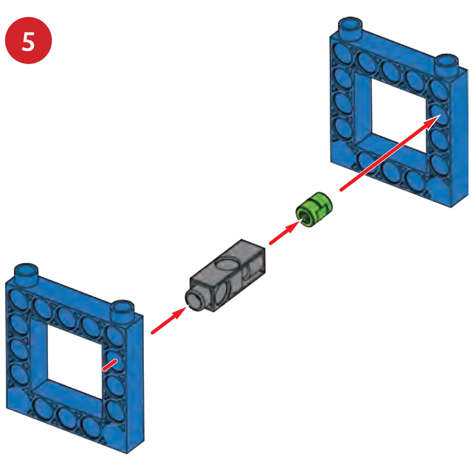


Subassembly **A**

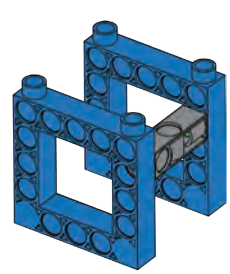


Use the sandpaper to rub the coating off the two ends of the wire.

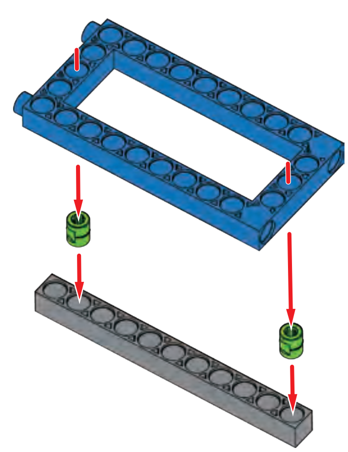
5



Subassembly **B**

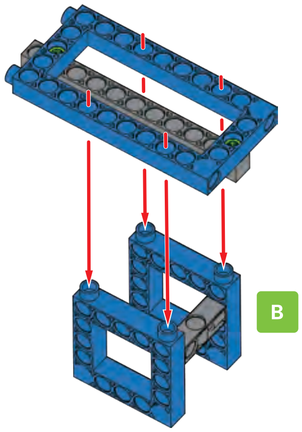


6

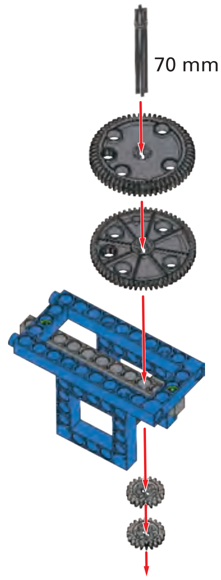


Assembly Steps for Activity 10, Part 1: Electromagnetic Crane Continued

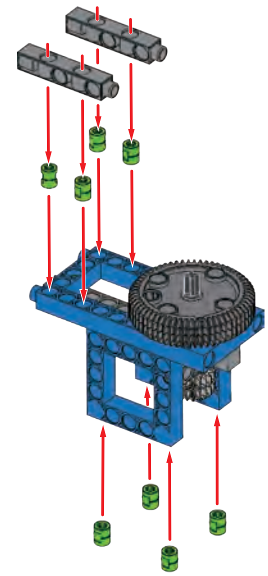
7



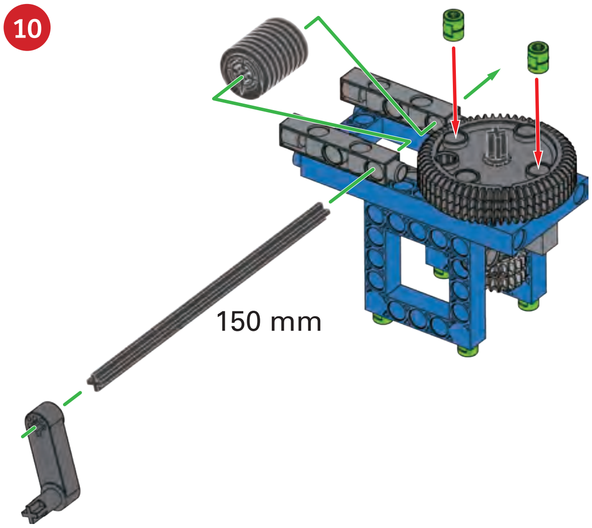
