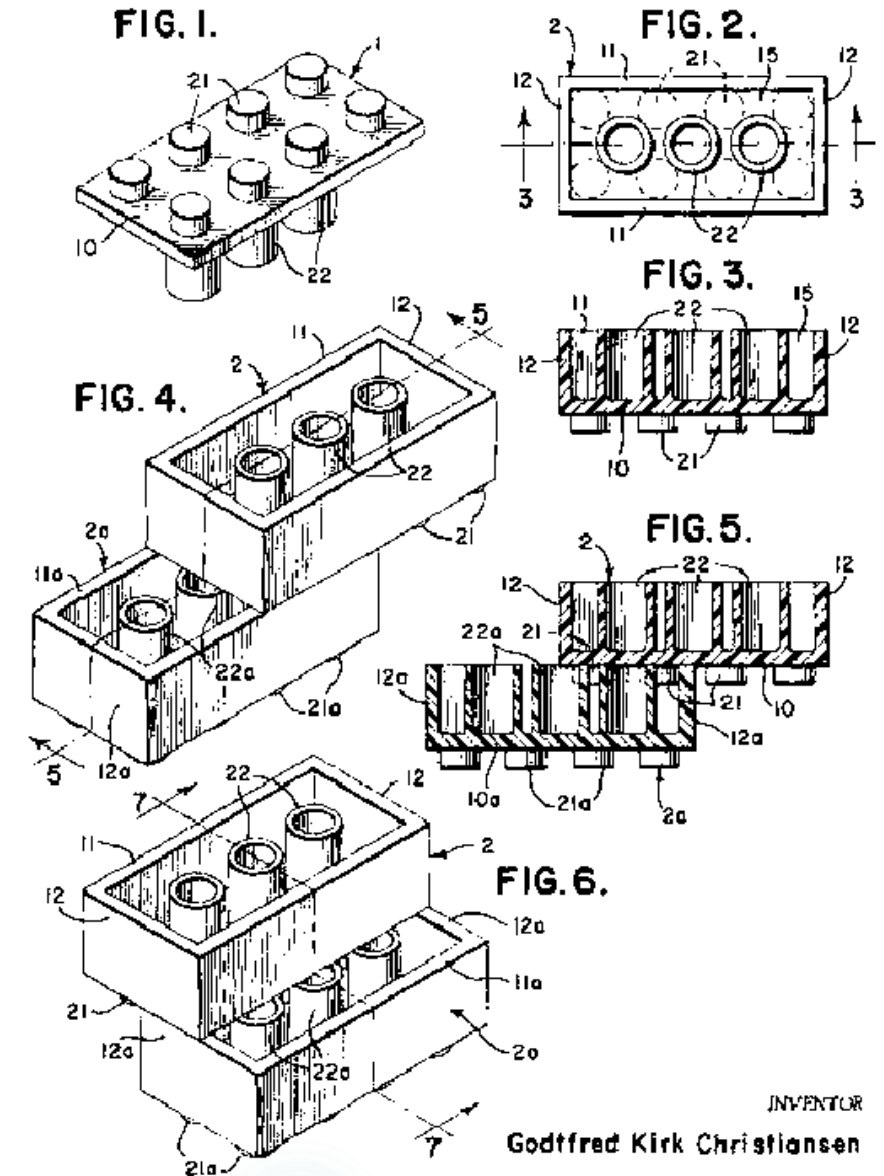


Building with LEGO® Mindstorms® 101

AN OVERVIEW OF LEGO® EV3
MINDSTORMS® ELEMENTS AND HOW
THEY WORK TOGETHER



INVENTOR
Godtfred Kirk Christiansen

WARNING

CHOKING HAZARD – Do **NOT** put the LEGO® blocks or pieces in you mouth for any reason. Not only is it gross, they just don't taste good.

Also no LEGO® pieces in your nose, ears, eyes or anywhere else they don't belong.



Hands-on Exercises Parts List

Qty	Item	P/N
8	Friction Peg	4121715
3	Beam 11M	4562805
2	Peg 3M	4514553
2	Beam 5M	4142135
2	3x5 90 beam	4585040
2	Beam 7M	4495935
2	Cross Axle 2M	4142865
2	Technic Cross Block 2x1	4140430
2	Technic Cross Block 2x2	4162857
3	Non-friction pegs	4211807

Qty	Item	P/N
2	Axle 5M	4211639
2	Double cross block	4121667
1	24z gear	4514558
1	8z gear	6012451
1	Axle 3M	4211815
1	Axle 4M	370526
1	Bionicle eye	4173941
1	Half bushing	4239601
1	Bushing	4227155

Introduction

- Annual production of Lego bricks averages approximately 2.16 per hour, or about 36,000 elements per minute.
- Since 1958, more than 400 billion LEGO® pieces have been produced, or 62 for every person in the world! (June 2008)
- There are roughly 4,200 different LEGO® elements in 53 different colors.



Same piece, many different names
Same piece, many different colors

LEGO® Mindstorms® EV3 Core Kit (45544)

► The LEGO® Technic elements in the Mindstorms® sets are:

- Electronic elements
- Beams
- Pegs and axle pegs
- Axles and connectors
- Gears
- Wheels
- Decorative elements
- Miscellaneous elements



LEGO® Mindstorms® EV3 Core Kit (31313)



Three websites the compare EV3 kit

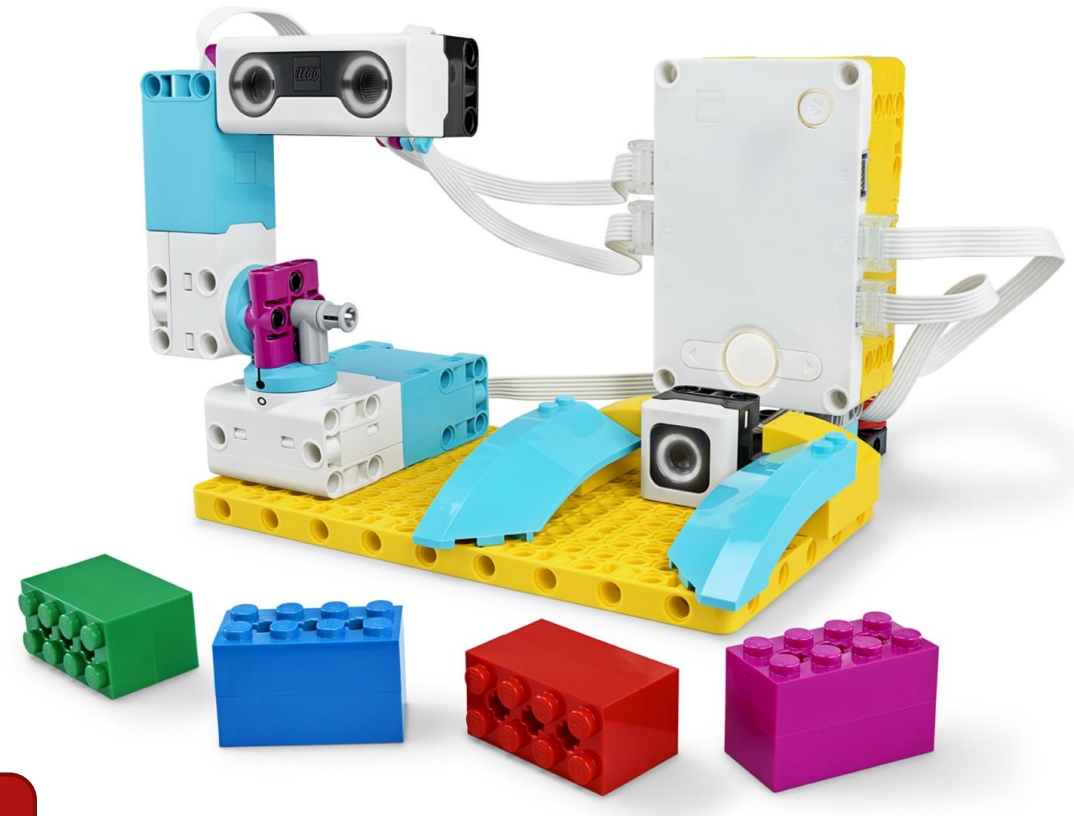
<http://robotsquare.com/2013/11/25/difference-between-ev3-home-edition-and-education-ev3/>

<http://www.generationrobots.com/blog/en/2015/02/differences-lego-mindstorms-education-ev3-kit-ev3-home-edition/>

<https://www.intorobotics.com/8-major-differences-between-mindstorms-ev3-education-and-home-edition/>

LEGO® Education SPIKE™ Prime Set (45678)

- ▶ New 3x3 biscuit
- ▶ New 2x4 brick has a cross axle hole
- ▶ New base plate
- ▶ New frames
- ▶ New wheels for easy mount with motor, precise turns and improved maneuverability
- ▶ New wire clips to help keep wires in check



Releases August 2019

LEGO® Education SPIKE™ Hub (45601)



The programmable Hub features:

- ▶ 5x5 light matrix
- ▶ 6 input/output ports
- ▶ Integrated 6-axis gyro
- ▶ Speaker
- ▶ Bluetooth connectivity
- ▶ Rechargeable battery

LEGO® Education SPIKE™ App

SPIKE Prime's drag-and-drop coding environment for tablets and computers is based on the popular Scratch programming language.

<https://scratch.mit.edu/>



Electronic Elements

- INTELLIGENT BRICK ■ DRIVE MOTORS
- TOUCH SENSOR ■ COLOR SENSOR
- ULTRASONIC SENSOR ■ GYROSCOPE ■ CONNECTOR CABLES



Intelligent Bricks History



Only these four Mindstorms® Bricks are permitted in FLL®.

▶ Spike Prime

- ▶ Releasing August 2019

▶ EV3

- ▶ Educational released August 1, 2013
- ▶ Commercial released September 1, 2013

▶ NXT

- ▶ Released 2006

▶ RCX

(Robotic Command eXplorers)

- ▶ Released 1998

Sensors

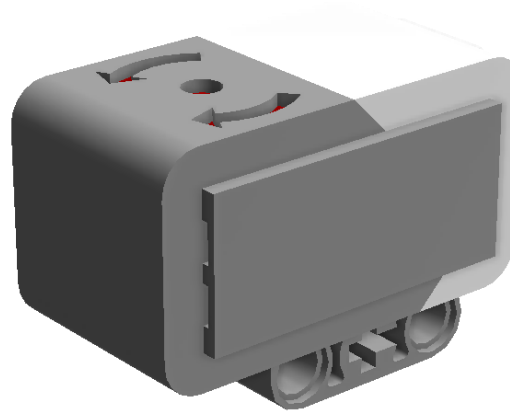
- ▶ 6008472: EV3 Touch Sensors (2)
- ▶ 6008919: EV3 Color Sensor
- ▶ 6008916: Gyro
- ▶ 6008924: Ultrasonic Sensor



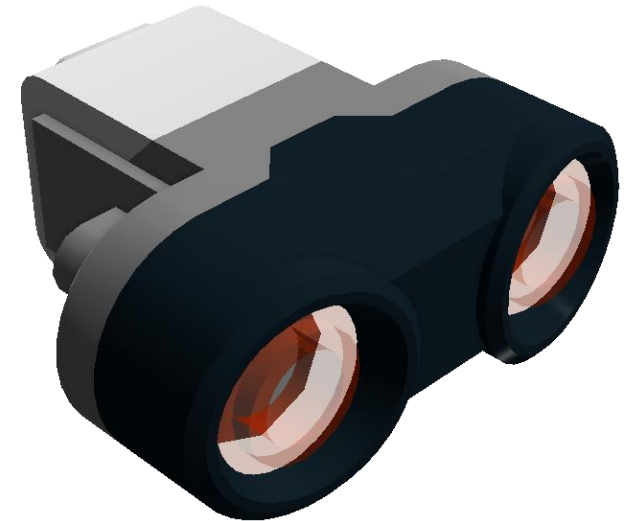
Touch Sensor



Color Sensor



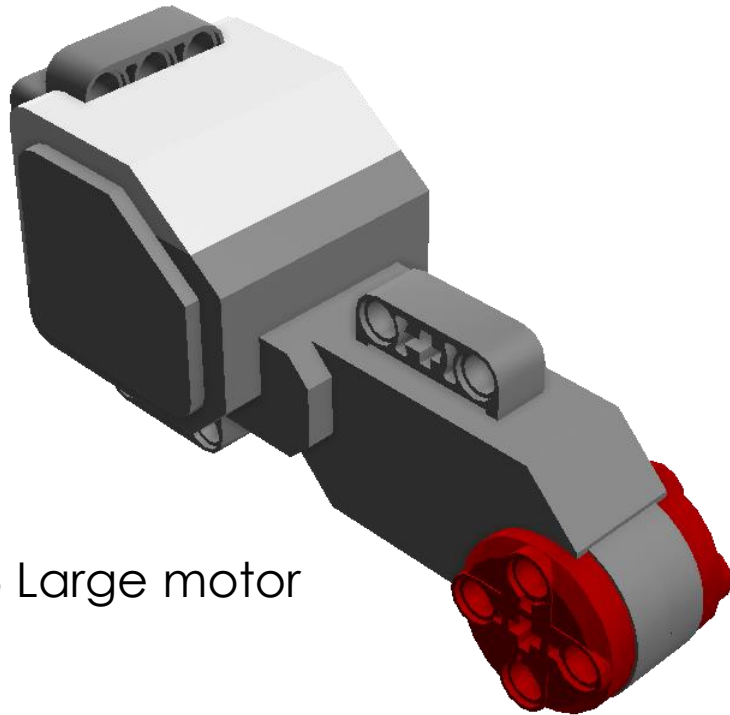
Gyro Sensor



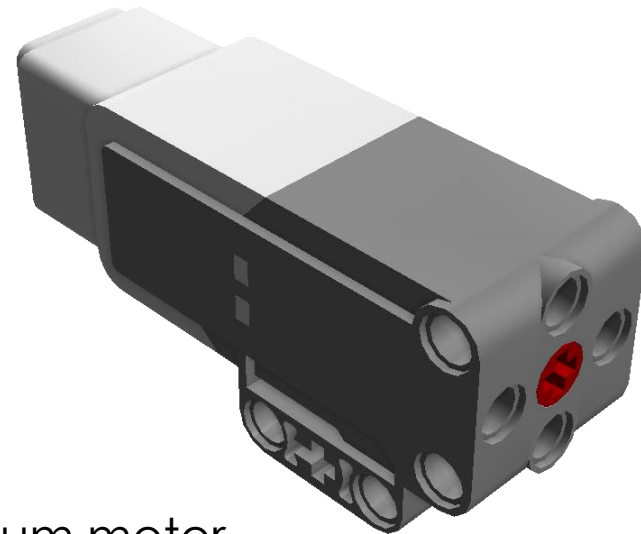
Ultrasonic Sensor

Drive Motors

- ▶ 6009430: EV3 Large motor (2)
- ▶ 6008577: EV3 Medium motor



EV3 Large motor



EV3 Medium motor

Beams and Pegs

- STRAIGHT BEAMS ■ ANGULAR BEAMS
- FRAMES ■ THIN BEAMS ■ FRICTION PEGS
- NON-FRICTION PEGS



Beams - Straight

- ▶ Beams are measured by counting the number of holes.
 - ▶ Beams are available in odd numbers when counting the holes, with one exception.
 - ▶ Beams start with 15 holes and go down in size by two holes to the 3 hole beam and include one even-numbered beam with 2 holes.
- ▶ The number of holes corresponds to the length of the beam in **Fundamental LEGO® Units** or **Modules** (1M is 8mm).

Beams - Straight



▶ 3M Beam



▶ 5M Beam



▶ 7M Beam



▶ 9M Beam



▶ 11M Beam



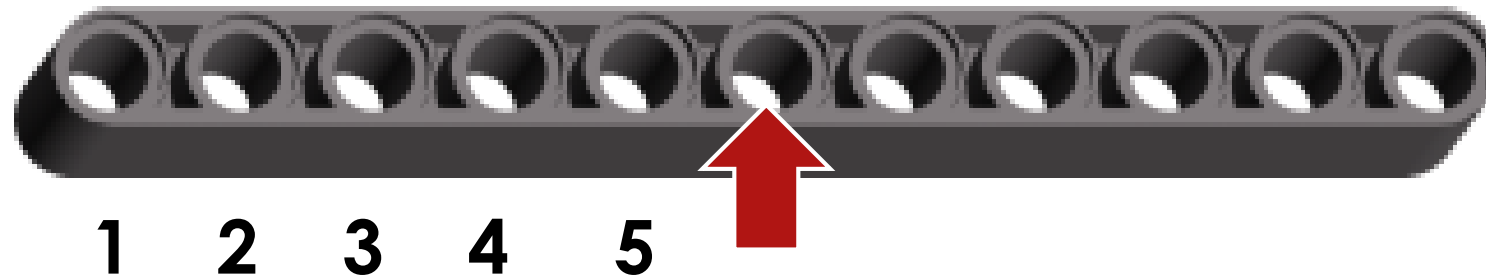
▶ 13M Beam



▶ 15M Beam

Tip for determining beam size.

- ▶ To quickly determine the size of the longer beams: place a finger on the middle hole of the beam, then you can quickly count how many holes are on one side, double it, and add one.



Specialty beams

- ▶ 6008527: Horizontal to Vertical (HTV) Beam 90 Degrees
- ▶ 6006140: Beam 1X2 with Cross And Hole
- ▶ 4538007: Axle and Triple Peg Cross Block



HTV Beam



1x2 Cross and Hole Beam



Axle and Triple Peg Cross Block

Pegs and Axle Pegs

- ▶ Pegs are like the nails, screws, and bolts of LEGO® Mindstorms®, they hold things together.
- ▶ Pegs fit in the holes of other part.
- ▶ Two primary groups of pegs:
 - ▶ Friction
 - ▶ Non-Friction

Pegs and Axle Pegs – Friction



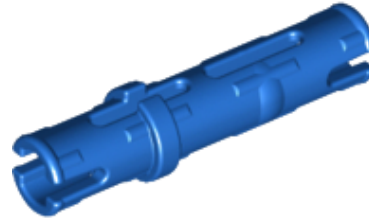
- ▶ 4121715: Connector Peg - Friction
- ▶ 4140806: 2M Snap with Cross Hole - Friction
- ▶ 4514553: 3M Connector Peg - Friction
- ▶ 4206482: Connector with Cross axle - Friction
- ▶ 4184169: Ball With Friction Snap*



Connector
Peg -
Friction



2M Snap with
Cross Hole -
Friction



3M Connector
Peg - Friction



Connector
with Cross axle
- Friction



Ball With
Friction Snap*

*Not included in the 45544 EV3 kit, but is a common piece

Pegs and Axle Pegs – Non-friction



- ▶ 4211807: Connector peg
- ▶ 4514554: 3M Connector peg
- ▶ 4666579: Connector peg Cross Axle



Non-friction connector peg



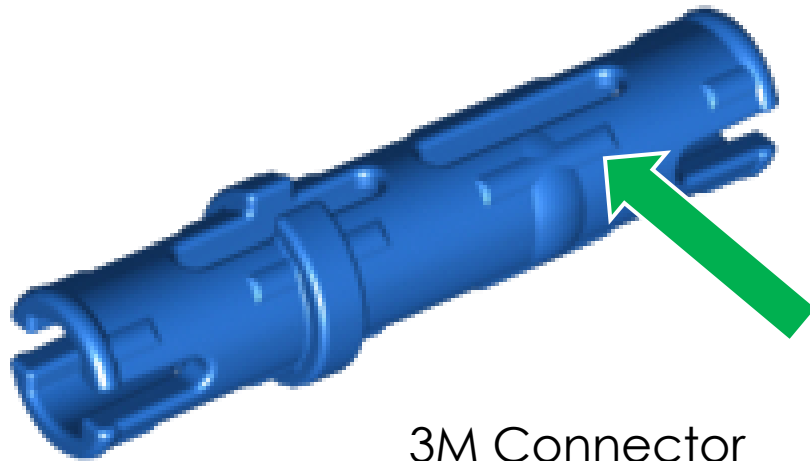
Non-friction 3M
connector peg



Non-friction
connector peg
with axle

Identifying friction and non-friction pegs

- ▶ Friction pegs have ridges that help to create friction with the beams.
- ▶ Non-Friction pegs are smooth.