8



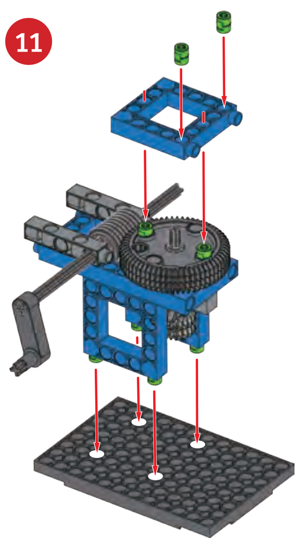
9

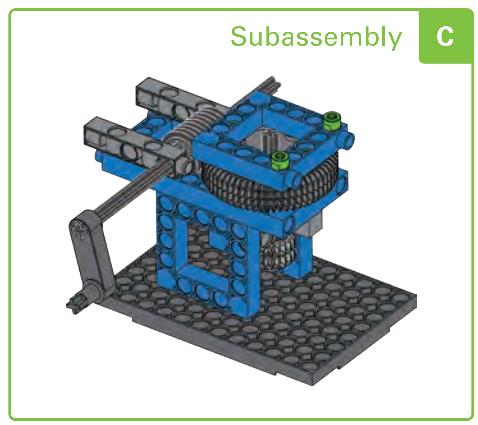


10

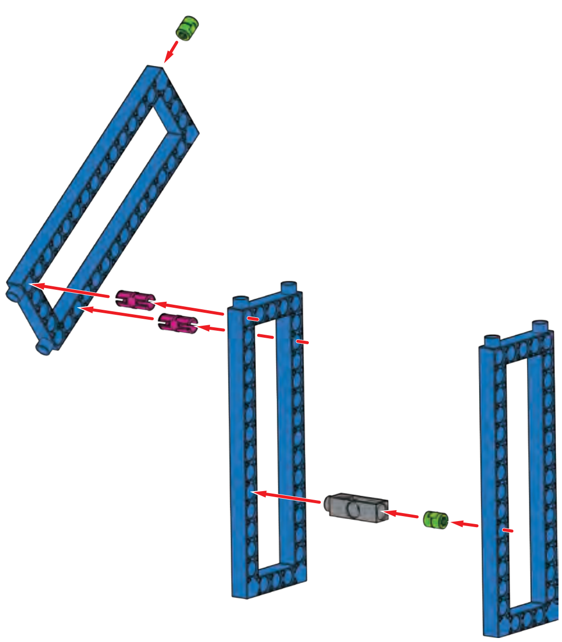


11

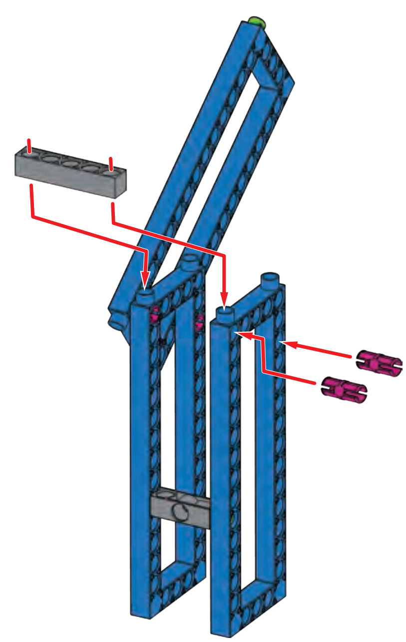




12

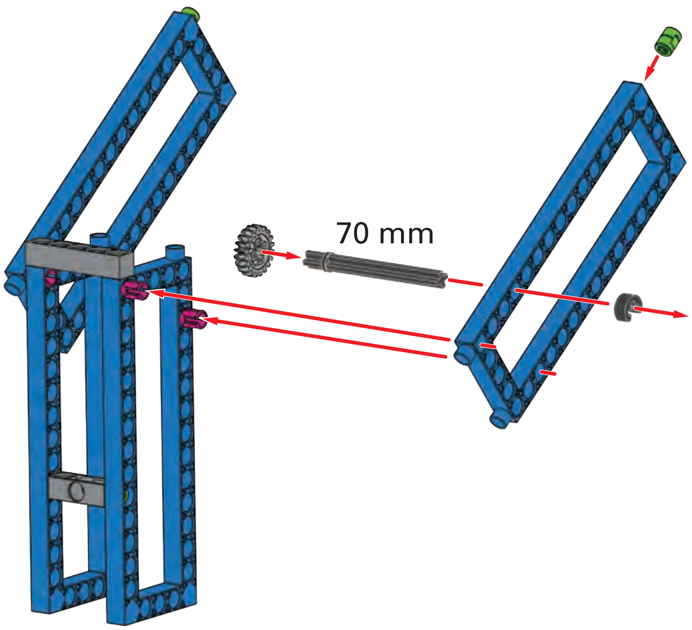


13

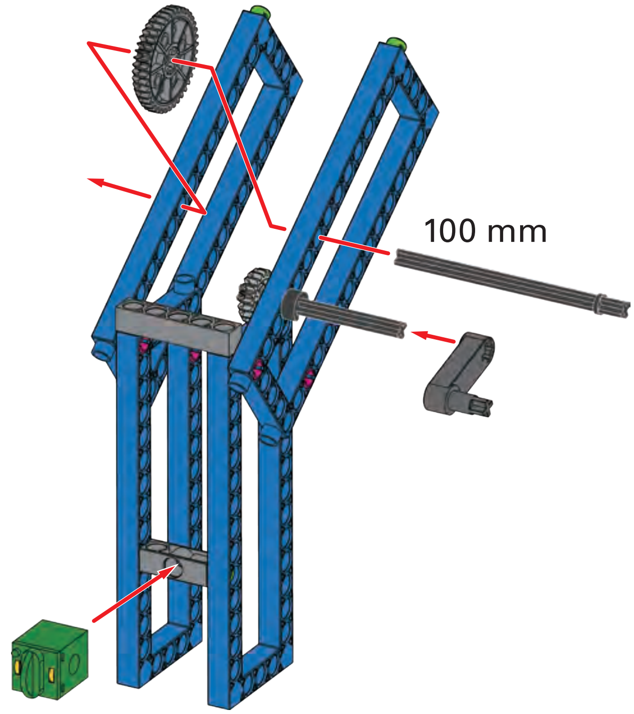


Assembly Steps for Activity 10, Part 1: Electromagnetic Crane Continued

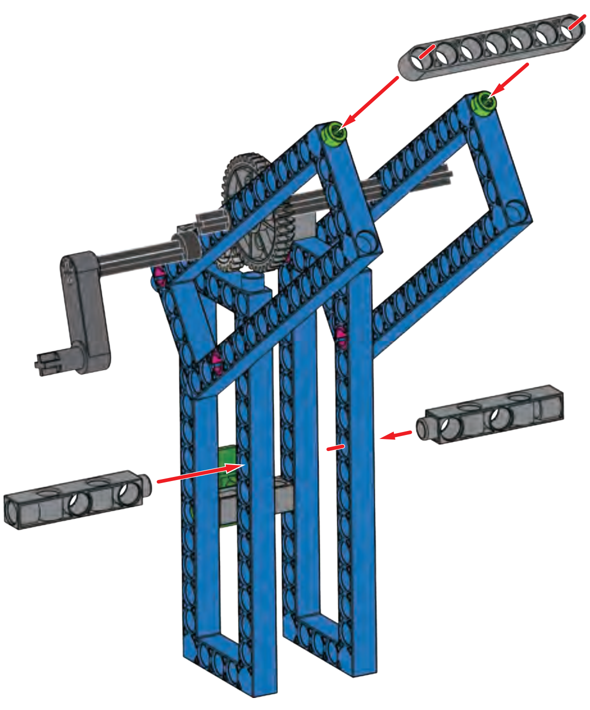
14



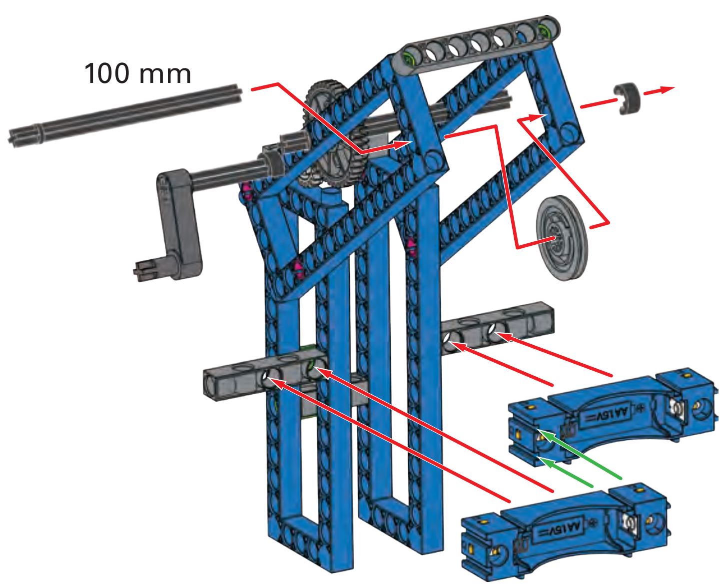
15