3M Connector
Peg - Friction



Non-friction 3M
connector peg

Beams and “snap” combinations

- ▶ 4225033: Beam 3M with 4 Snaps
- ▶ 4296059: Angular Beam 90° with 4 Snaps



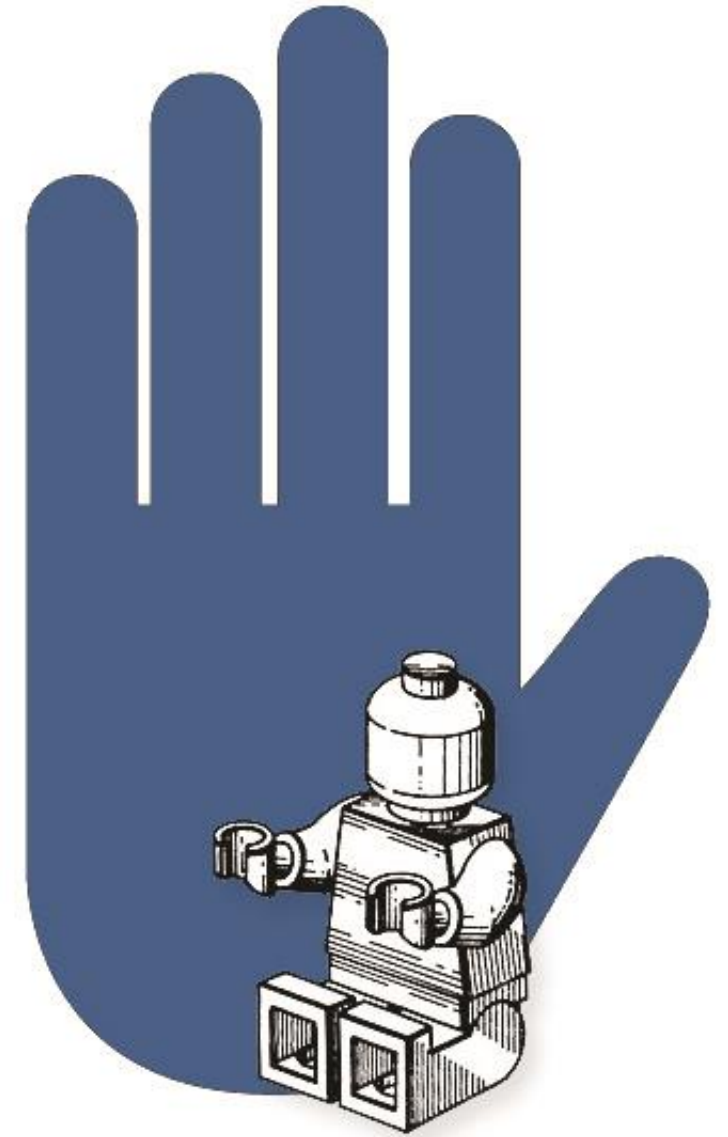
AKA: H connector



AKA: L connector
or Llama connector

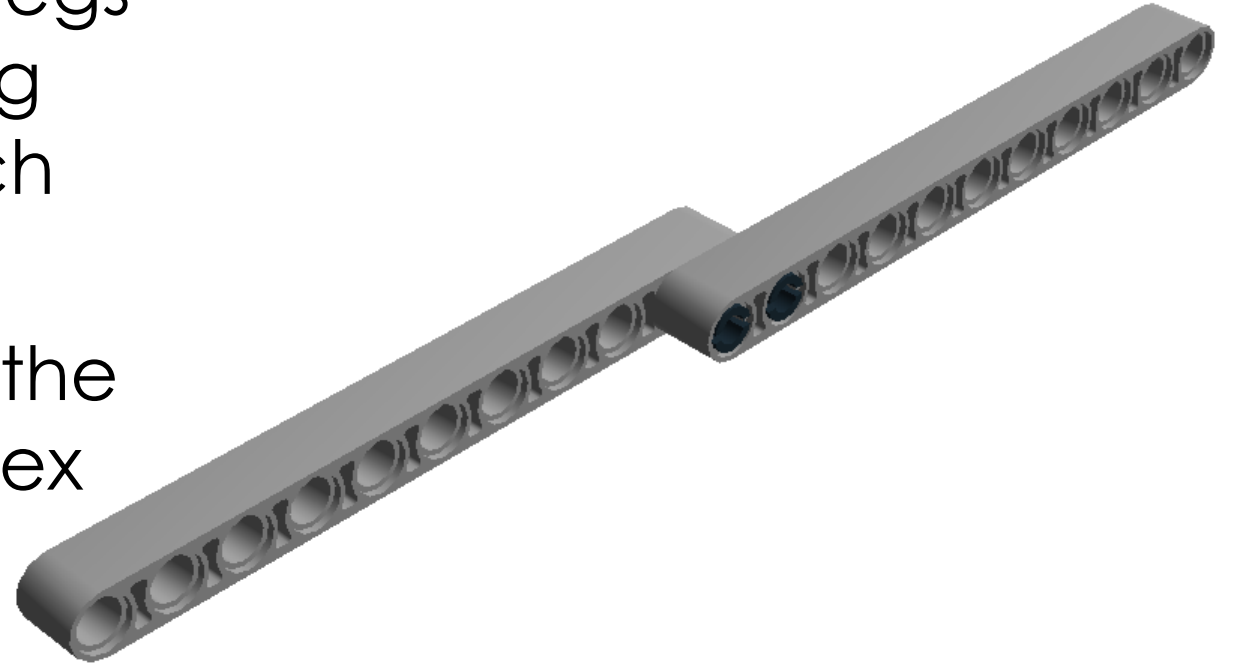
Using Beams and Pegs

- ▶ Hands-on activity



Extending Beams

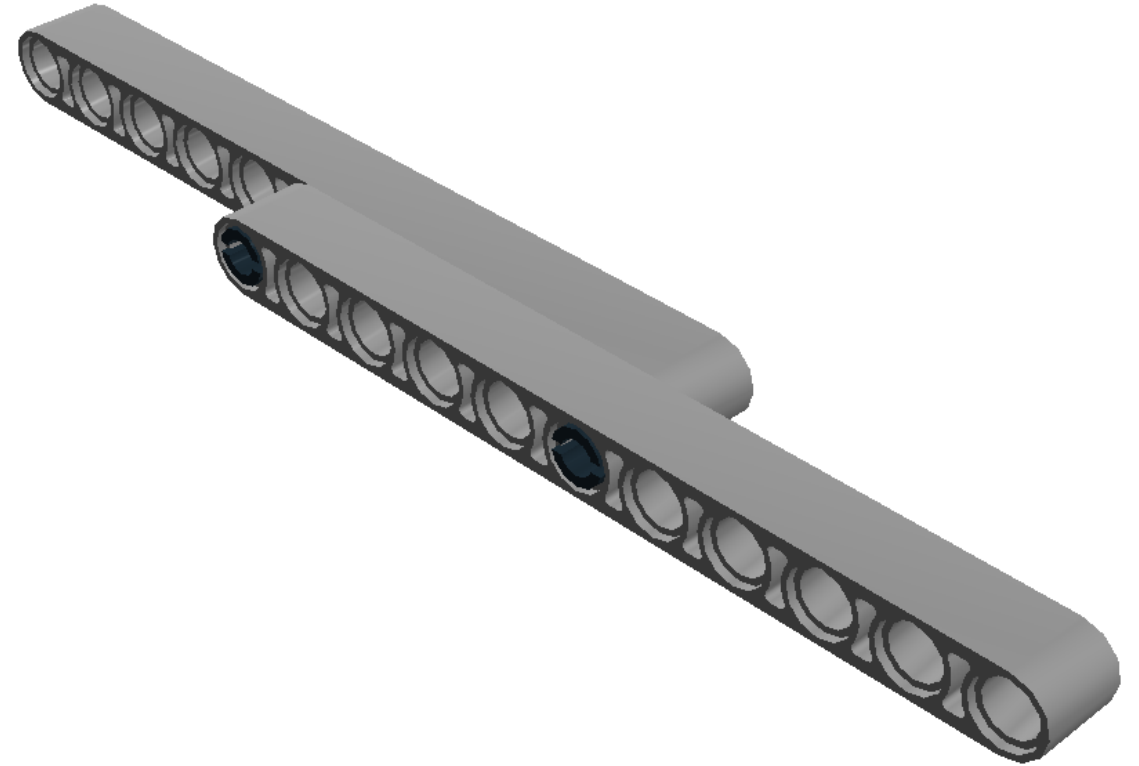
- ▶ Using two black friction pegs connect two beams using the two end holes of each beam.
- ▶ Test: Holding the ends of the extended beam gently flex it.
- ▶ Result: The beam is straight but still has some flex.



Extending Beams

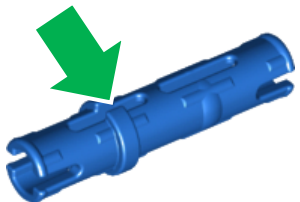
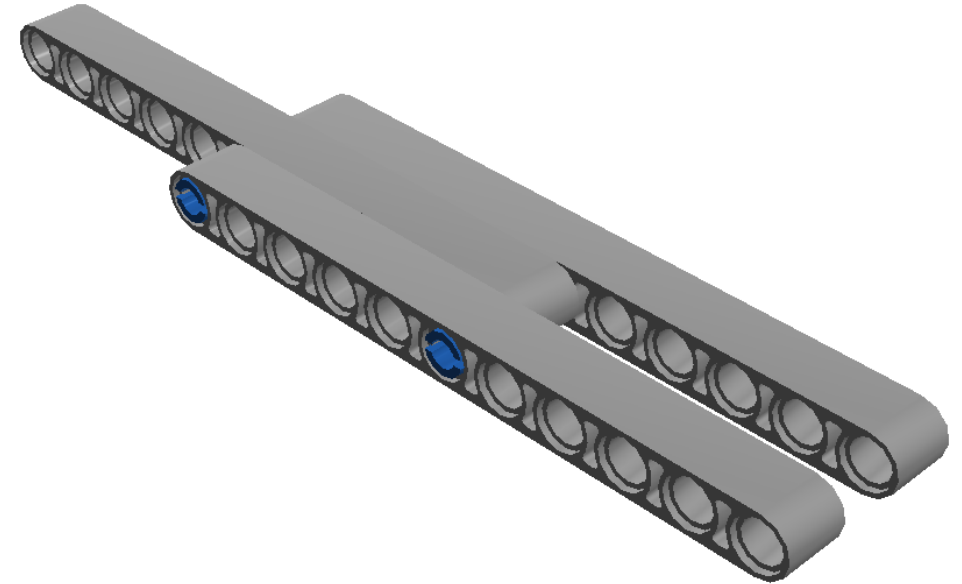
- ▶ Using the same two black pegs with friction, overlap the beams five holes.
- ▶ Test: Holding the ends of the extended beam gently flex it.
- ▶ Result: Structure is more rigid.

Note: Adding additional black pegs will hold the beams together better, but not required for strength.



Increasing Strength by Making Wider

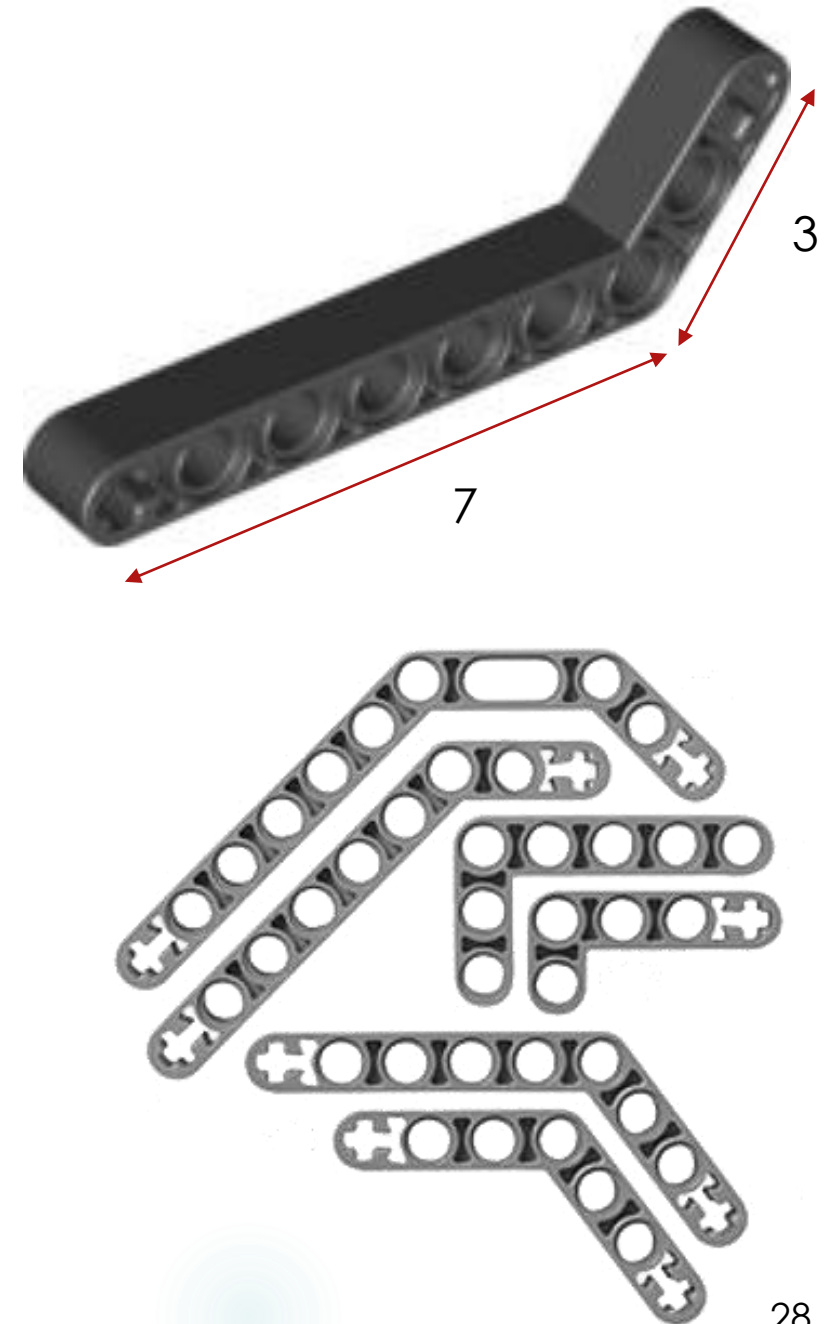
- ▶ Using two 3M blue friction pegs, overlap the beams five holes. Then add an additional beam on the pegs extending.
- ▶ Result: A more ridged structure.



Note: Alternate the direction of the 3M blue peg ridge can reduce separation. Peg ridge can be used to help in keeping pegs in place when removable attachments.

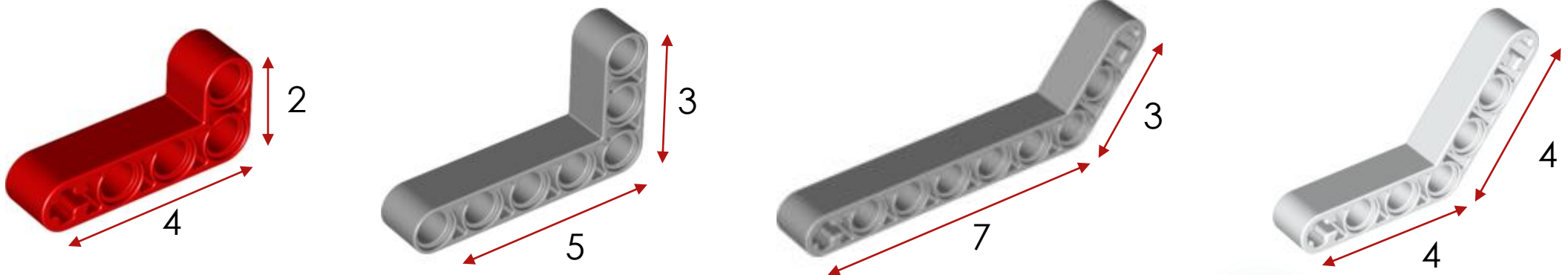
Angular beams

- ▶ An angular beam with three holes before and seven holes after the bend is a 3x7 angular beam.
- ▶ 3x5 90° angular beam has holes at both ends.
- ▶ 2x4 90° angular beam has a hole at one end and cross axle at the other.
- ▶ All other angular beams have cross axles at both ends.



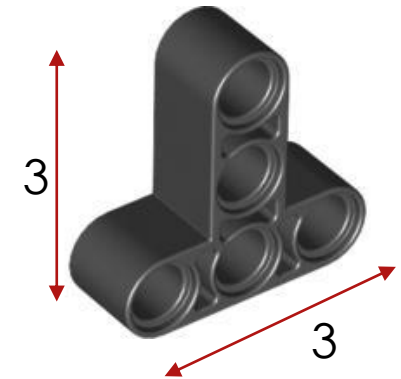
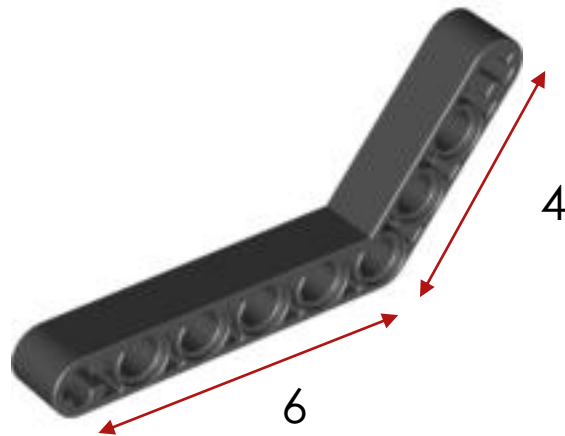
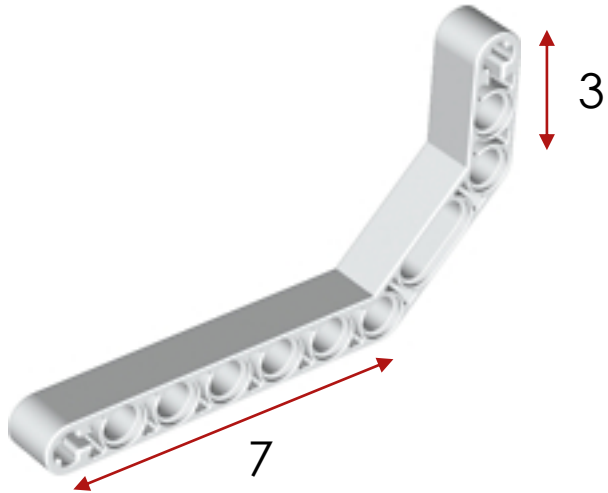
Angular beams

- ▶ 4141270: Angular Beam 4X2 90°
- ▶ 4211713: Angular Beam 3X5 90° (Med. Grey)
- ▶ 4585040 Angular Beam 3X5 90° (White)
- ▶ 4211624: Angular Beam 3X7
- ▶ 4509912: Angular Beam 4X4

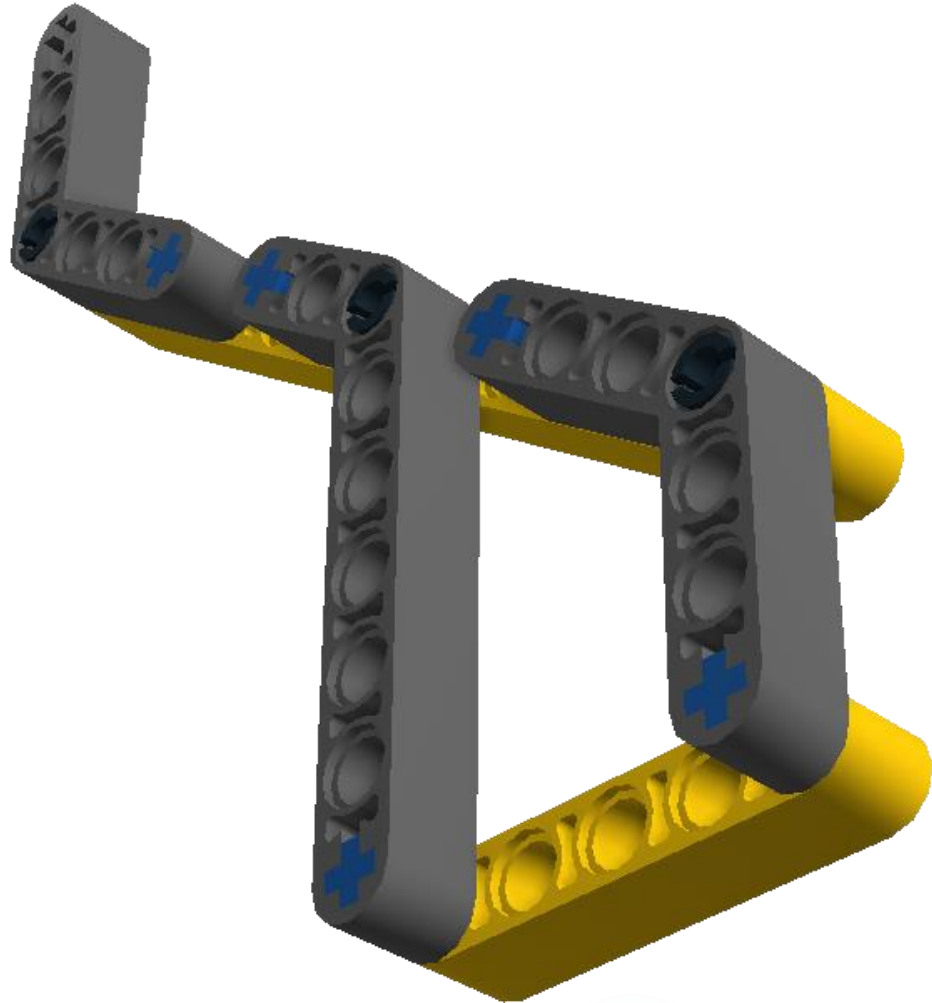
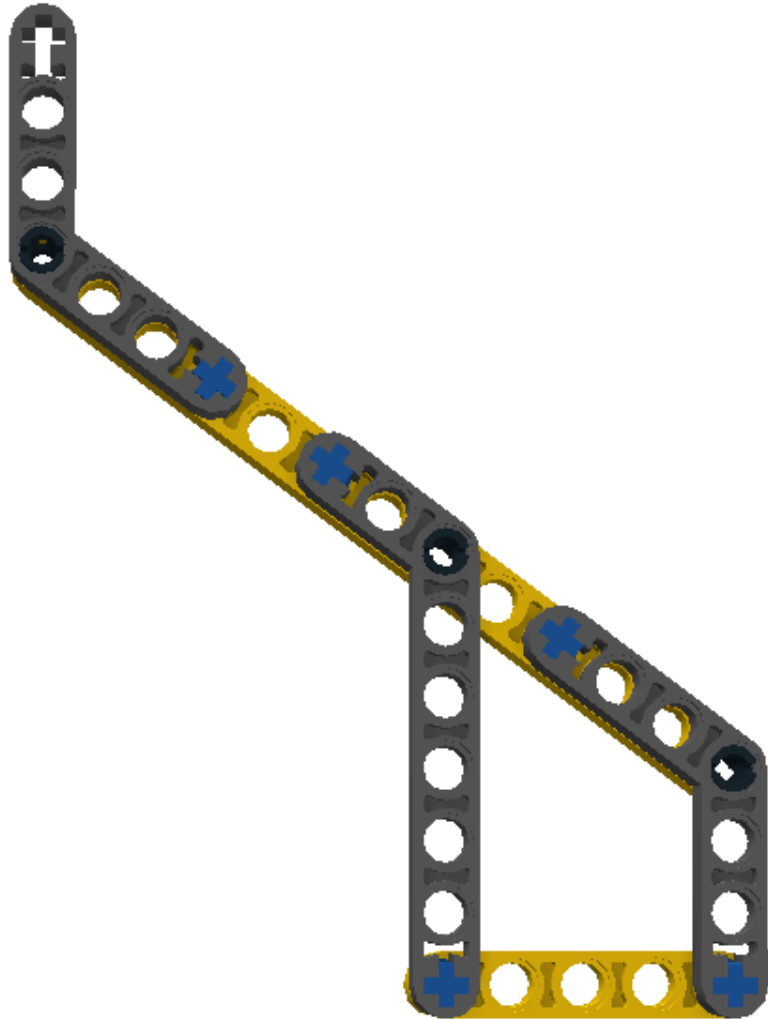


Angular beams

- ▶ 4495412: Double Angular Beam 3X7
- ▶ 4112282: Technic Angular Beam 4X6
- ▶ 4552347: T-Beam 3X3 with Hole

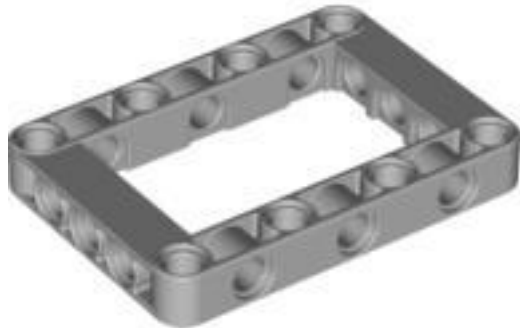


Angular combinations



Frames

- ▶ Frames are referred to based on their shape:
 - ▶ O frame
 - ▶ H frame
- ▶ Frames allow building in multiple directions and can add strength to structures.



4539880: Beam Frame 5X7



4539880: Beam Frame 5X7

Thin beams

- ▶ Are half the width of a normal beam.
- ▶ Useful for adding functions or styling to your robots.



6009019: Triangle



4142236: Lever 1X4,
Without Notch



4112287: Technic
Lever 3X3M, 90°*

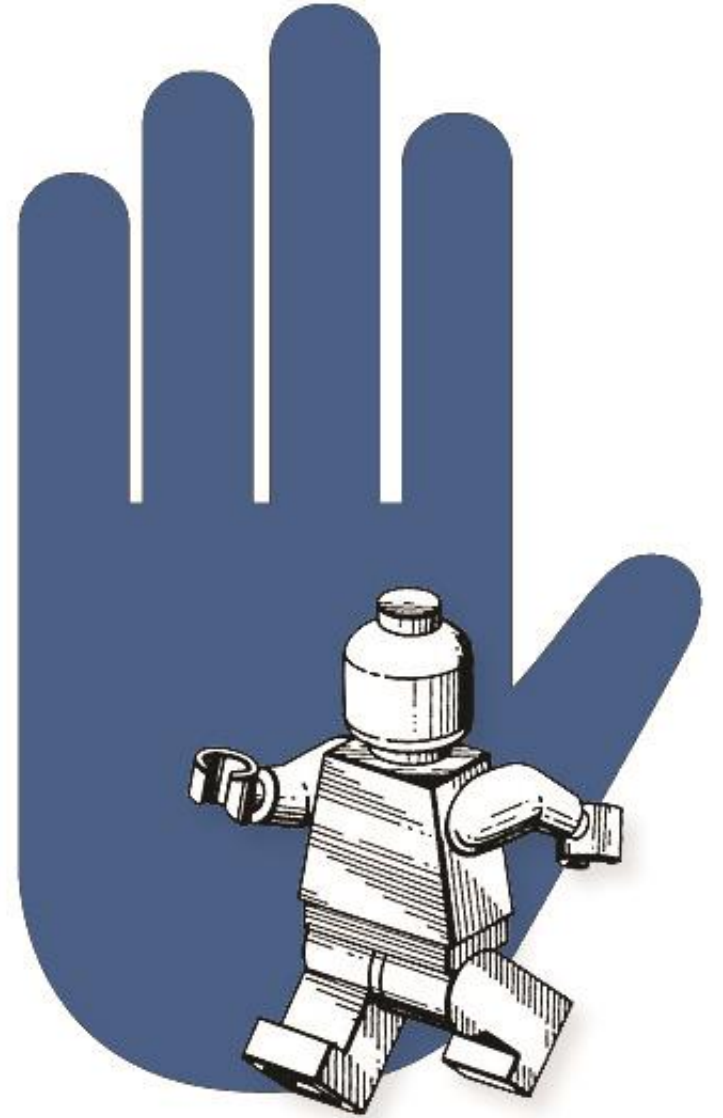


4503417: Technic 5M
Half Beam*

* Not part of the 45544 kit

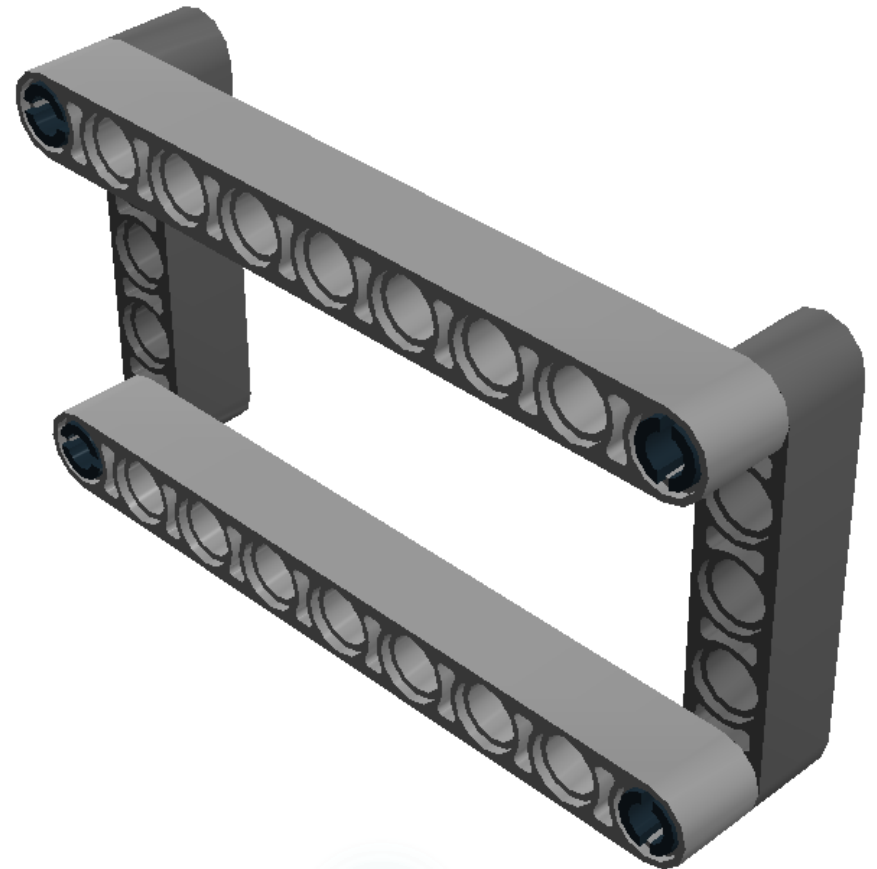
Structural frames

- Hands-on activity

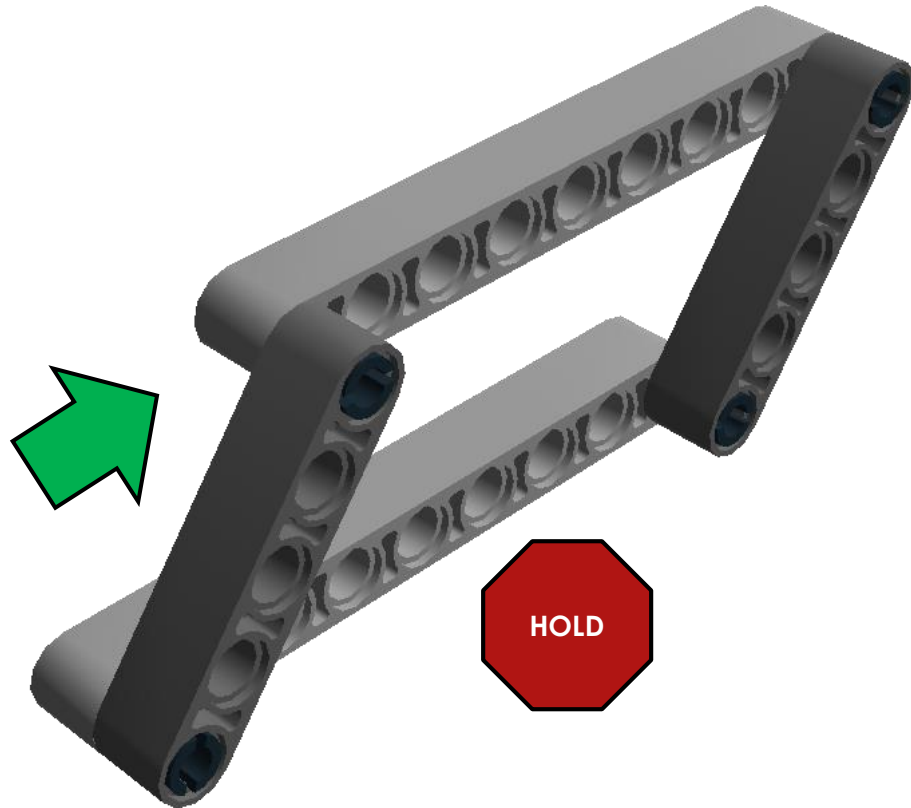


Make a Structural Frame

- ▶ Using two 11M beams, two 5M beam, and four black pegs, make a structural frame as shown.



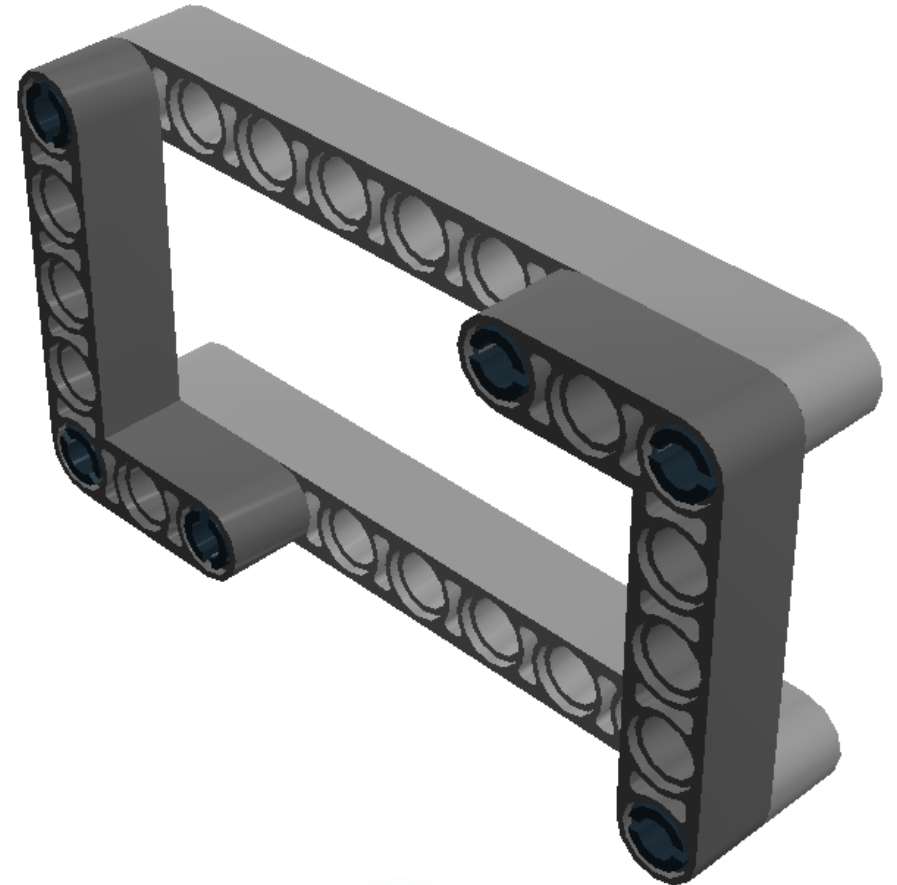
Strength Test of Structural Frame



- ▶ Hold the bottom and press on one side of the frame.
- ▶ What happens to the frame?

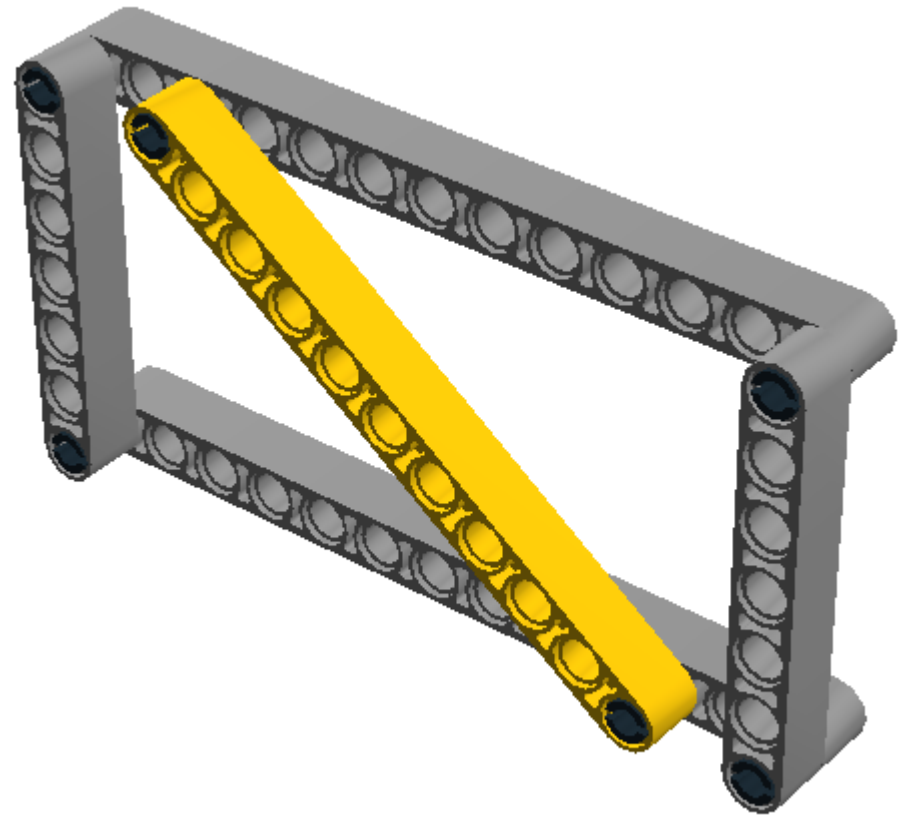
Adding Strength to the Structural Frame

- ▶ Using two 11M beams, two 3X5 90° angular beams, and six black pegs, make a structural frame as shown.
- ▶ Hold the bottom and press on one side of the frame.
- ▶ What happens to the frame this time?



Reinforcing with angles

- ▶ A beam angled between the two beams will also improve the structural strength.



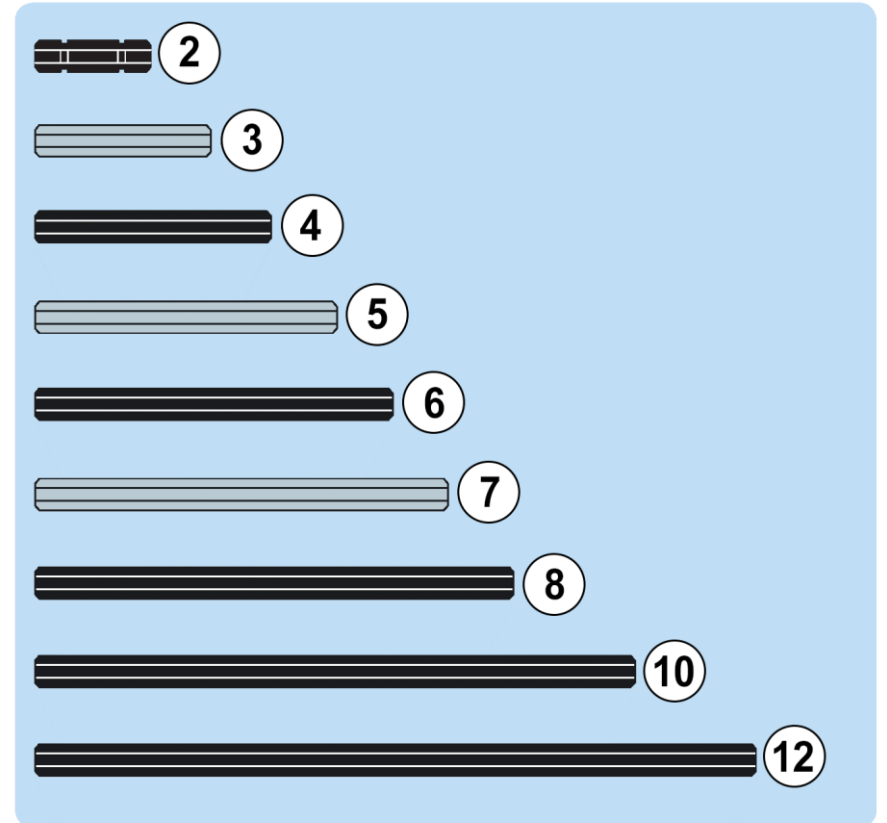
Axles and connectors

■ AXLES ■ BUSHINGS ■ CROSS BLOCKS



Axles

- ▶ Length is same as a Lego[®] brick, the smallest is called a 2M axle (with groove) and commonly red or black.
 - ▶ The odd number axles are typically grey (3, 5, 7M axle).
 - ▶ The even number axles are typically black (4, 6, 8M axle).



FLL[®] mission kits have a variety of color axles.

Specialty Axles

- ▶ Axle with end stop (5.5 M)
- ▶ Cross axle with end stop (4M and 8M)
- ▶ Cross axle with end knob (3M)



4263624: 5.5M
Double Cross Axle



4560177: Cross Axle
4M With End Stop



4499858: Cross Axle
8M With End Stop



6031821: Cross Axle
3M with End Knob

Bushings

- ▶ 4239601: Cross Axle Half Bushing
- ▶ 4211622: Cross Axle Bushing
- ▶ 4560175: Double 3M Bushing



Cross Axle Half Bushing



Cross Axle Bushing

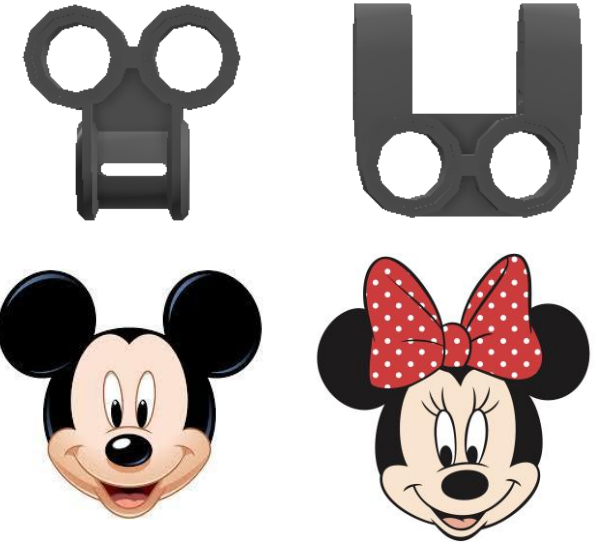


Double 3M Bushing

Bushings can be used as spacers to prevent tires from hitting beams or other structures.