16

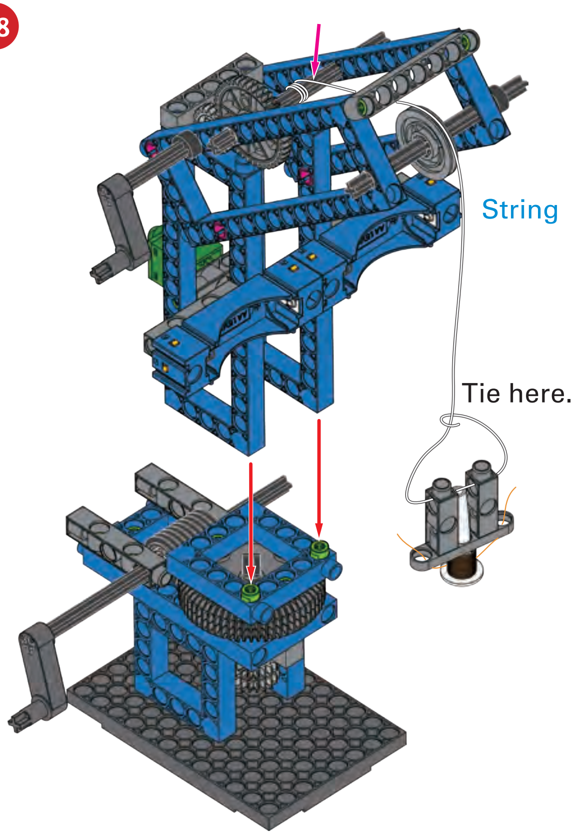


17

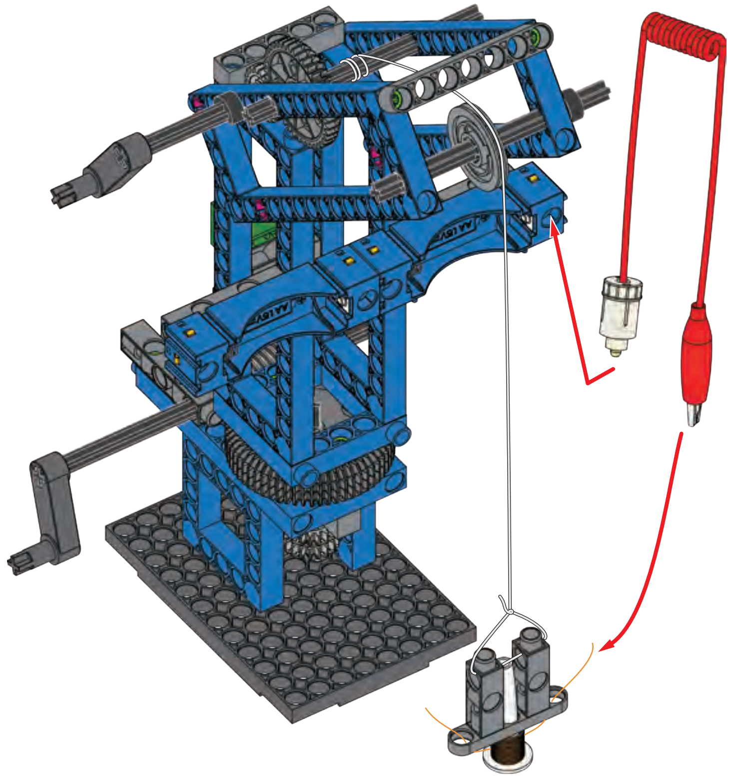


Assembly Steps for Activity 10, Part 1: Electromagnetic Crane Continued

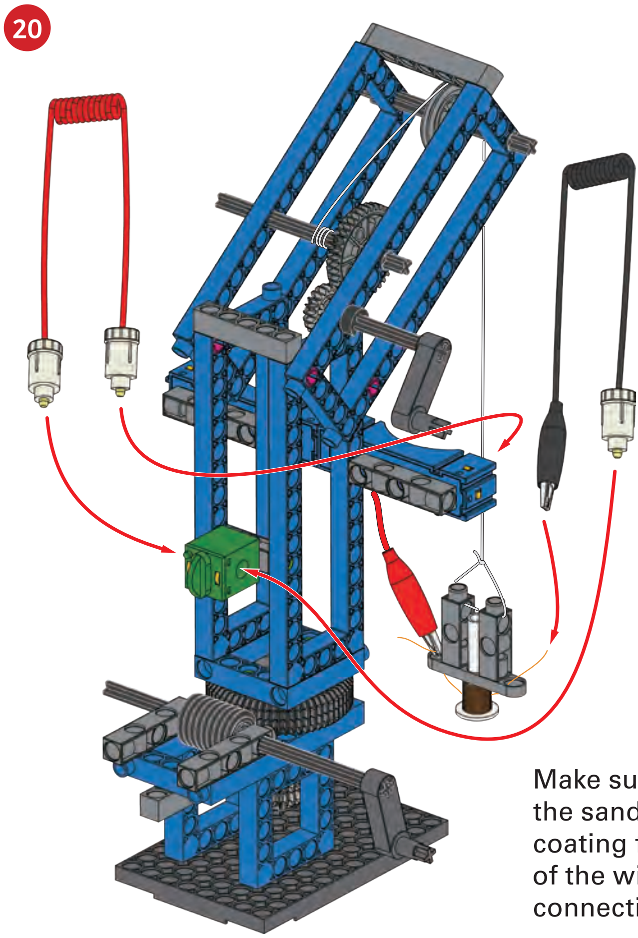
18



19

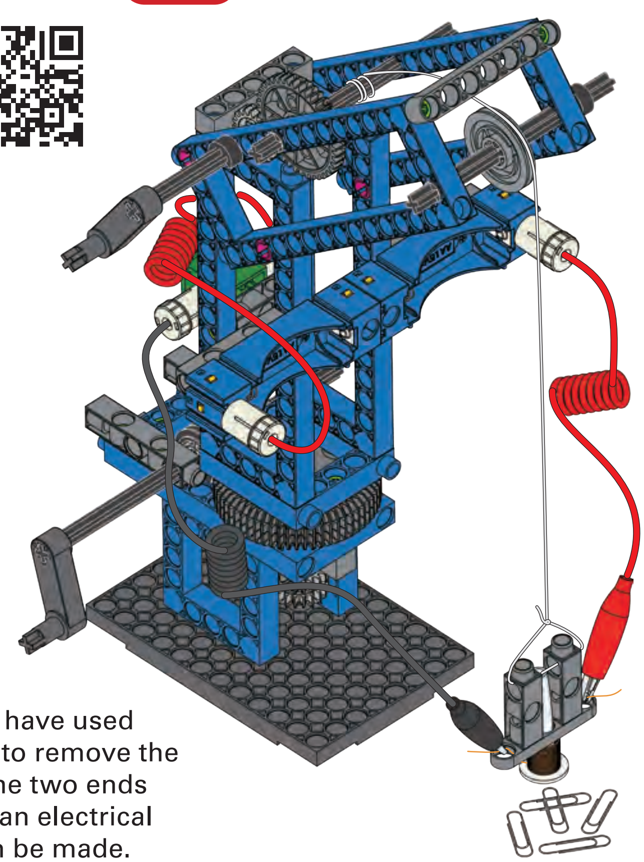


20



Scan this QR code video:

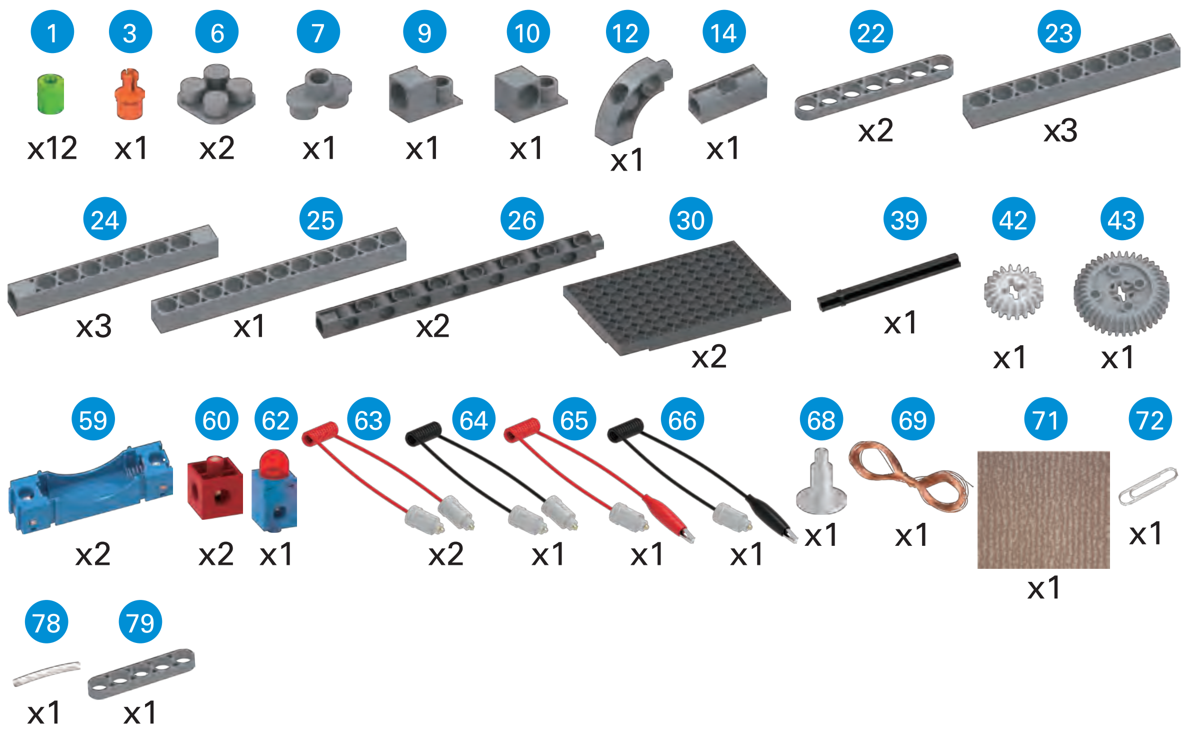
DONE



Make sure you have used the sandpaper to remove the coating from the two ends of the wire, so an electrical connection can be made.