Cross blocks

- ▶ 4173668 - Cross Block 90
- ▶ 4121667 - Double Cross Block
- ▶ 4140430 - Technic Cross Block 2X1 (Mickey)
- ▶ 4162857 - Technic Cross Block Fork 2X2 (Minnie)



Cross Block 90



Double Cross
Block



Cross Block 2x1
(Mickey)



Cross Block 2x2
(Minnie)

Additional cross blocks

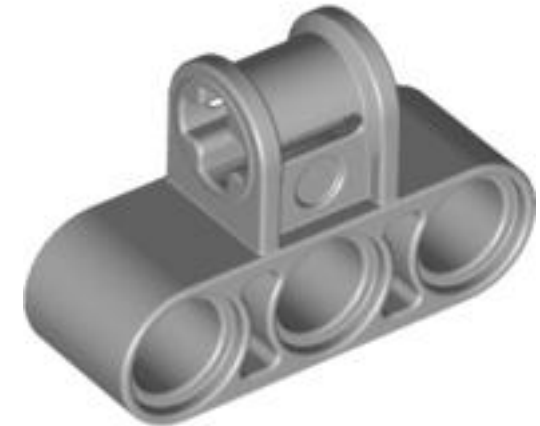
- ▶ 4210857: Cross Block 90, 3M
- ▶ 4502595: 3-Branch Cross Axle Cross Hole
- ▶ 4538007: Cross Block 3X2



Cross Block
90, 3M



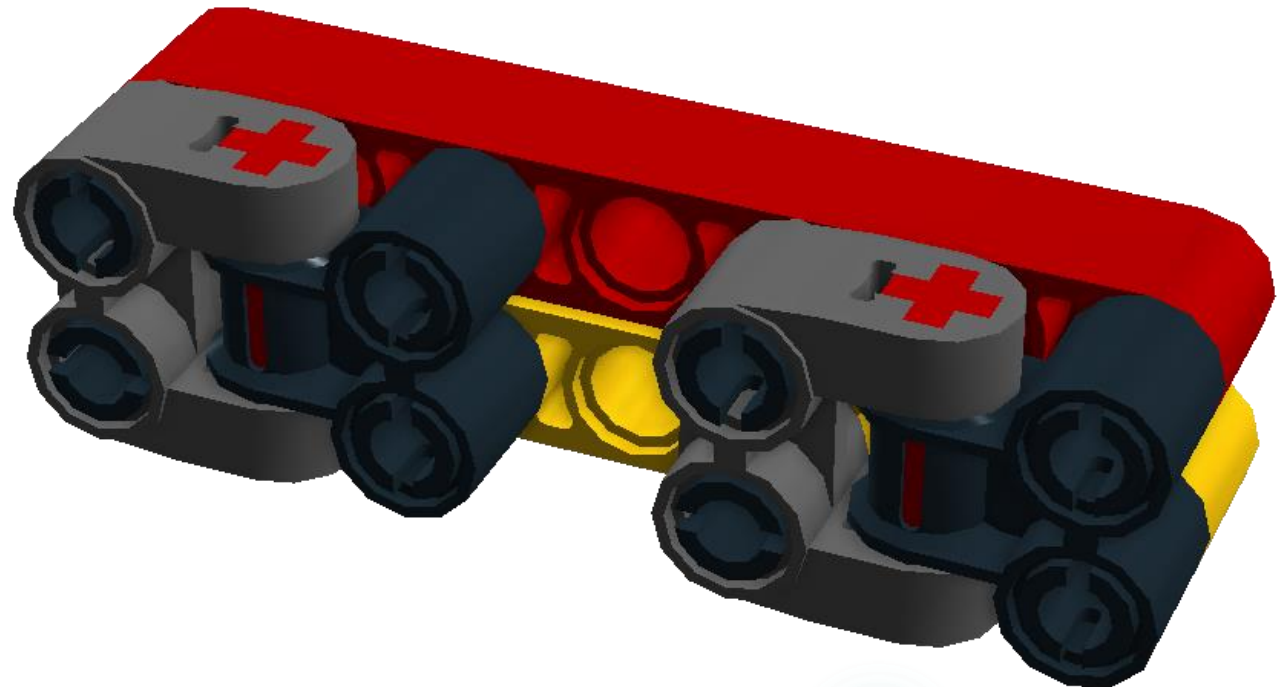
3-Branch
Cross Axle
Cross Hole



Cross Block
3X2

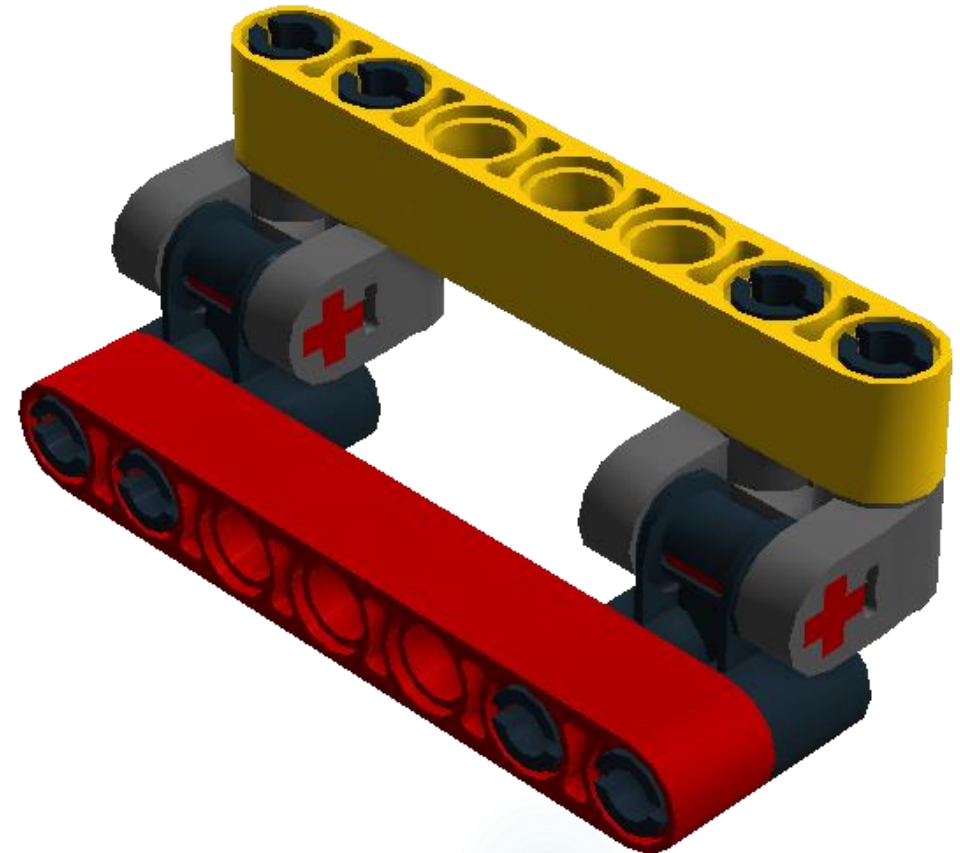
Cross blocks combinations

- ▶ This cross block combination allows two beams to be mounted smooth sides together.



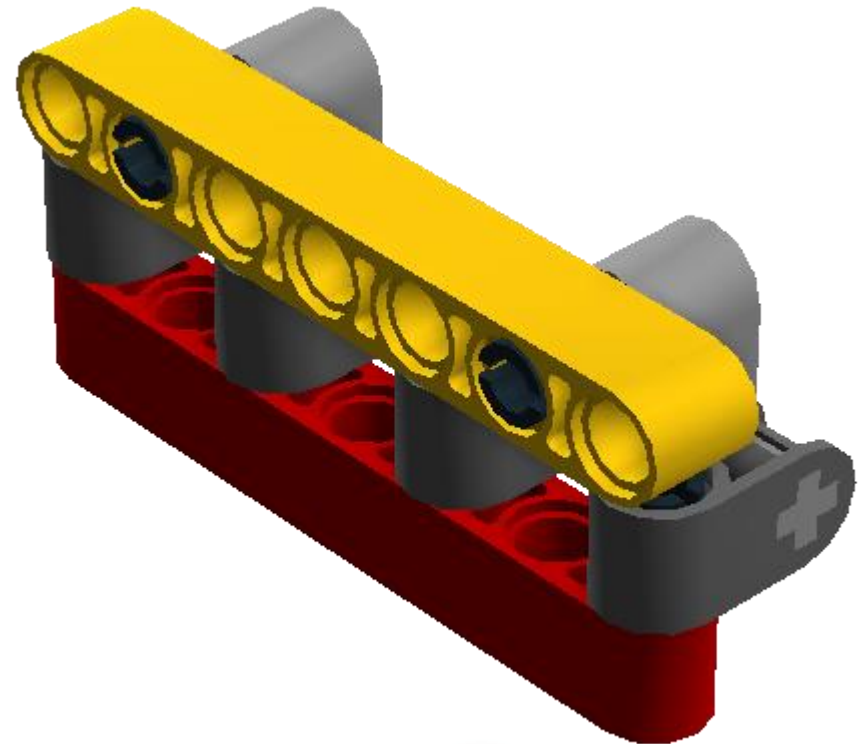
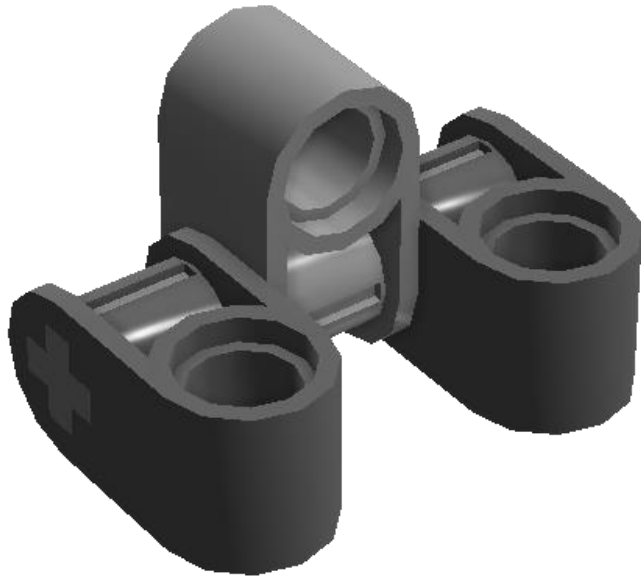
Cross blocks combinations

- ▶ Using this cross block combination allows mounting two beams at a right angle.



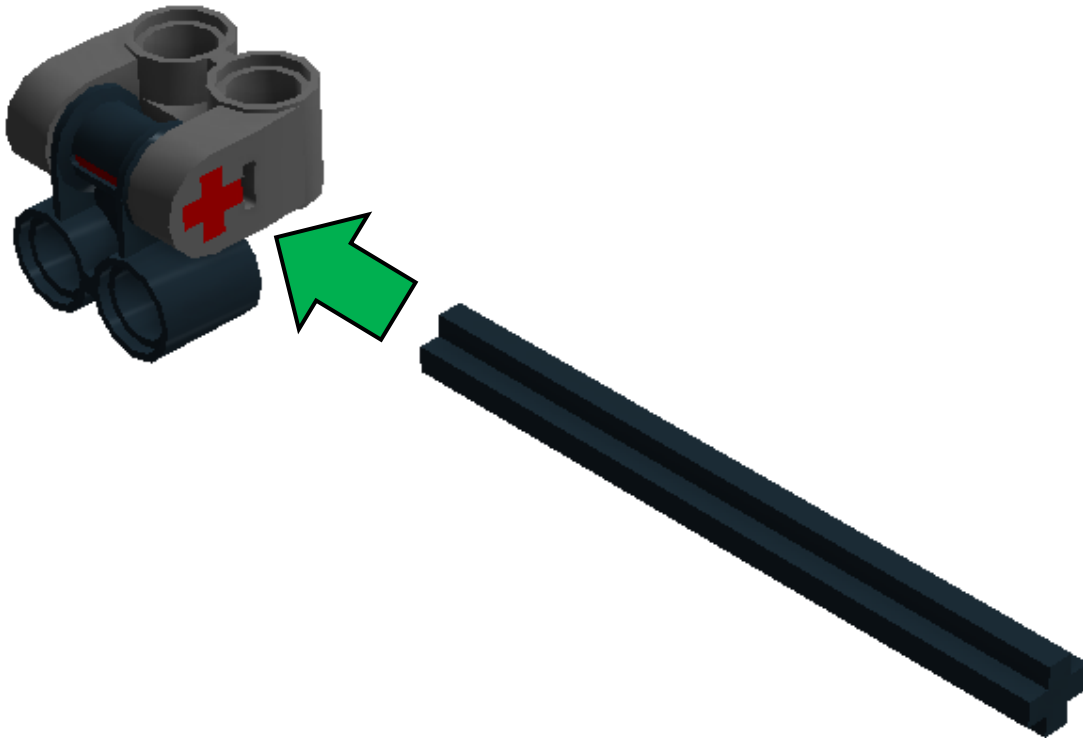
Cross block combinations

- ▶ This combination of cross blocks also allows mounting two beams at a right angle.



Tip for removing small cross axle connector

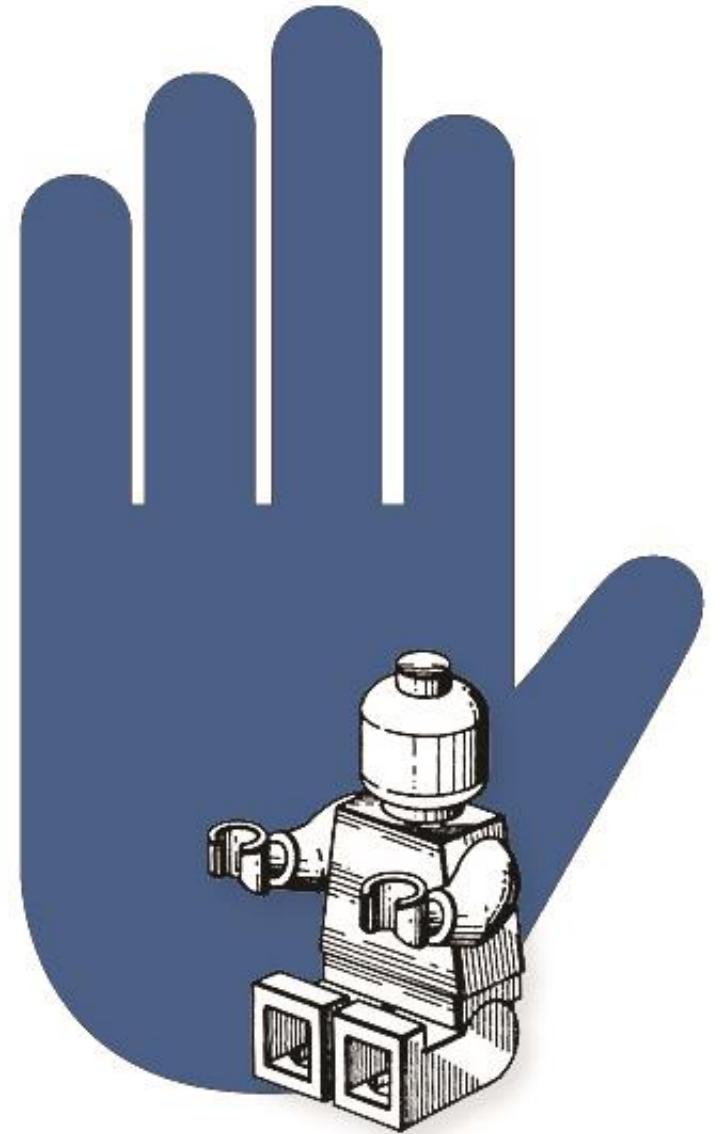
- ▶ Use long axle to push small axle through.



601172 Brick
Separator

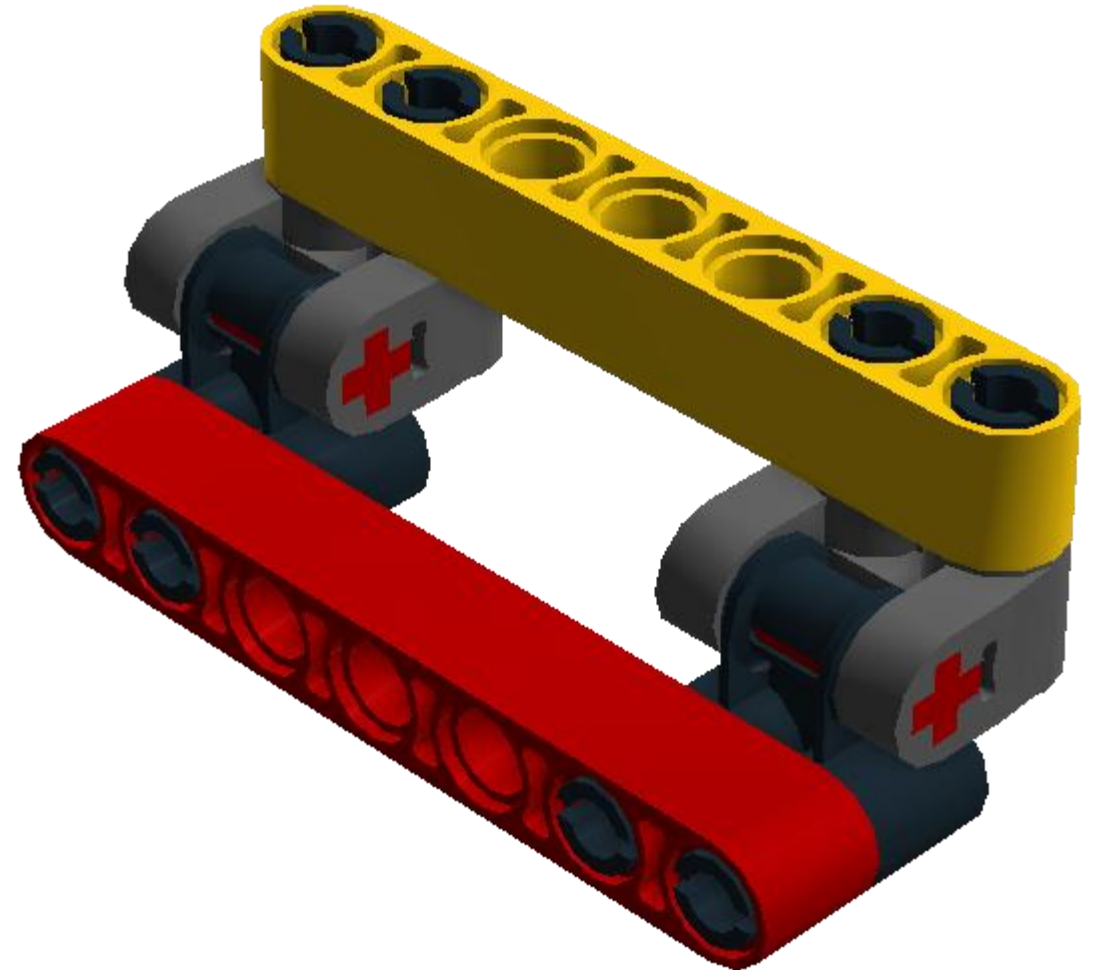
Cross blocks

- Hands-on activity



Cross blocks: Hands-on parts needed

- ▶ 7M beams (2)
- ▶ Technic Cross Block 2X1 (Mickey) (2)
- ▶ Technic Cross Block Fork 2X2 (Minnie) (2)
- ▶ Black peg with Friction (8)
- ▶ 2M Cross Axle with Groove (2)



Cross block building instructions

1. Align Technic Cross Block 2X1 (Mickey) with Technic Cross Block Fork 2X2 (Minnie).
2. Insert 2M Cross Axle with Groove.
3. Repeat to make a second cross block assembly.