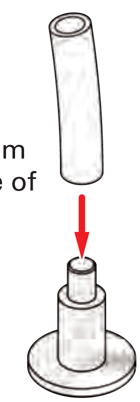
Assembly Steps for Activity 10, Part 2: Electromagnetic Switch

You will need:

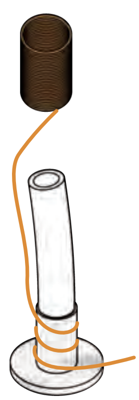


1

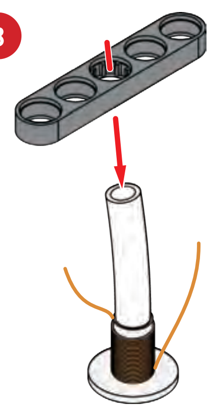
Cut a 30-mm piece of tube.



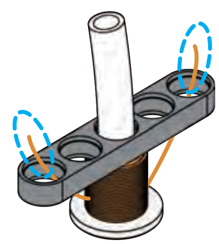
2



3

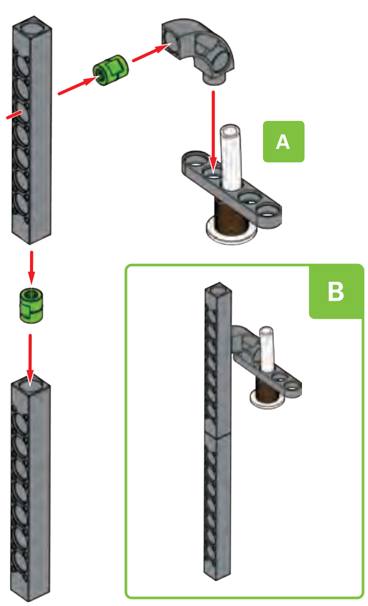


Subassembly A

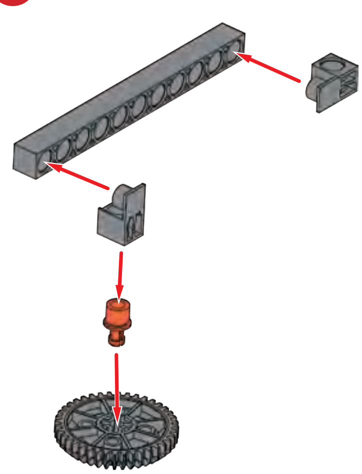


Use the sandpaper to rub the coating off the two ends of the wire.