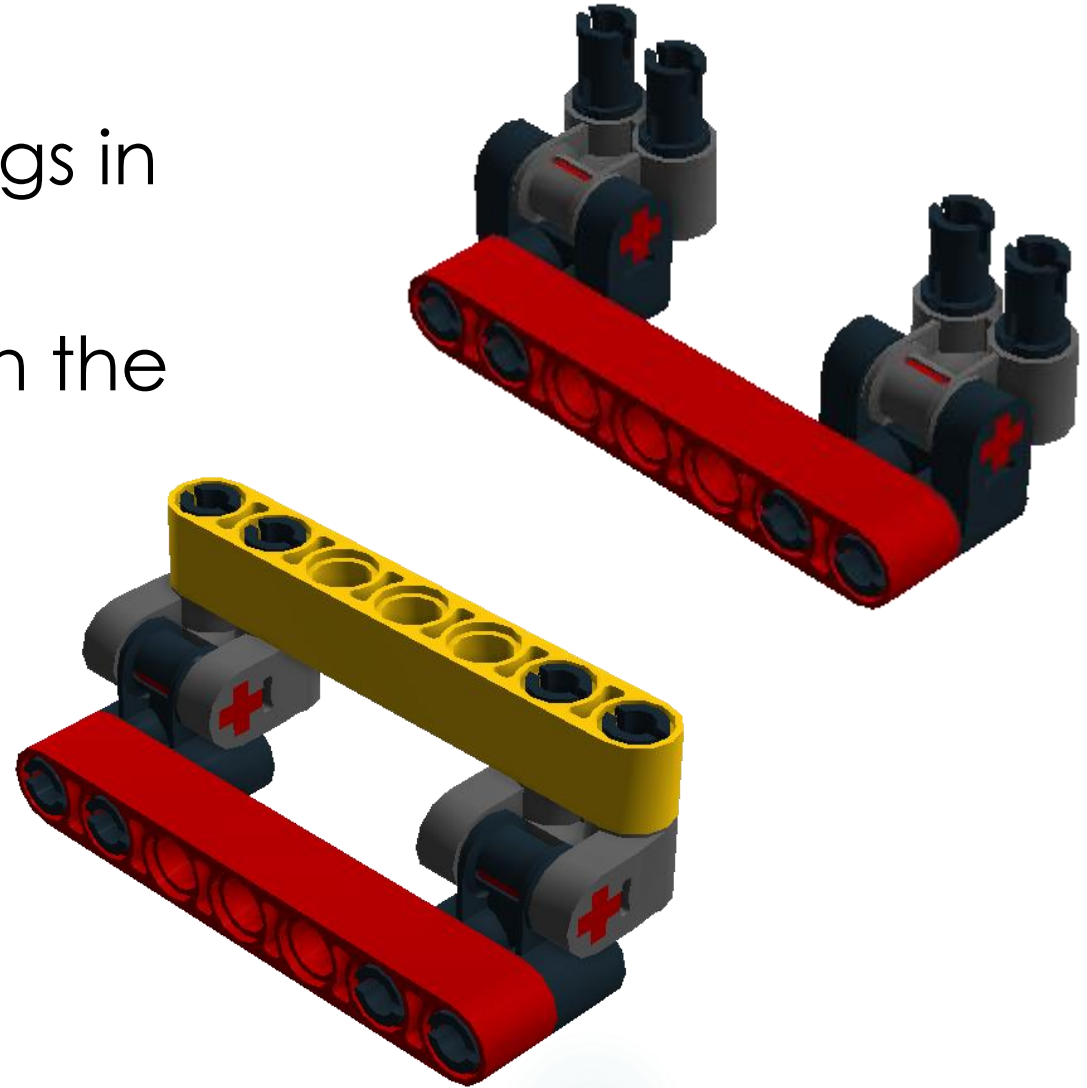
Cross block building instructions

4. Insert four black pegs into the cross block assembly.
5. Repeat on second cross block assembly.



Cross blocks building Instructions

6. Place 7M beam on the pegs in cross blocks.
7. Place second 7M beam on the pegs in cross blocks.



Bracing

- ▶ LEGO® pieces are designed to separate when pulled. When intentional it is called disassembly.
- ▶ Sometimes assemblies pull apart unintentionally simply sitting there or while operating. This is called structural failure.
- ▶ One solution for structural failure is bracing. Bracing can add strength with minimum weight increase.

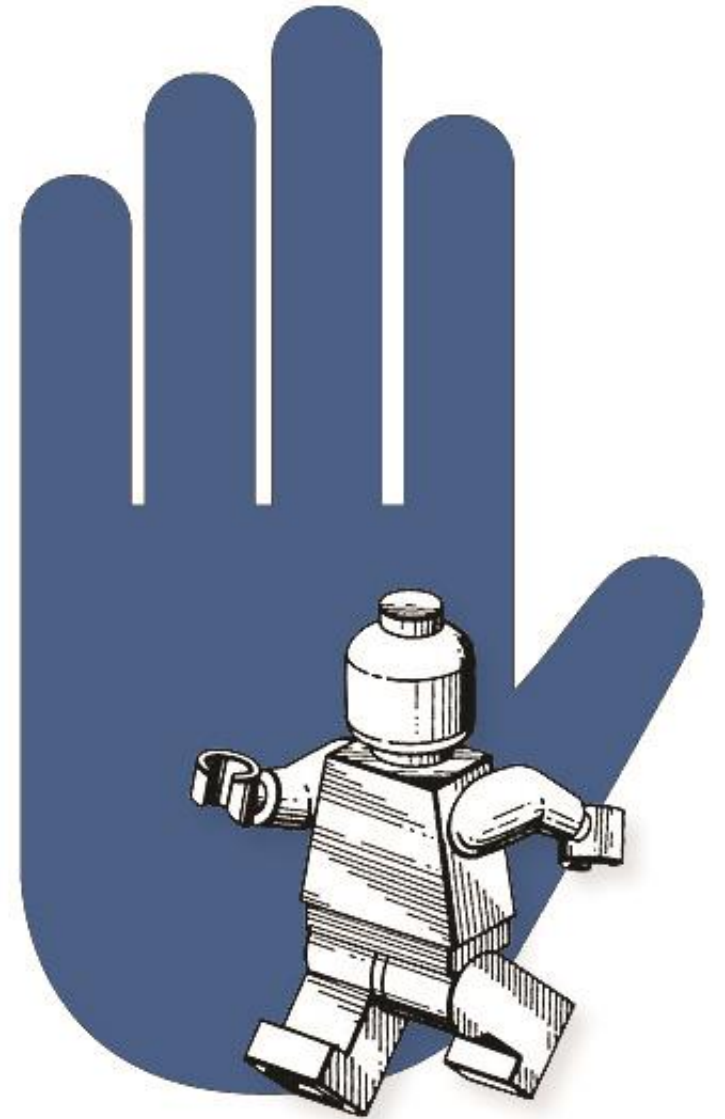
Bracing – Sample 1

- ▶ Bracing uses combinations of LEGO® parts at right angles.



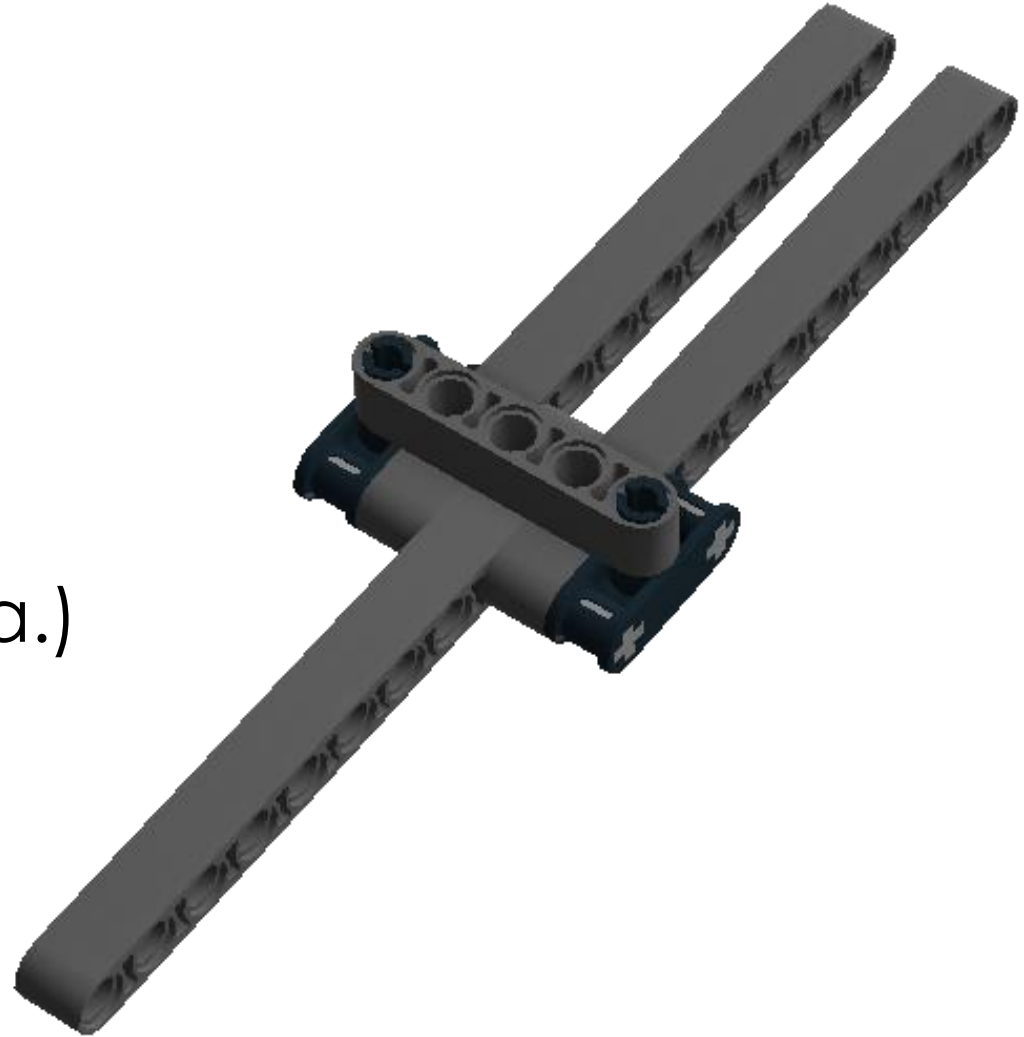
Bracing

- ▶ Hands-on activity



Bracing: Hands-on parts needed

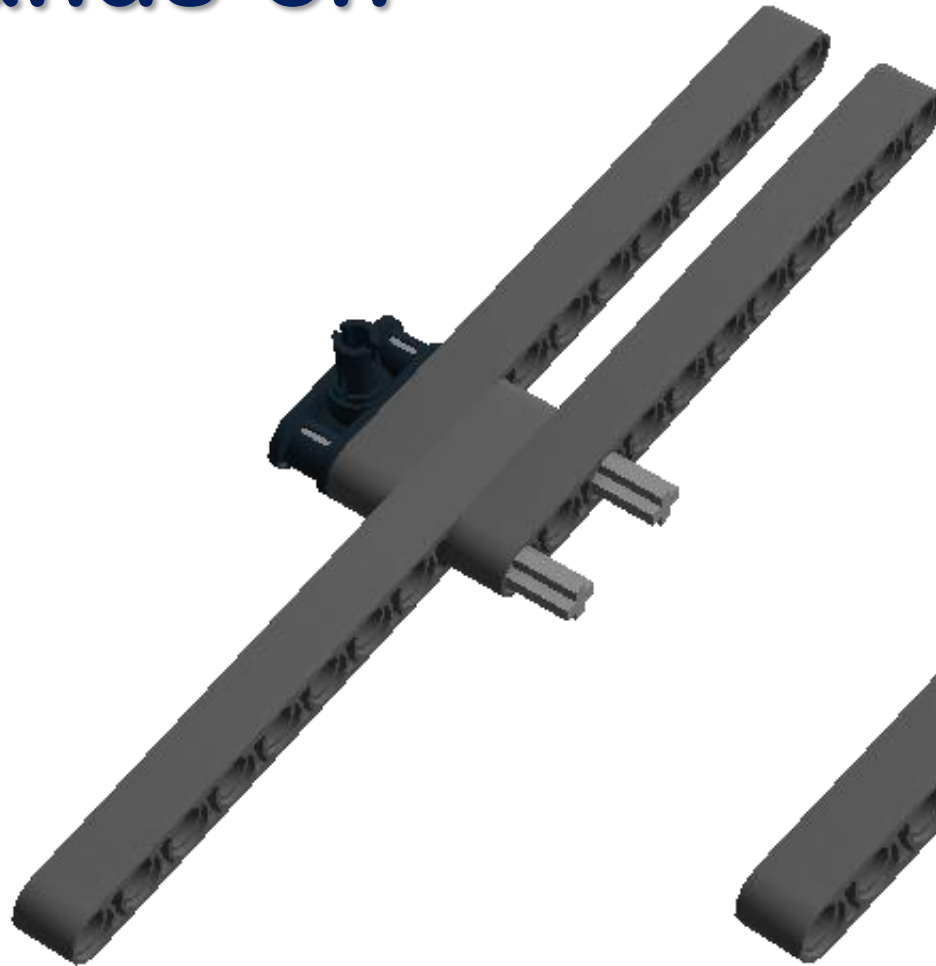
- ▶ 11M beams (3 ea.)
- ▶ 5M beam (1 ea.)
- ▶ Double cross block (2 ea.)
- ▶ 5M axle (2 ea.)
- ▶ Black peg with friction (2 ea.)



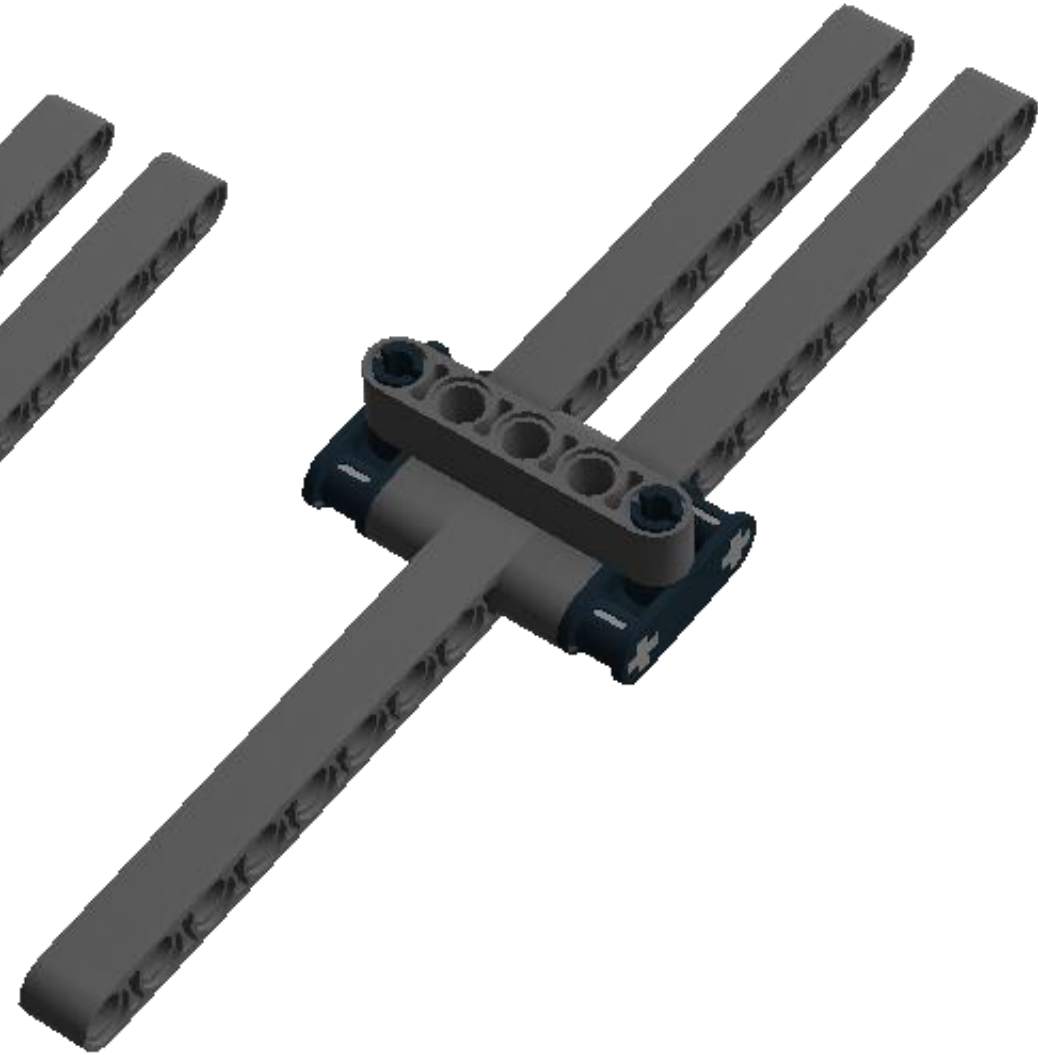
Bracing: Hands-on



Step 1

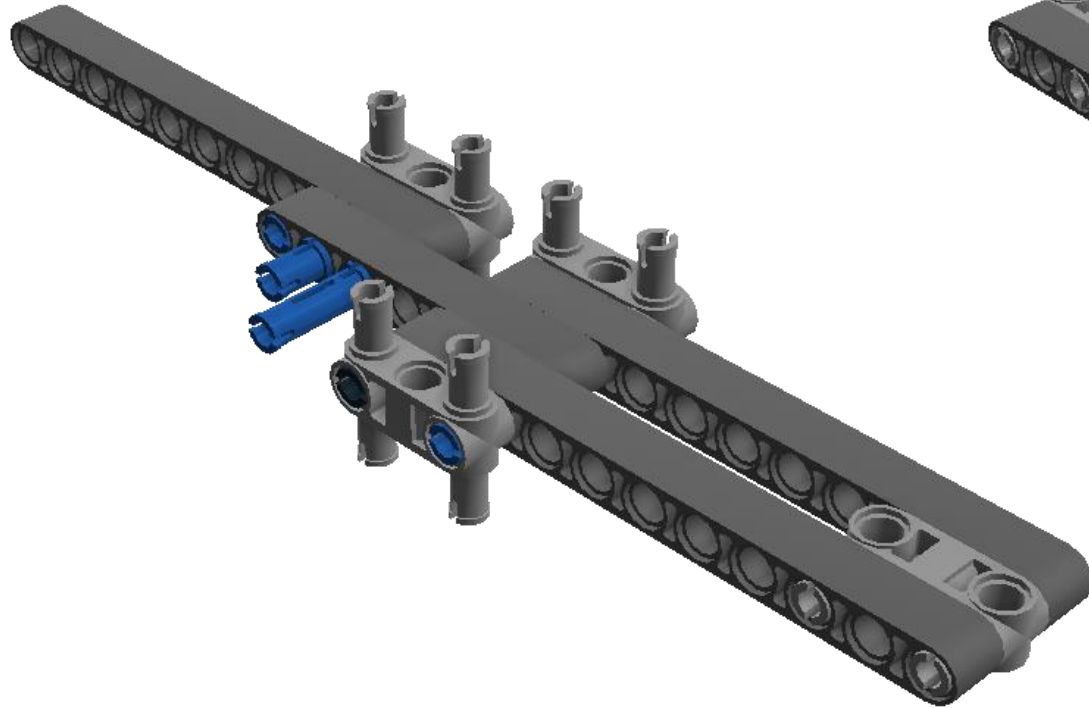


Step 2

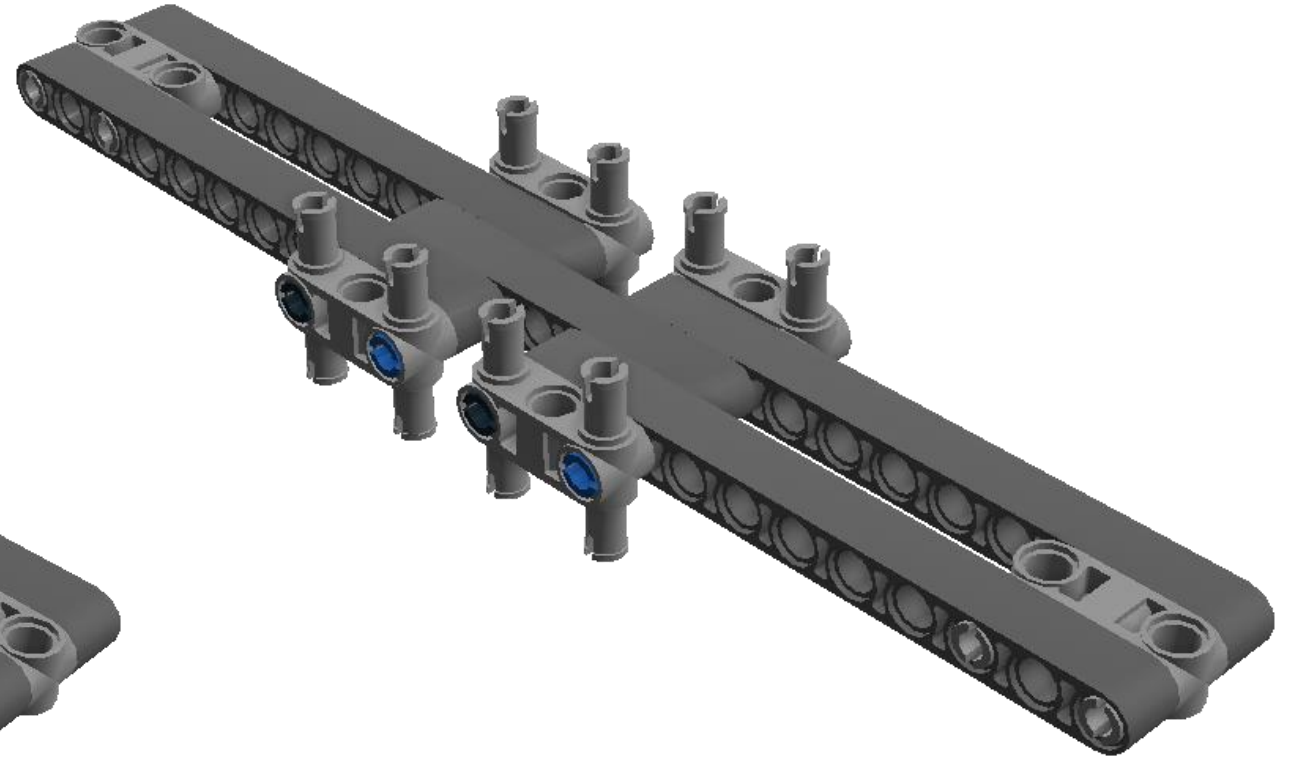


Step 3

Bracing – Sample 2

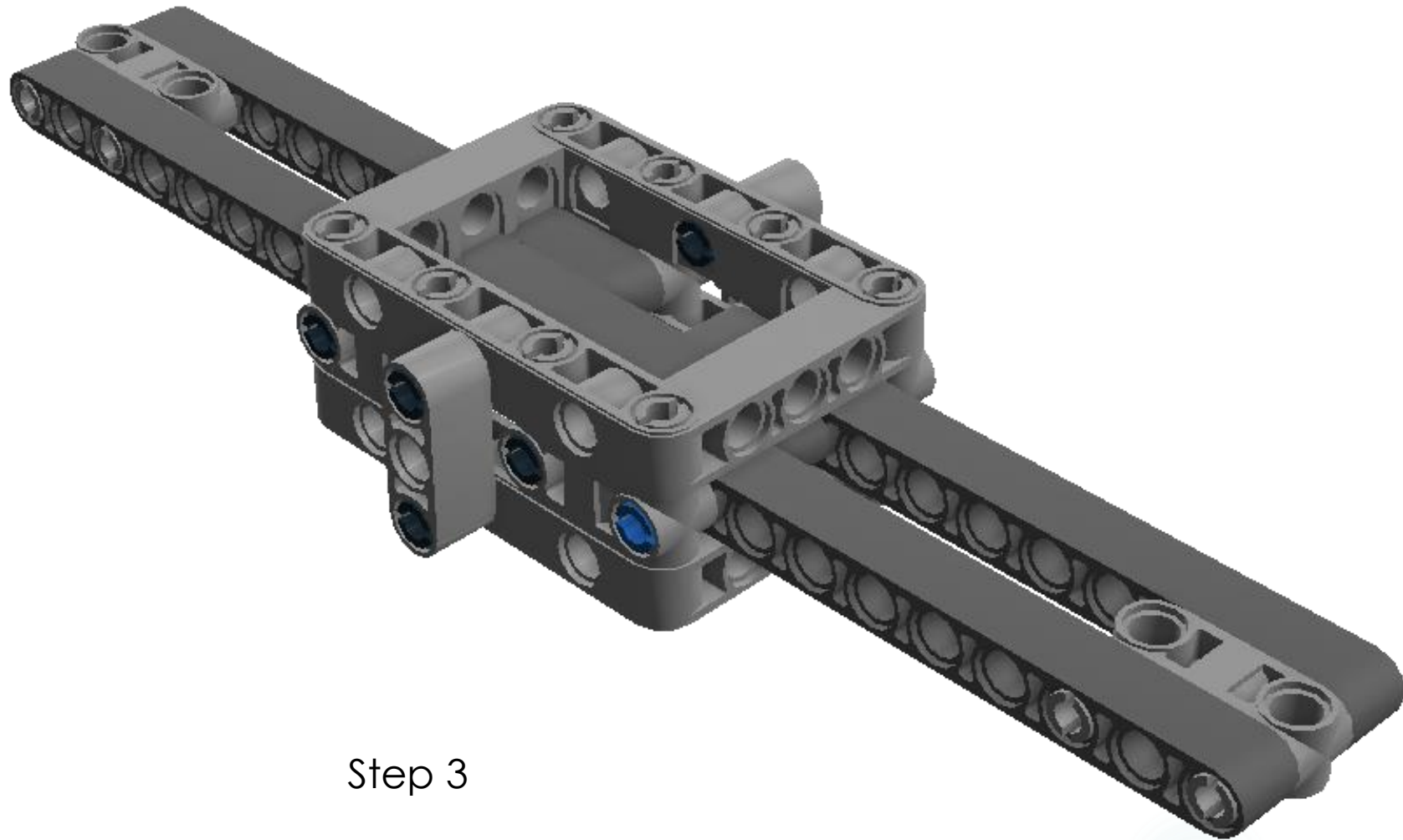


Step 1



Step 2

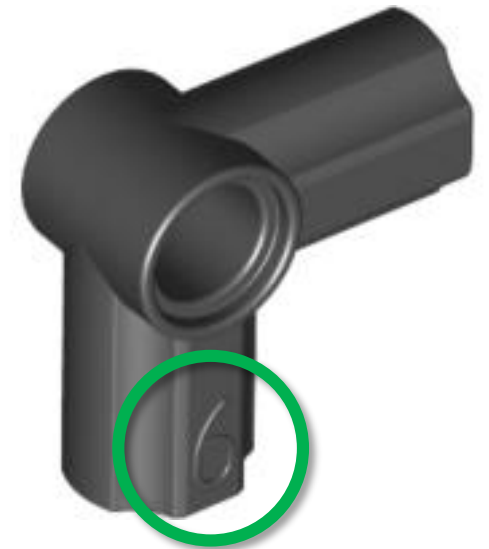
Bracing – Sample 2



Step 3

Axle connectors

- ▶ 4107085: Angle Element, 0 Degrees [1]
- ▶ 4107783: Angle Element, 180 Degrees [2]
- ▶ 4107767: Angle Element, 90 Degrees [6]
- ▶ 4513174: Cross Axle, Extension, 2M
- ▶ 4526985: Tube W/Double Ø4.85



Axle connectors are identified with a number



Angle Element,
0 Degrees [1]



Angle Element,
180 Degrees [2]



Angle Element,
90 Degrees [6]



Cross Axle,
Extension, 2M



Tube W/Double
Ø4.85



Gears

Gears

- ▶ Gears are rotating parts with teeth that mesh with other parts with teeth.
- ▶ LEGO® gears are identified by the number of teeth followed by a “z”.
- ▶ Most gears are 1M thick



Combination Reference: <http://gears.sariel.pl/>

Gears

- ▶ 6012451 - Gear Wheel 8z
- ▶ 4177431 - Double Conical Wheel 12z
- ▶ 4640536 - Gear Wheel 16z
- ▶ 4514558 - Gear Wheel 24z
- ▶ 4285634 - Gear Wheel 40z



Gear Wheel 8z



Double Conical
Wheel 12z



Gear Wheel 16z



Gear Wheel 24z



Gear Wheel 40z

Gears

- ▶ 4565452 - Conical Wheel 12z
- ▶ 4177430 - Double Conical Wheel 20z 1M
- ▶ 4255563 - Double Conical Wheel 36z
- ▶ 4211510 - Worm gear



Conical Wheel 12z



Double Conical
Wheel 20z 1M



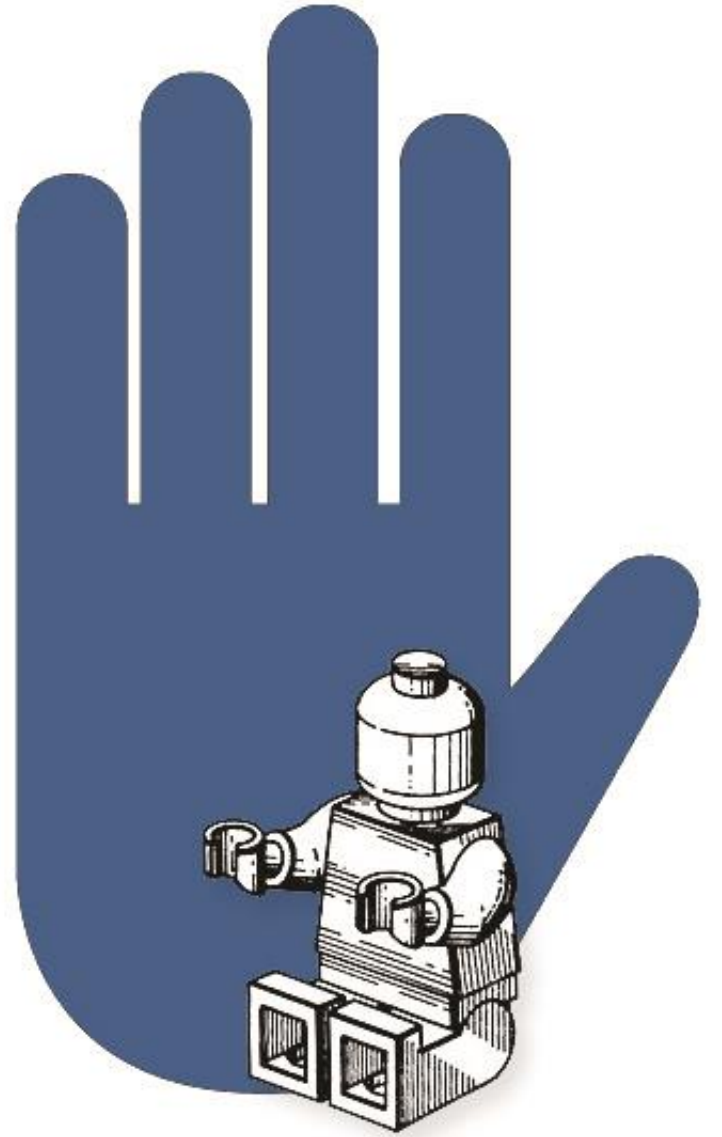
Double Conical
Wheel 36



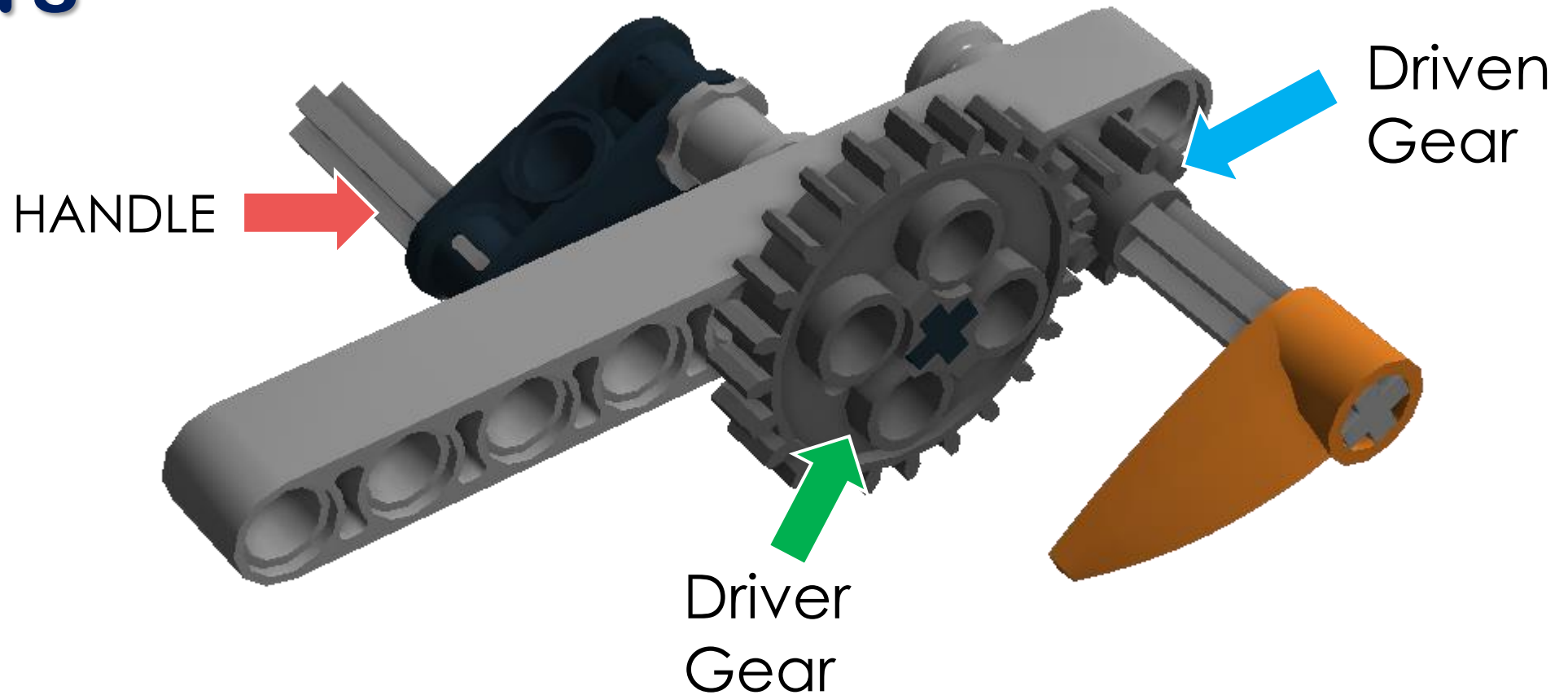
Worm gear

Gears

- Hands-on activity



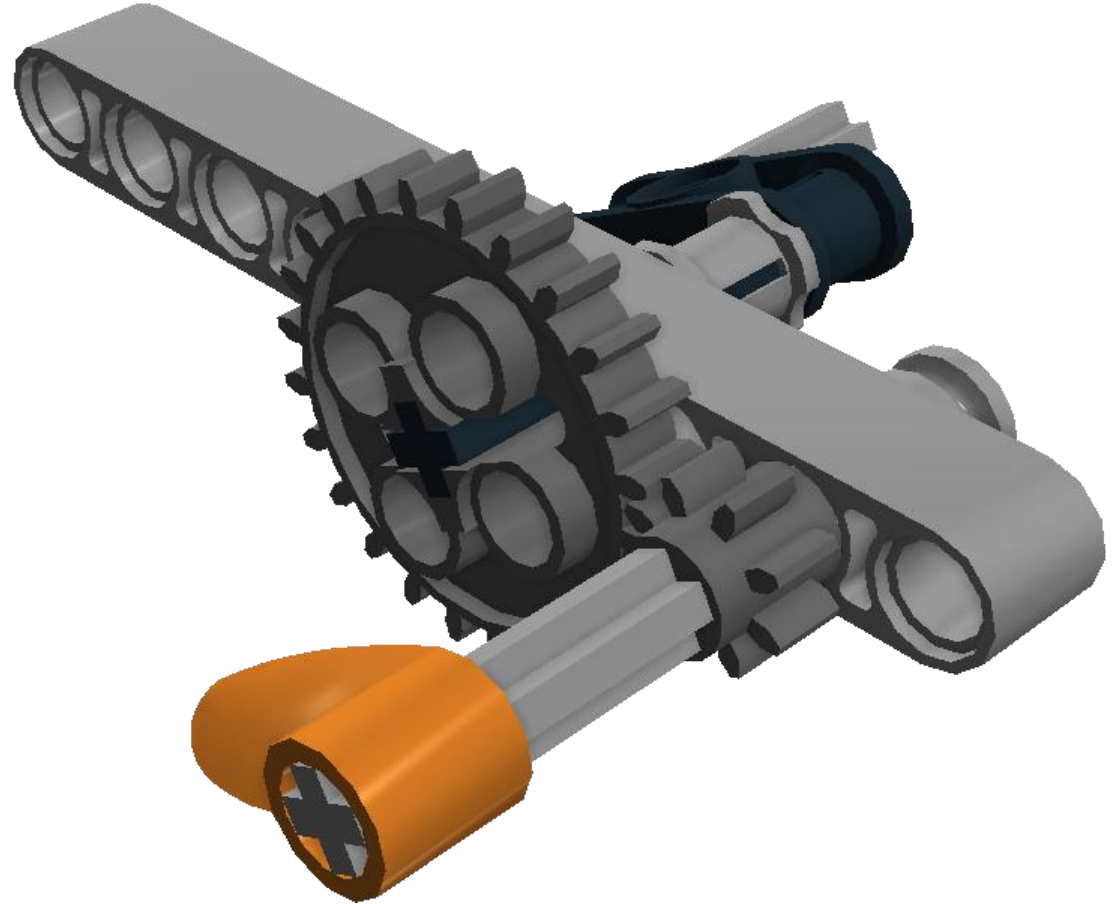
Gears



Gear Ratio: the difference between the rates at which the last (driven) and first (driver) gears rotate.

Gears: Hands-on parts needed

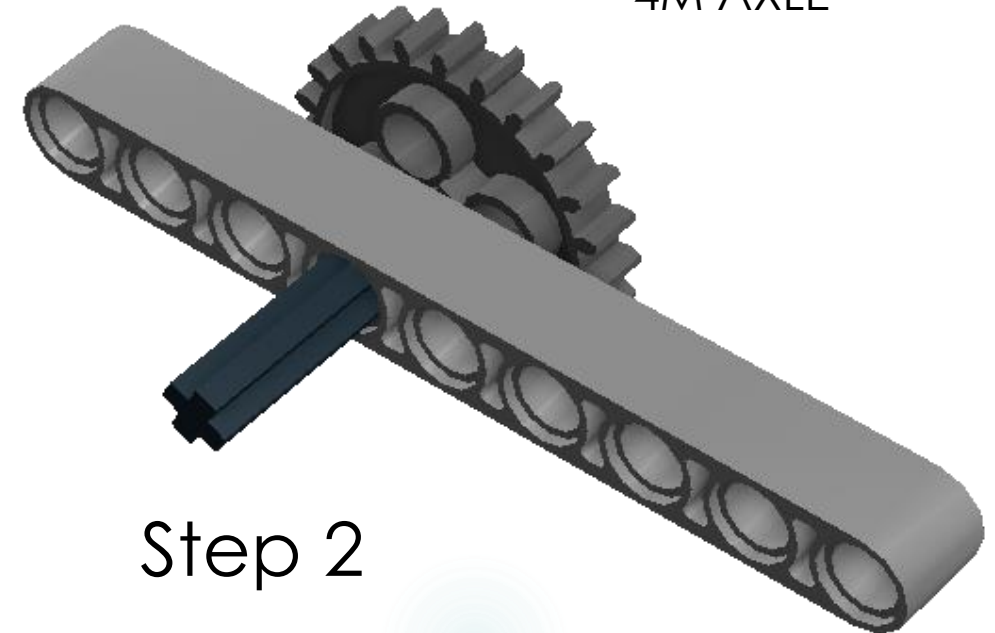
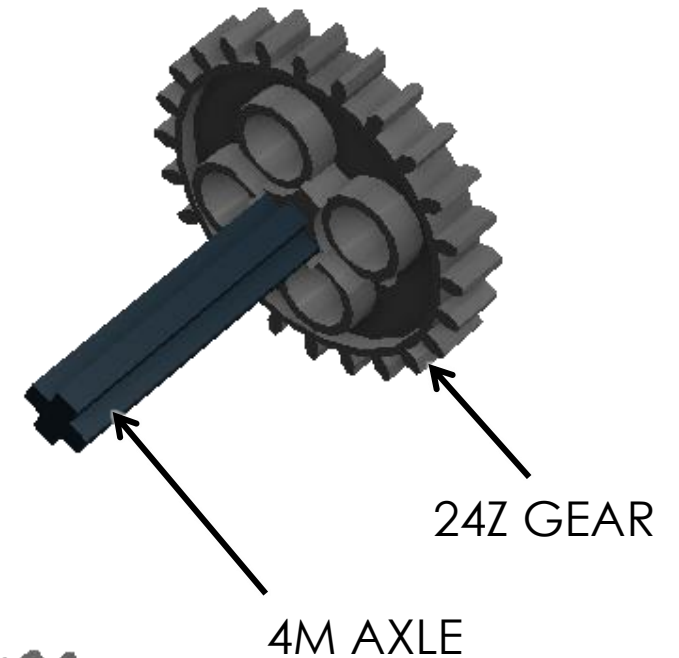
- ▶ 24z gear
- ▶ 8z gear
- ▶ 3m axle
- ▶ 4m axle
- ▶ 5m axle
- ▶ Double Cross Block
- ▶ Bionicle Eye
- ▶ Half-bushing
- ▶ bushing