4

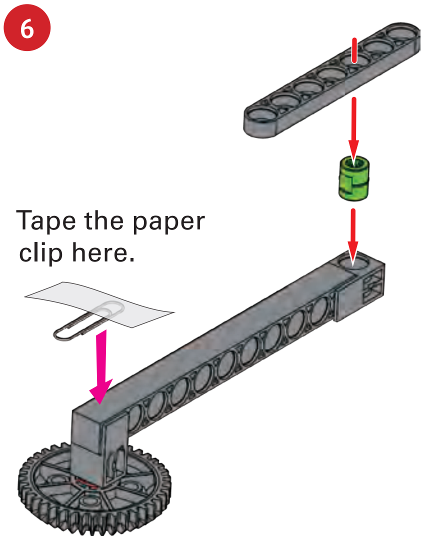


5



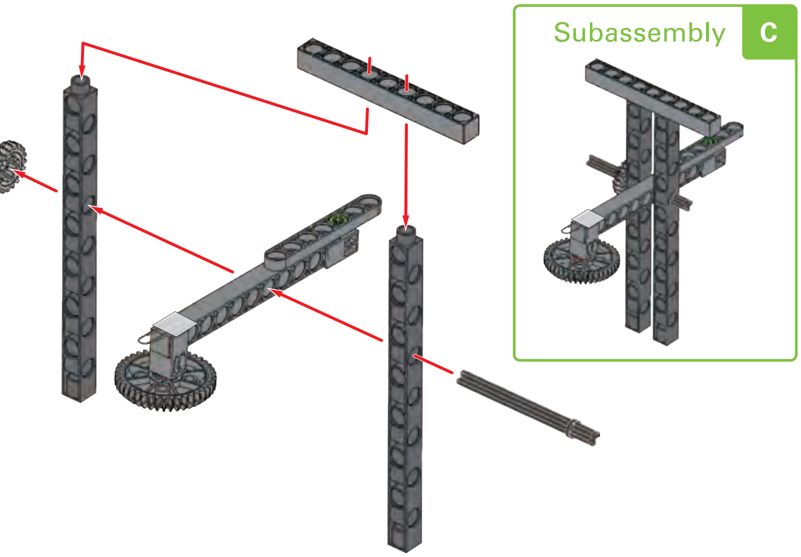
6

Tape the paper clip here.