Gears: Building instructions

1. Insert 4M axle into the 24z gear.
2. Insert the gear assembly through the fourth hole in the beam.

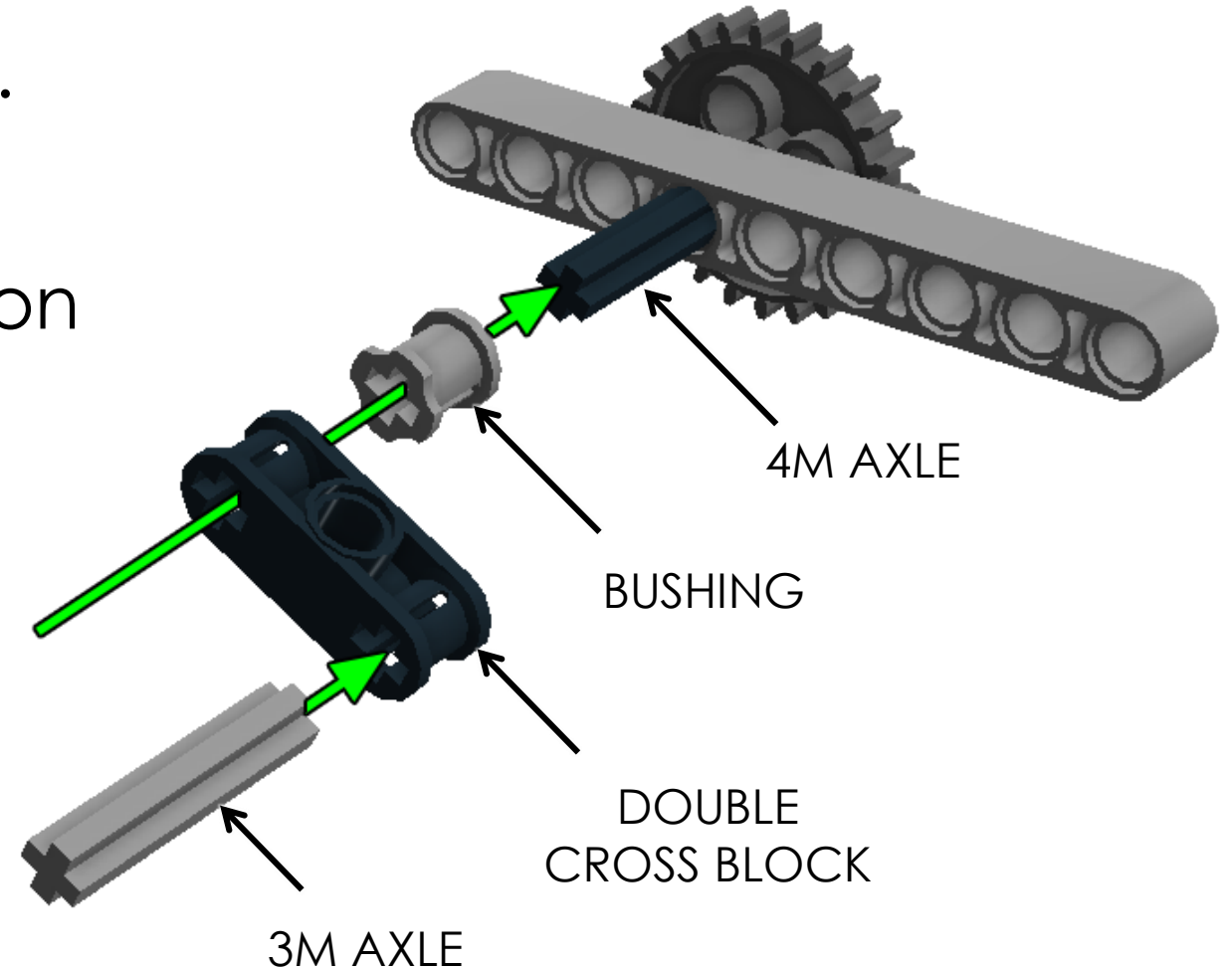
Step 1



Step 2

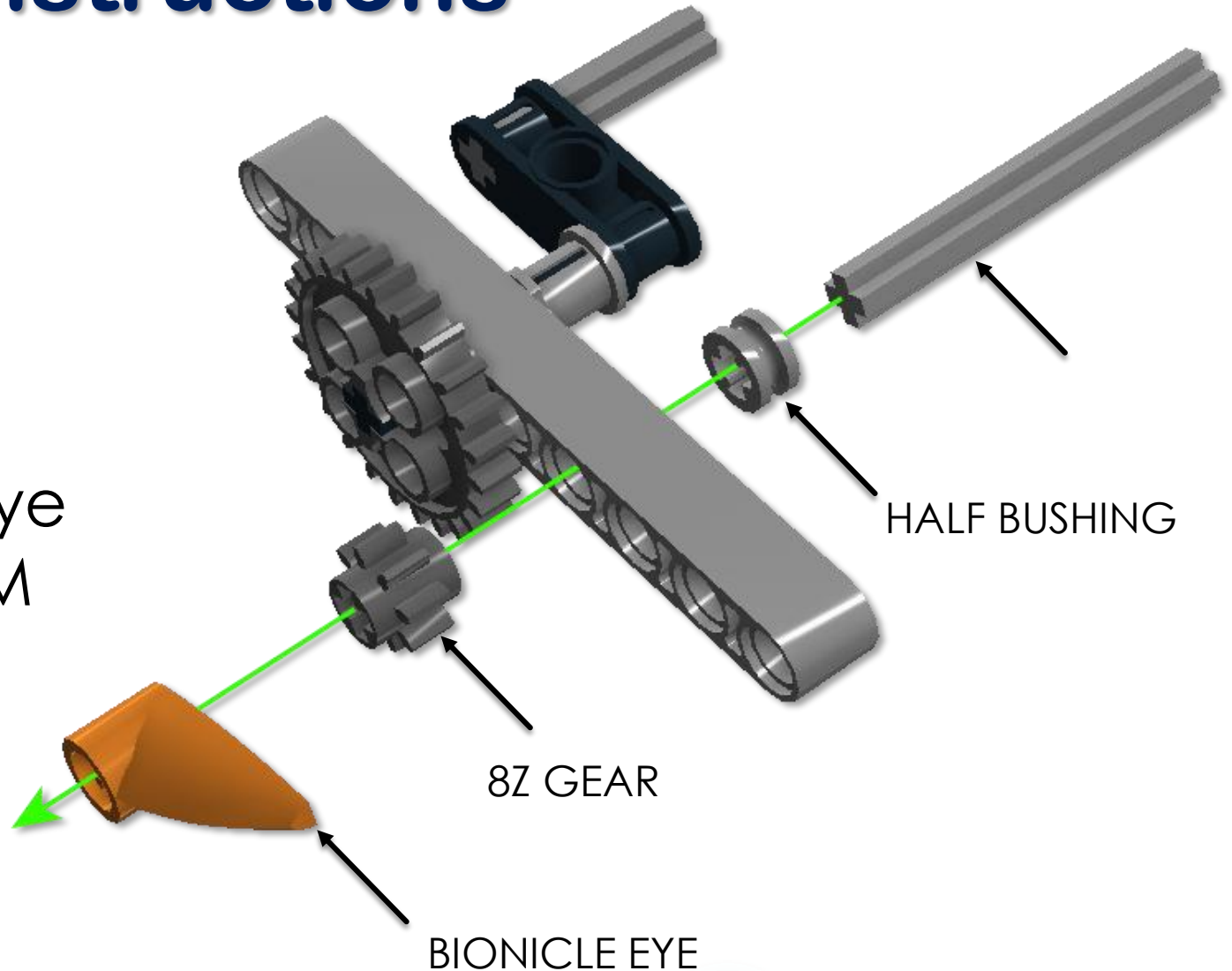
Gears: Building instructions

3. Install bushing on the axle.
4. Install double cross block on the axle behind the bushing.
5. Insert the 3M axle into the other end of the double cross block.



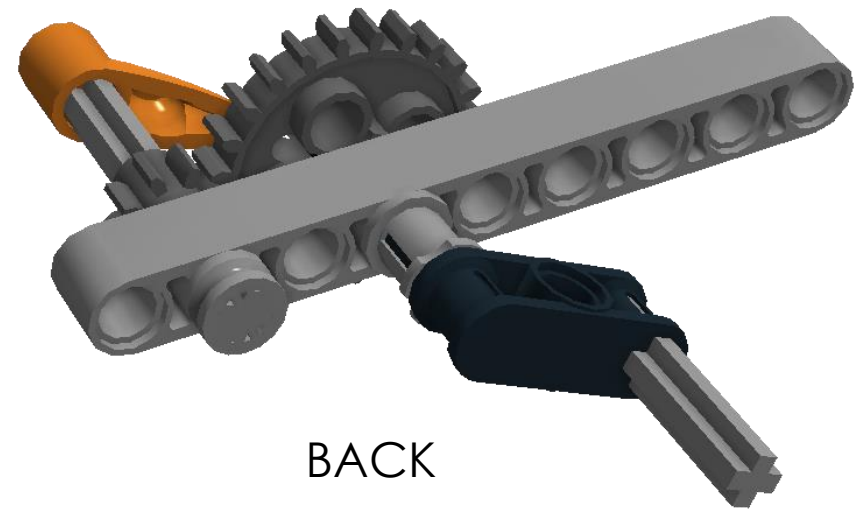
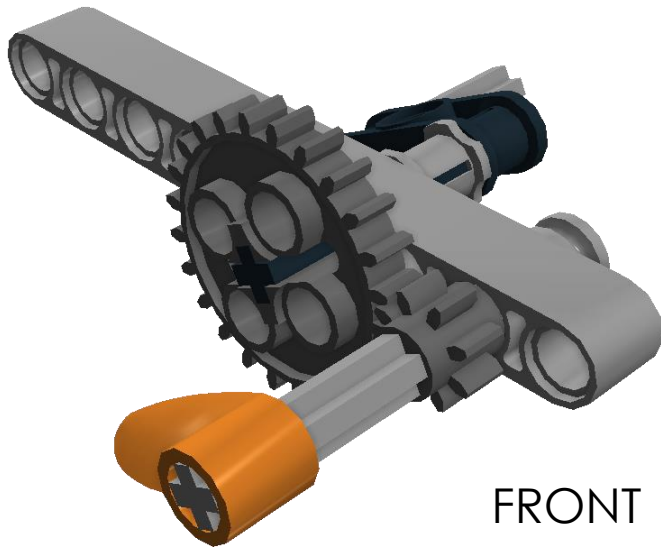
Gears: Building instructions

6. Insert a 5M axle through the half bushing, the beam, and the 8z gear.
7. Install the bionicle eye on the end of the 5M axle.



Gears: Build Check

Does your project look like this?



How is gear ratio calculated?

A simple equation is used to find the ratio of your gearing system:

$$\frac{\text{Number of Teeth on the Driven gear}}{\text{Number of Teeth on the Driver gear}}$$

For this example:

$$\text{Driven gear } 8z / 24z \text{ Driver gear} = 1/3 \text{ or } 1:3$$

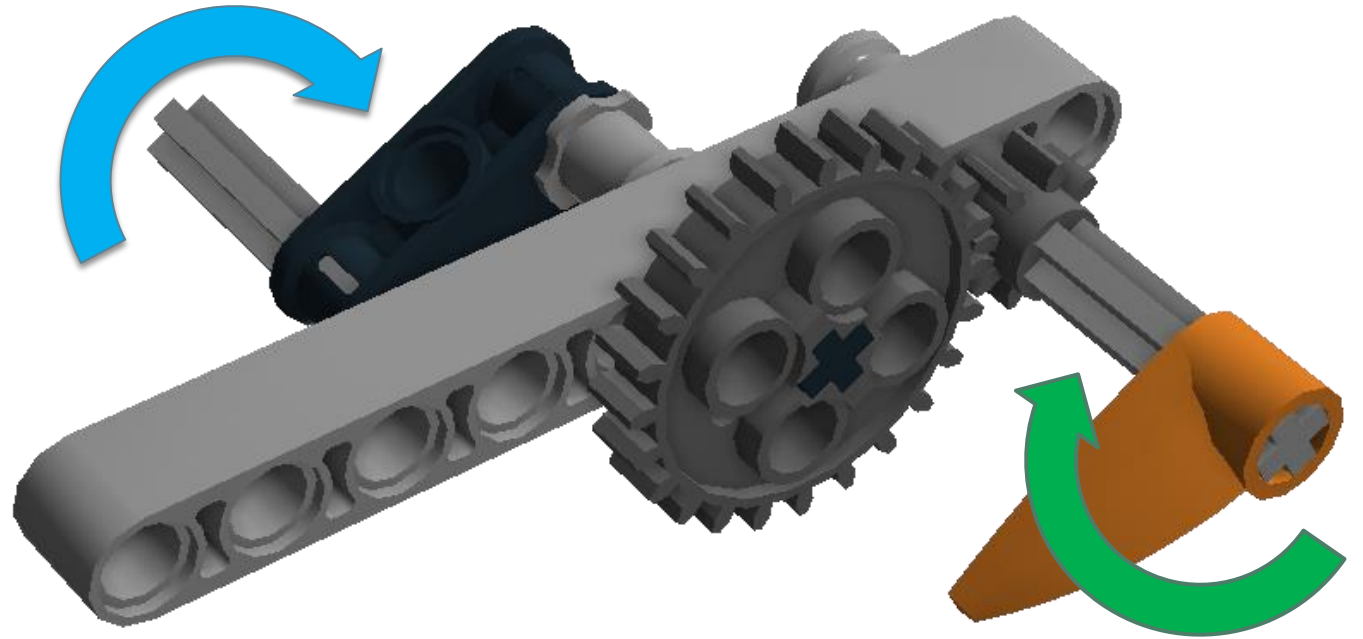
How is gear ratio expressed?

- ▶ Gear Ratios are expressed as fractions and can be written a number of ways:
 - ▶ 1 to 3
 - ▶ $1/3$
 - ▶ 1:3 most commonly used
- ▶ Remember that the driven gear will turn in the opposite direction of the driver gear

Gear ratio: Testing

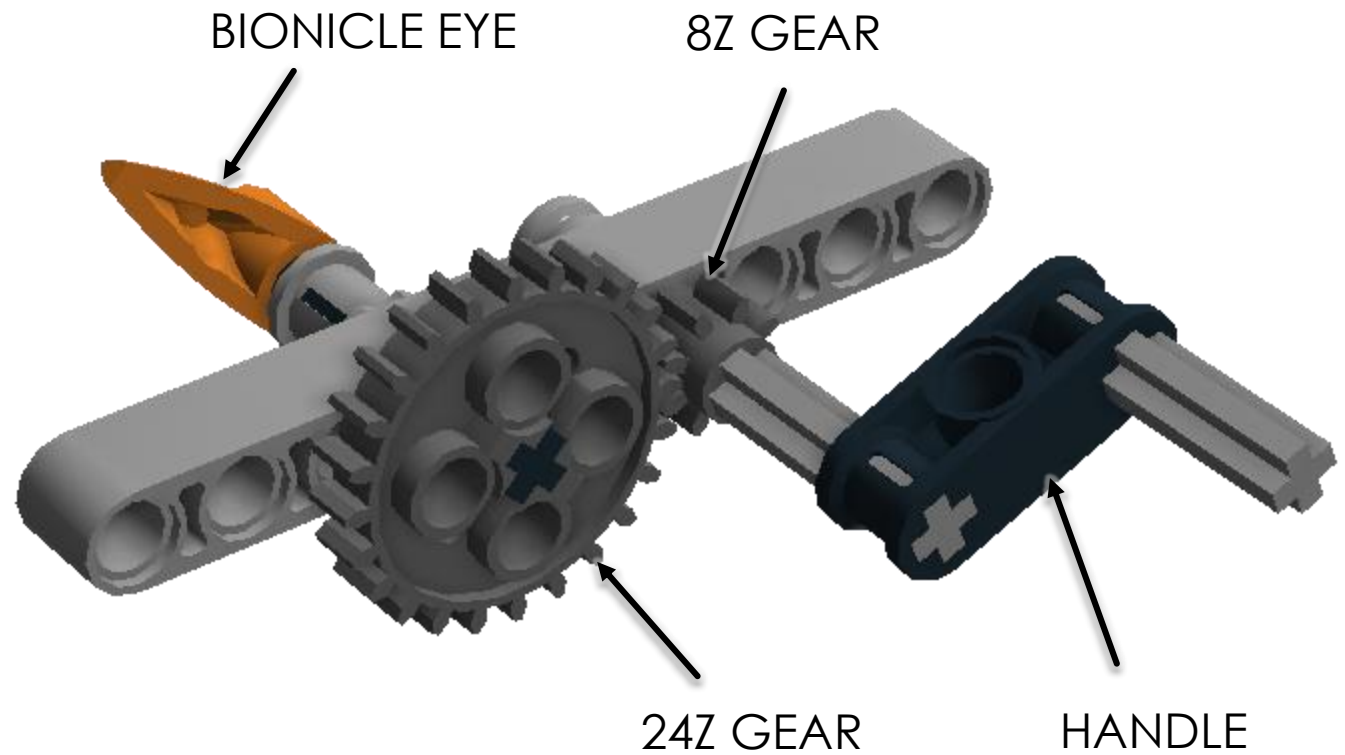
- ▶ Turn the crank slowly one rotation and count the number of rotation of the bionicle eye.

How many turns did
the bionicle eye make



Gear ratio: Testing

- Switch the handle and Bionicle eye.



How many turns did
the bionicle eye make ?

Gear combinations

Teeth	8	12	16	20	24	36	40
8	1:1				1:3		1:5
12				3:5		1:3	
16			1:1				
20					5:6		
24					1:1		3:5
36							
40							1:1



Stable
combination



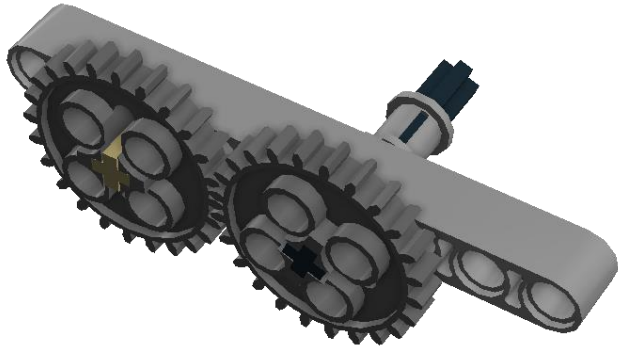
Unstable
combination



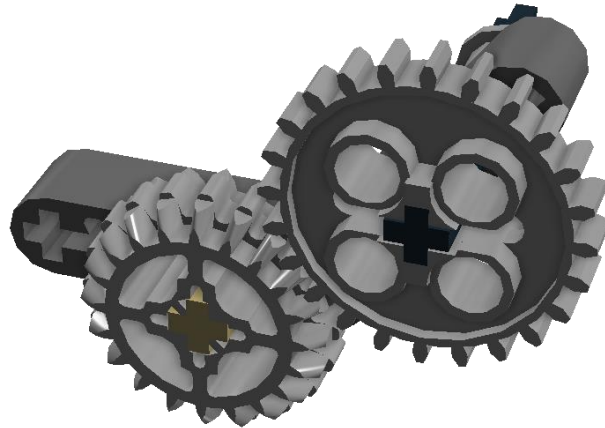
Unknown
Combination

Gear combinations

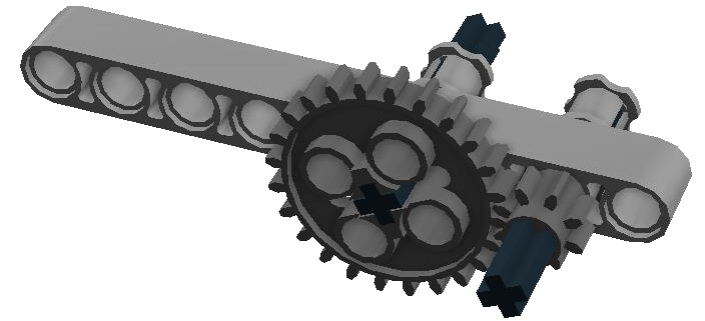
<http://gears.sariel.pl/>



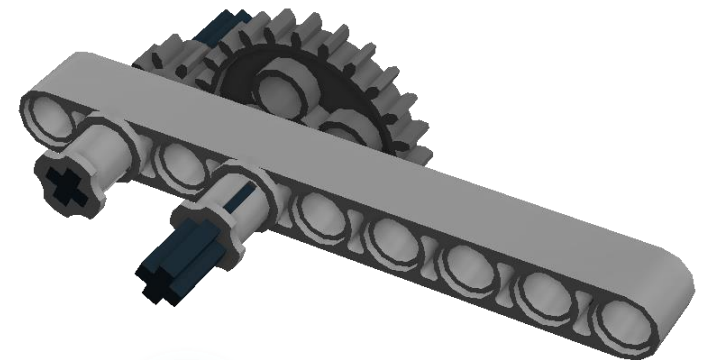
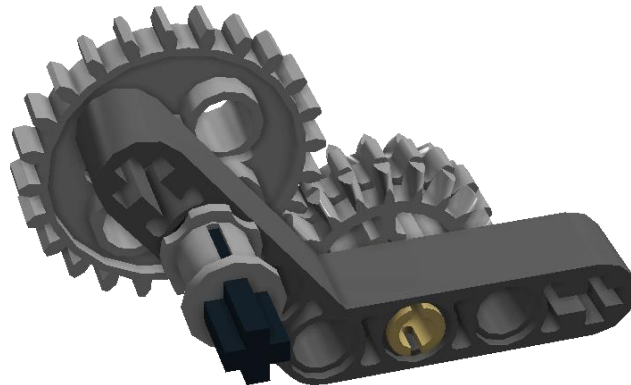
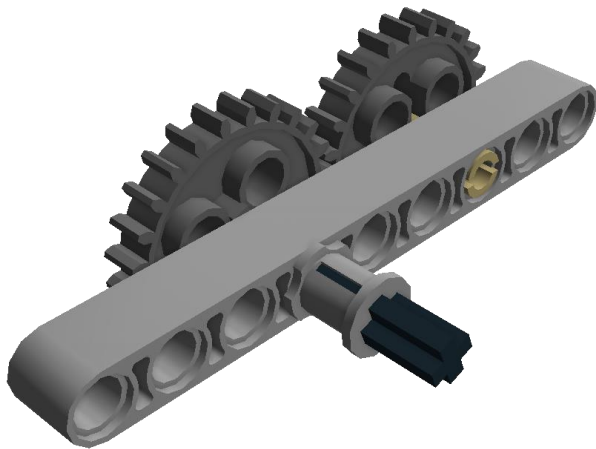
24z to 24z (1:1)



20z to 24z (5:6)



24z to 8z (3:1)



Gears: Motion Transfer

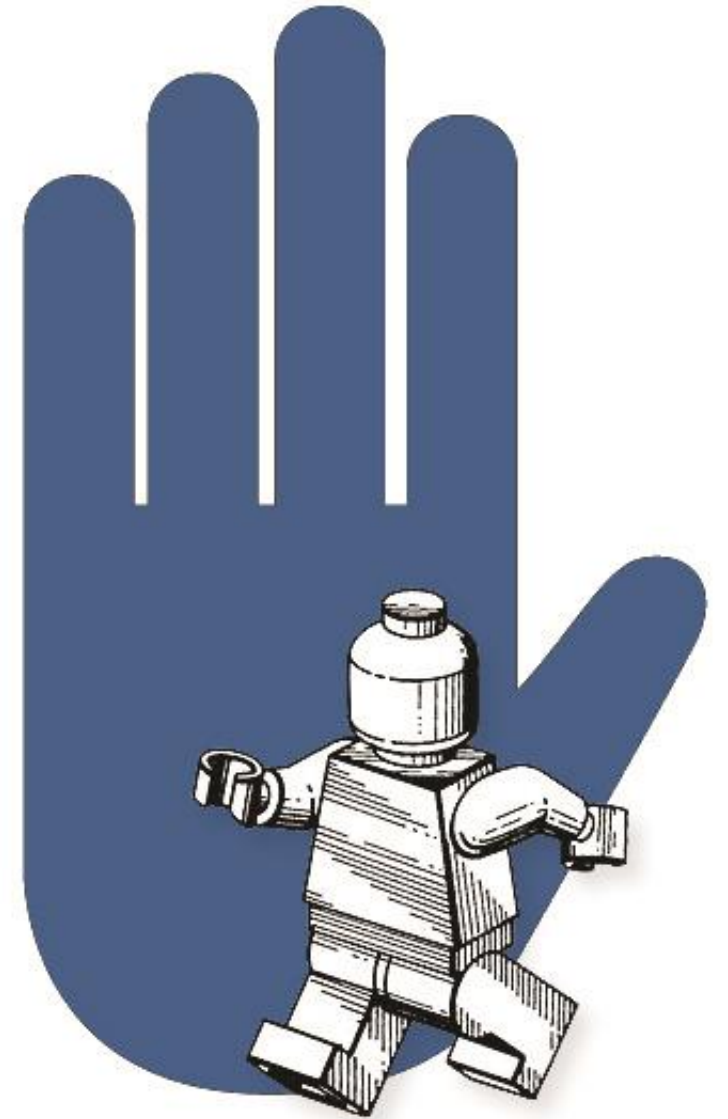
- ▶ Motion transfer is using a circular motion action to produce a linear motion.
- ▶ What is linear motion?