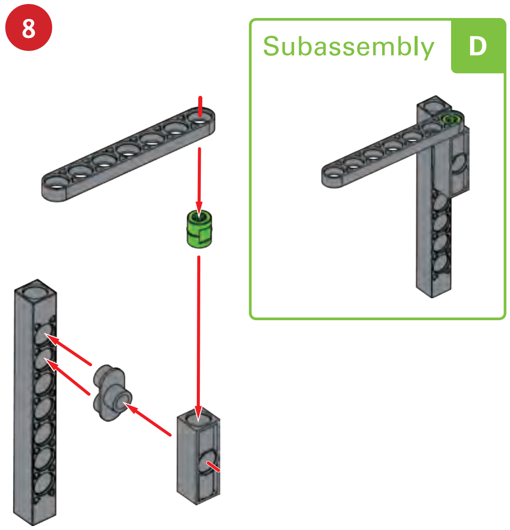


Assembly Steps for Activity 10, Part 2: Electromagnetic Switch Continued

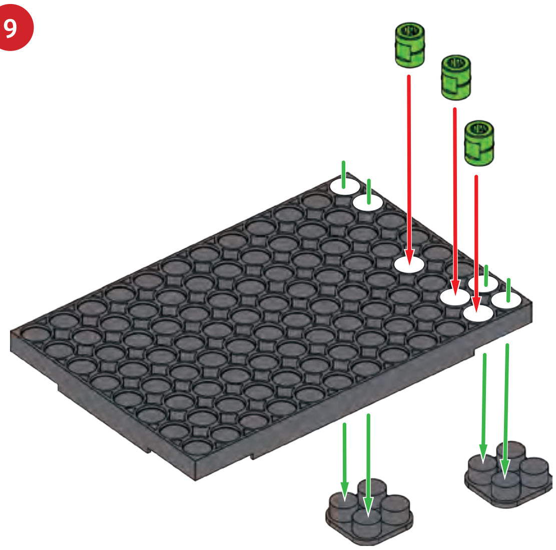
7



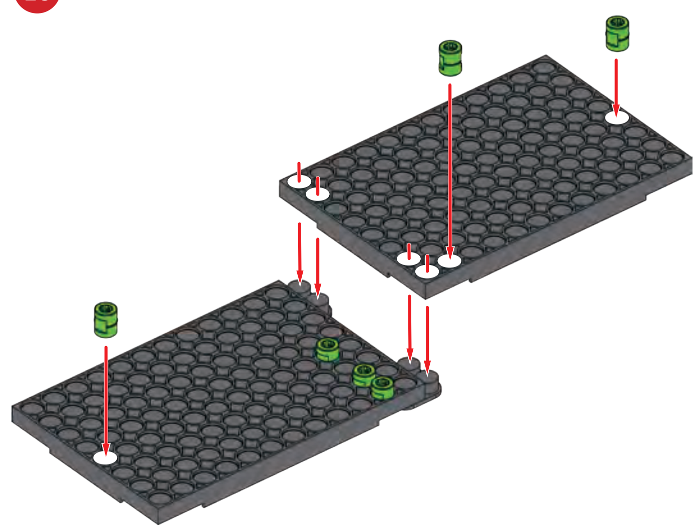
8



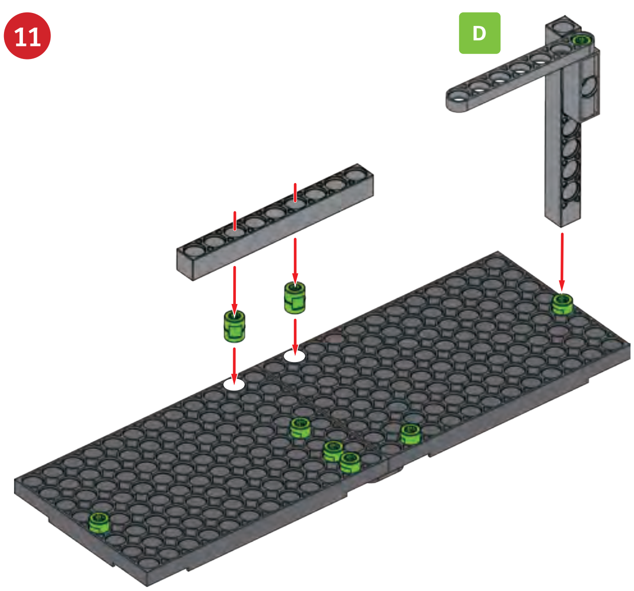
9



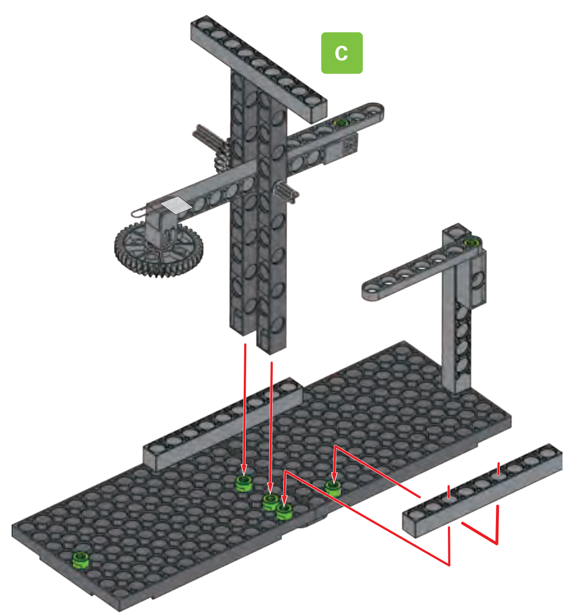
10



11

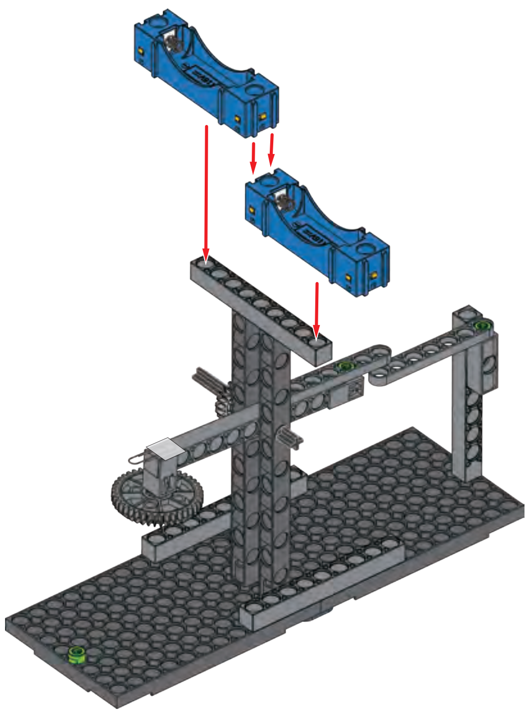


12

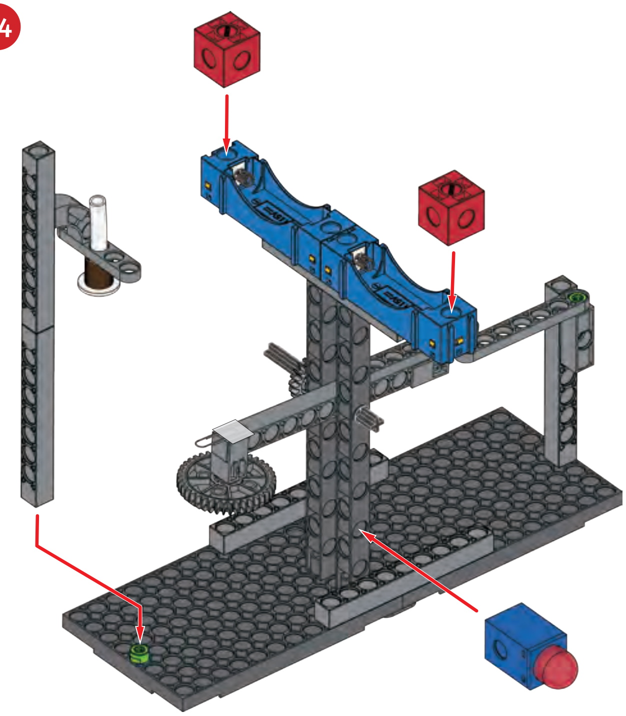


Assembly Steps for Activity 10, Part 2: Electromagnetic Switch Continued

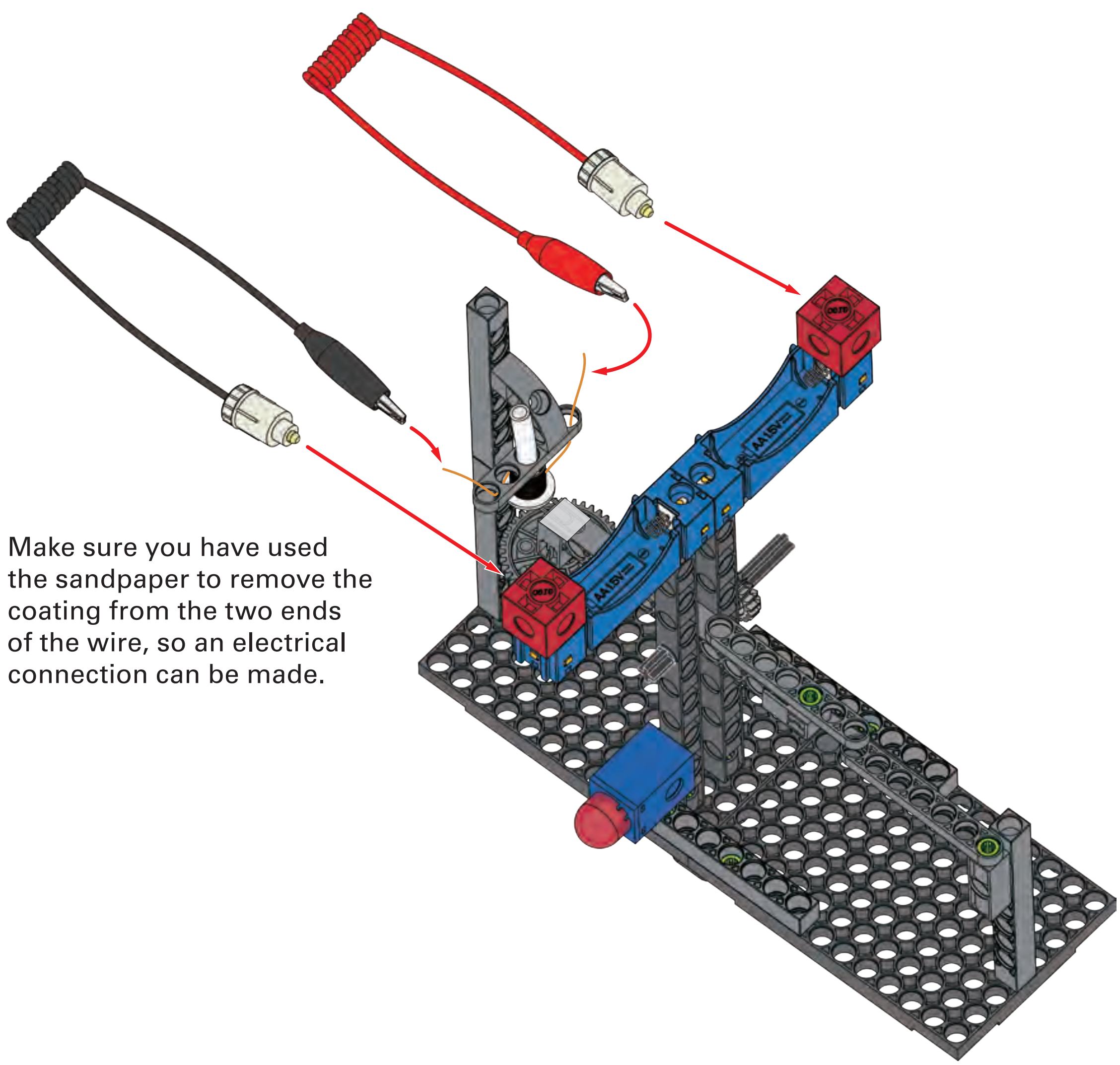
13



14



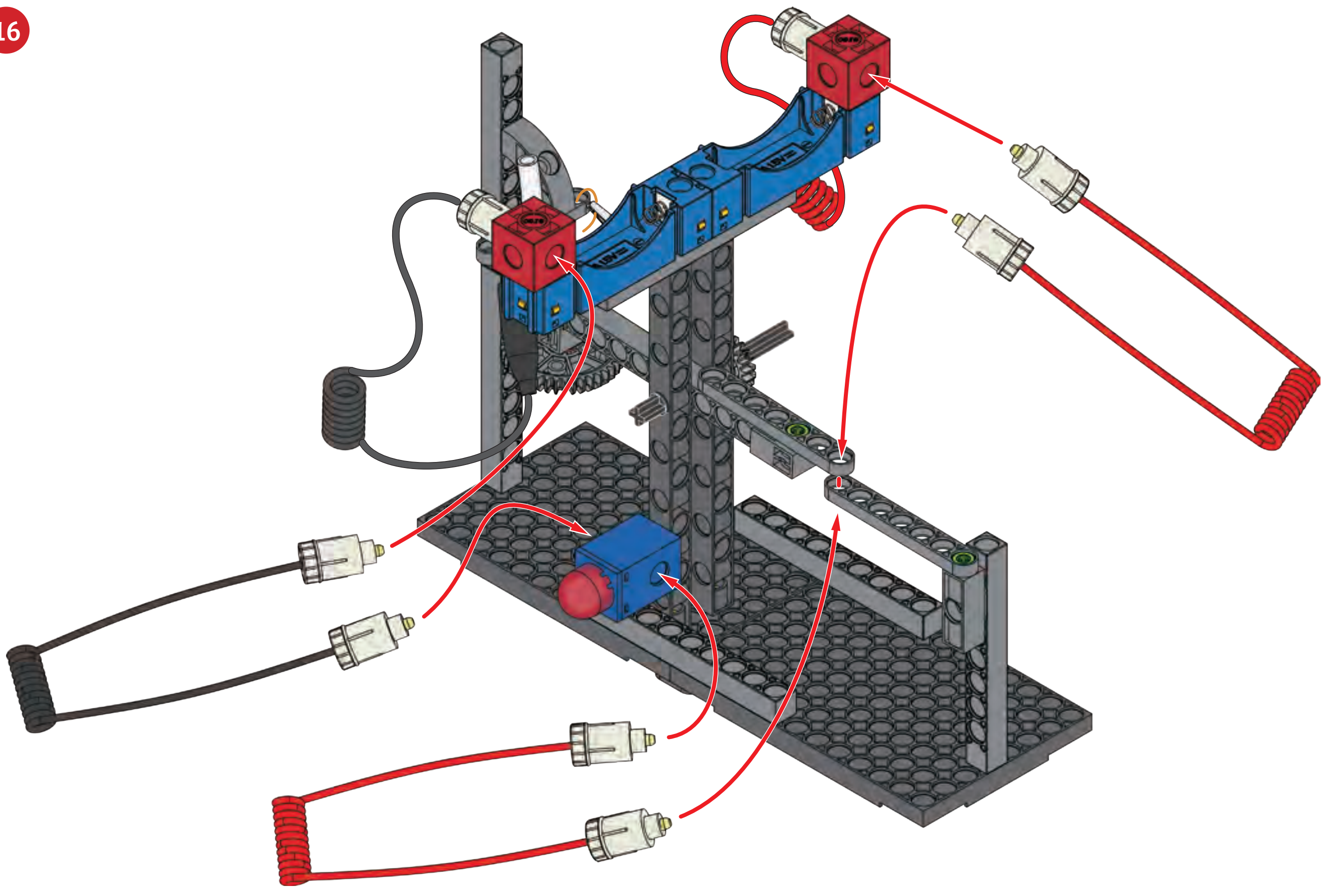
15



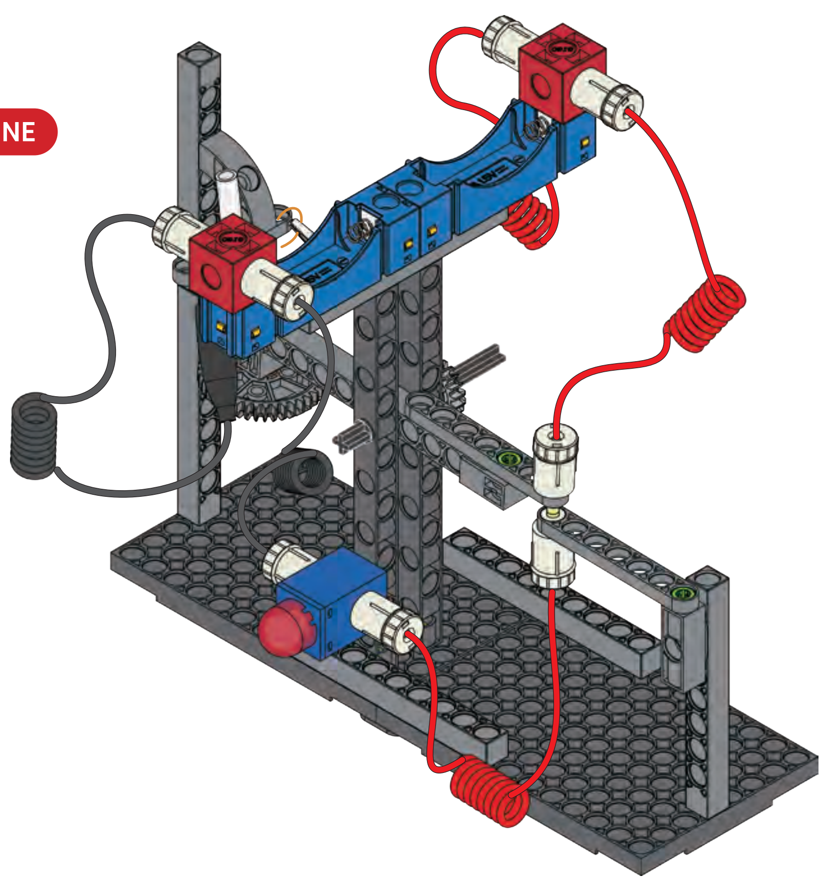
Make sure you have used the sandpaper to remove the coating from the two ends of the wire, so an electrical connection can be made.

Assembly Steps for Activity 10, Part 2: Electromagnetic Switch Continued

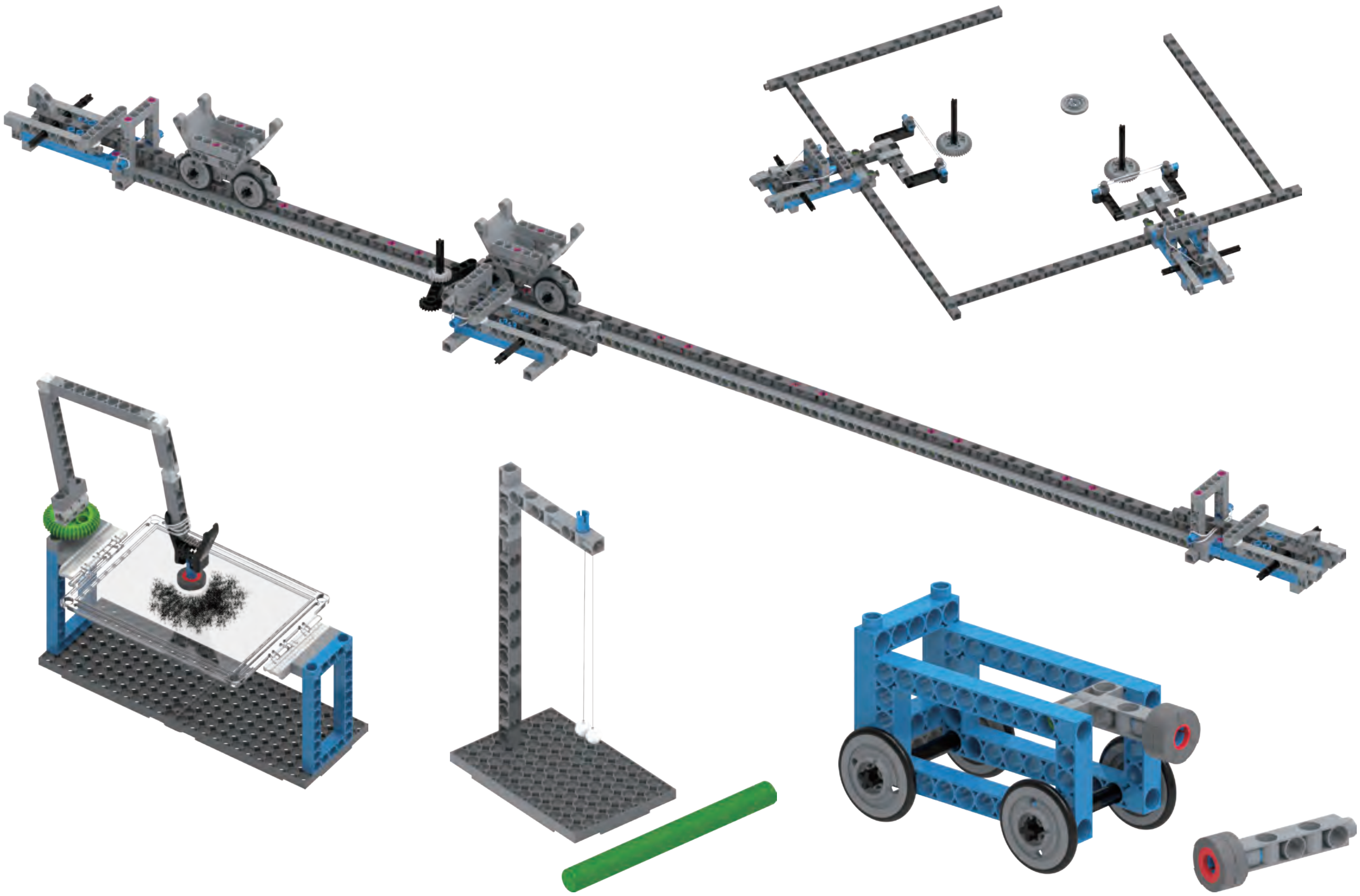
16



DONE



Scan this QR code video:



700100-03-160823