- ▶ How can you make linear motion using gears that turn in circles?

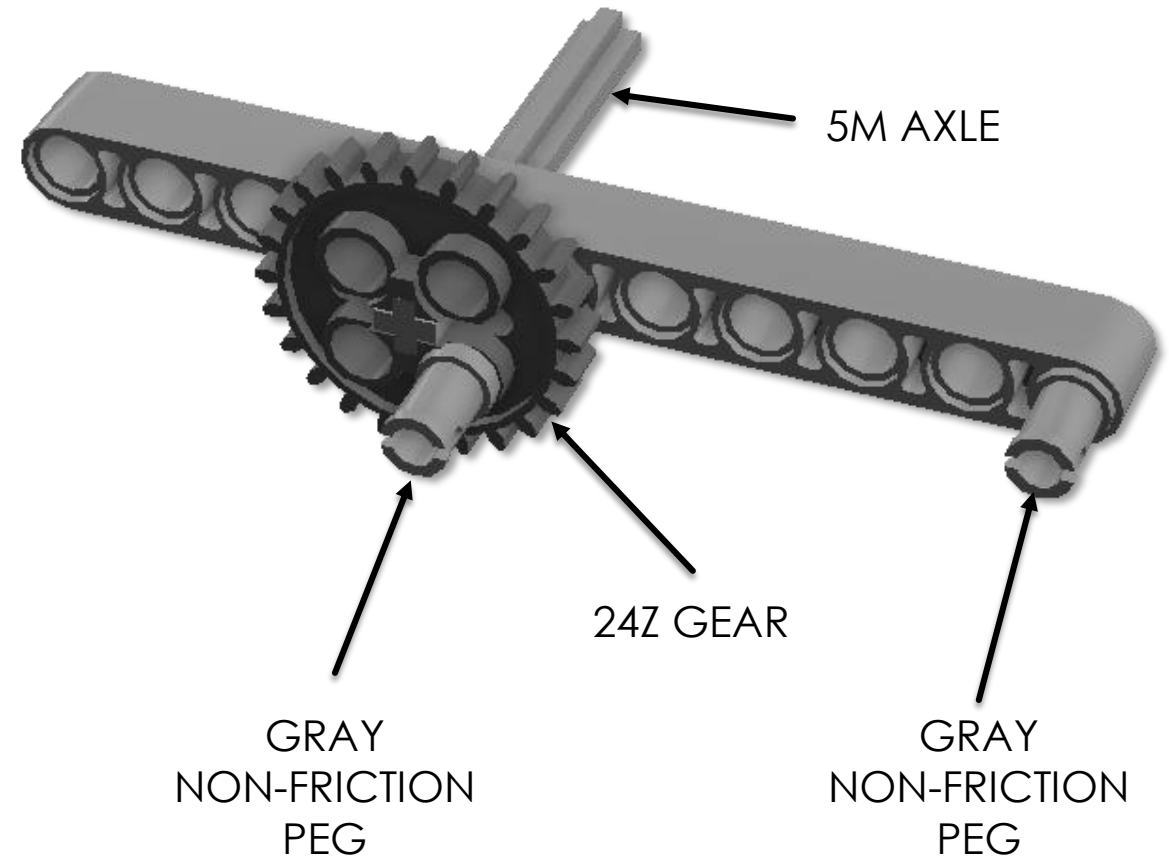
Motion Transfer

- ▶ Hands-on activity



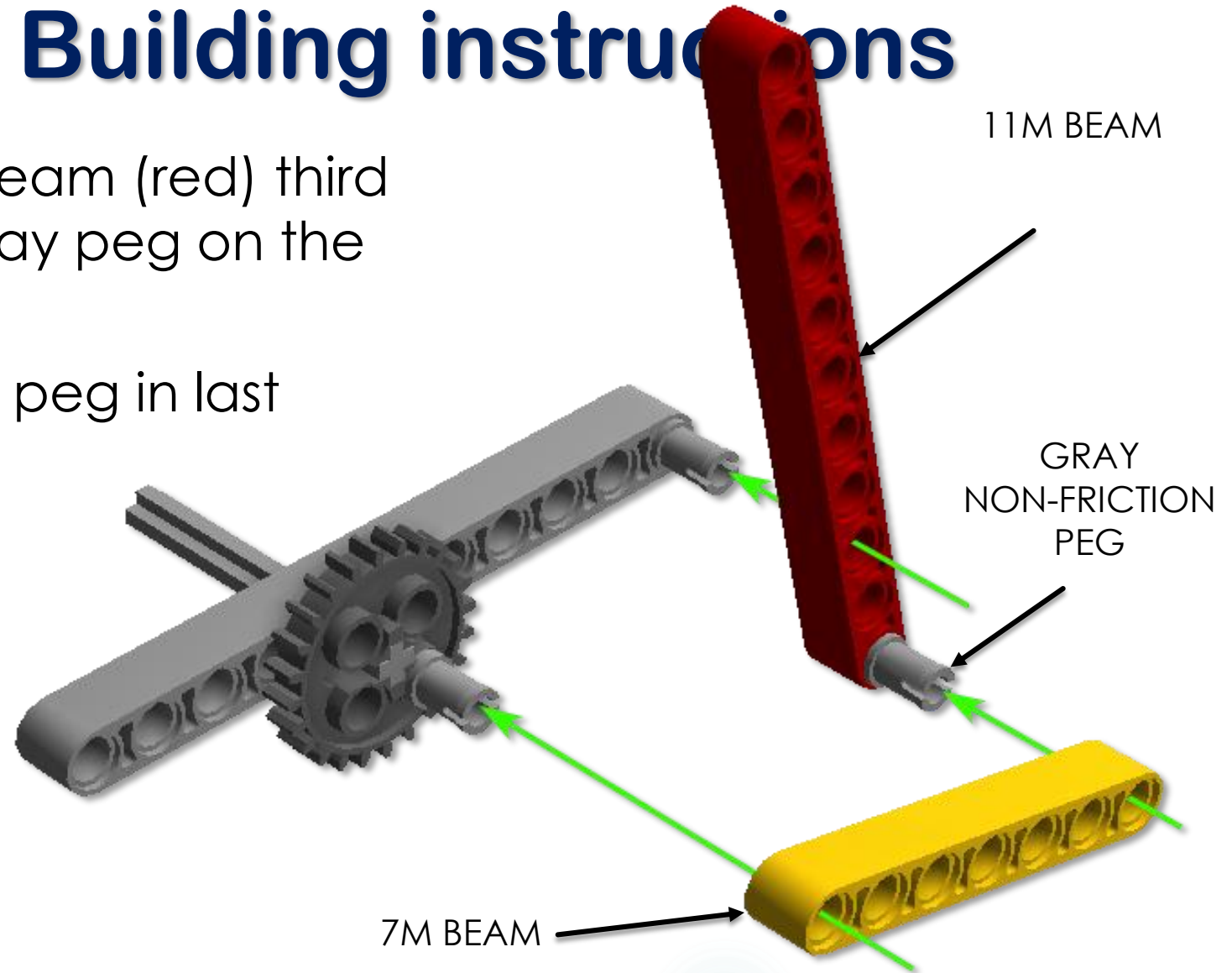
Motion Transfer: Building instructions

1. Place a 5M axle in a 24z gear.
2. Insert the 5M axle and gear into fifth hole in an 11M beam.
3. Insert gray non-friction peg into a hole on gear.
4. Insert gray non-friction peg in last hole on 11M beam on the long end.



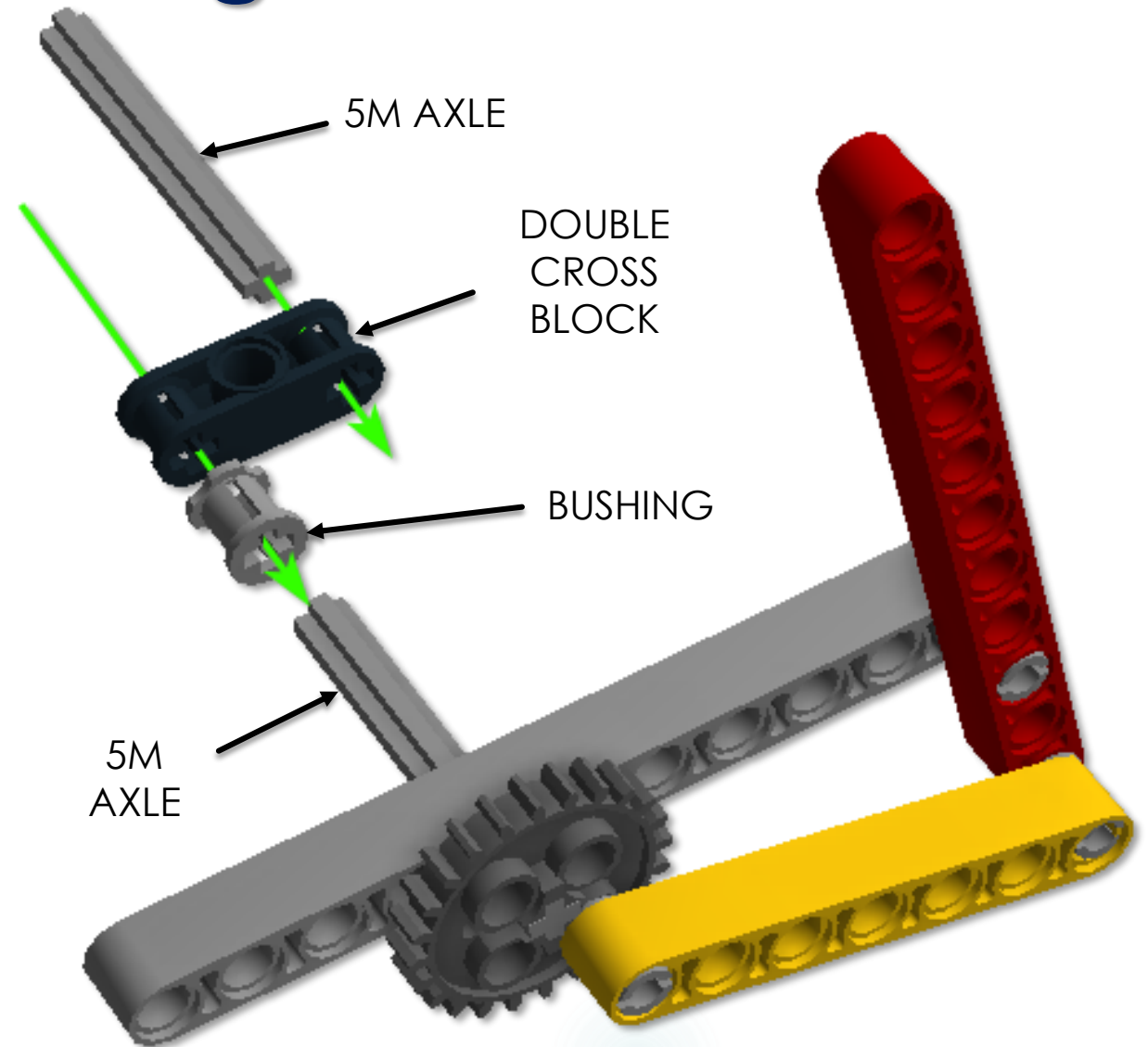
Motion Transfer: Building instructions

5. Insert a second 11M beam (red) third hole on non-friction gray peg on the first beam.
6. Insert gray non-friction peg in last hole of 7M beam.
7. Insert 7M beam (yellow) on gray non-friction pegs on gear and 11M beam (red).



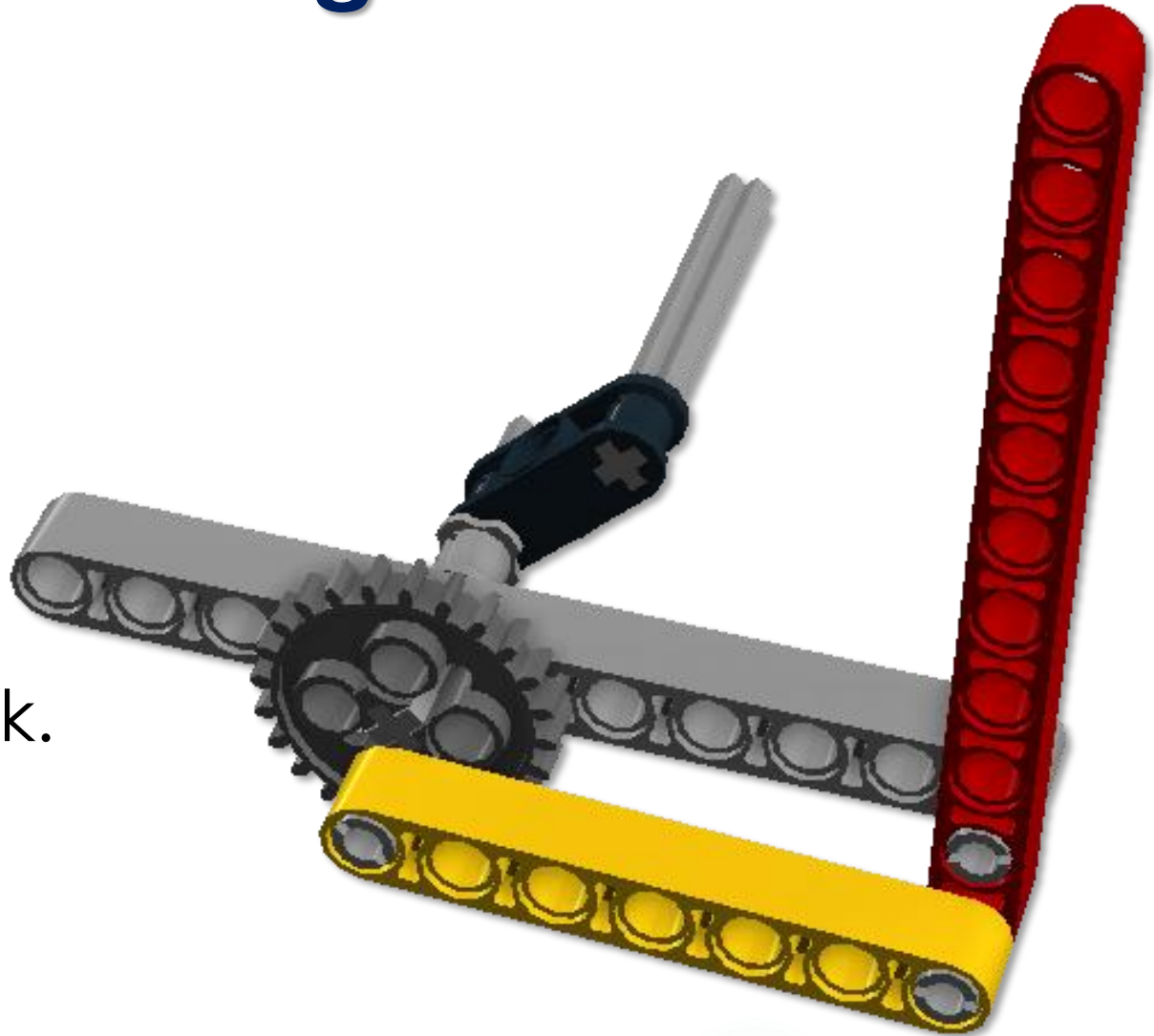
Motion Transfer: Building instructions

8. Insert bushing on 5M axle on the opposite side of 11M beam.
9. Insert double cross block on 5M axle.
10. Insert a 5M axle into double cross block.



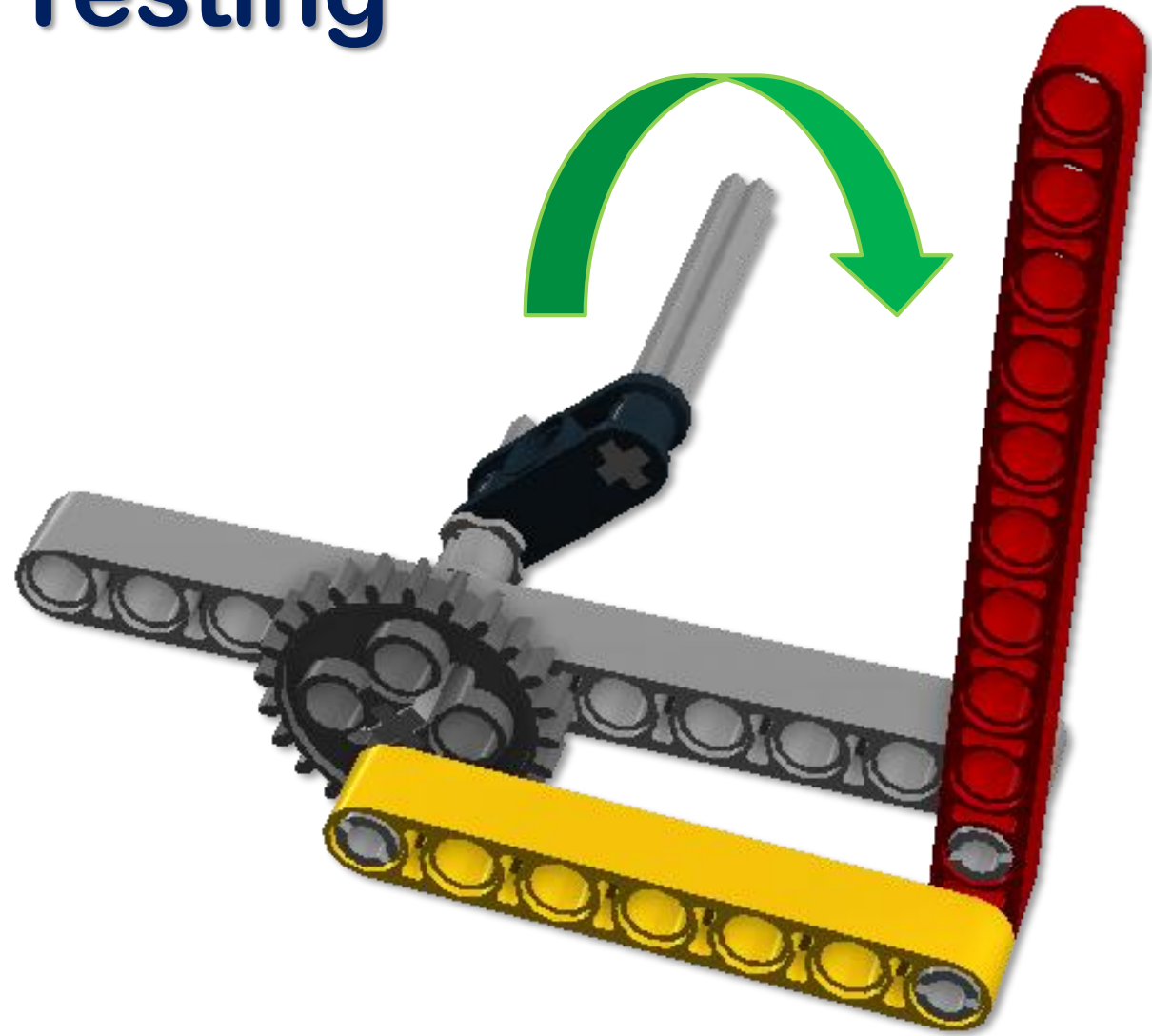
Motion Transfer: Building instructions

- ▶ Insert bushing on 5M axle on the opposite side of 11M beam.
- ▶ Insert double cross block on 5M axle.
- ▶ Insert second 5M axle into double cross block.



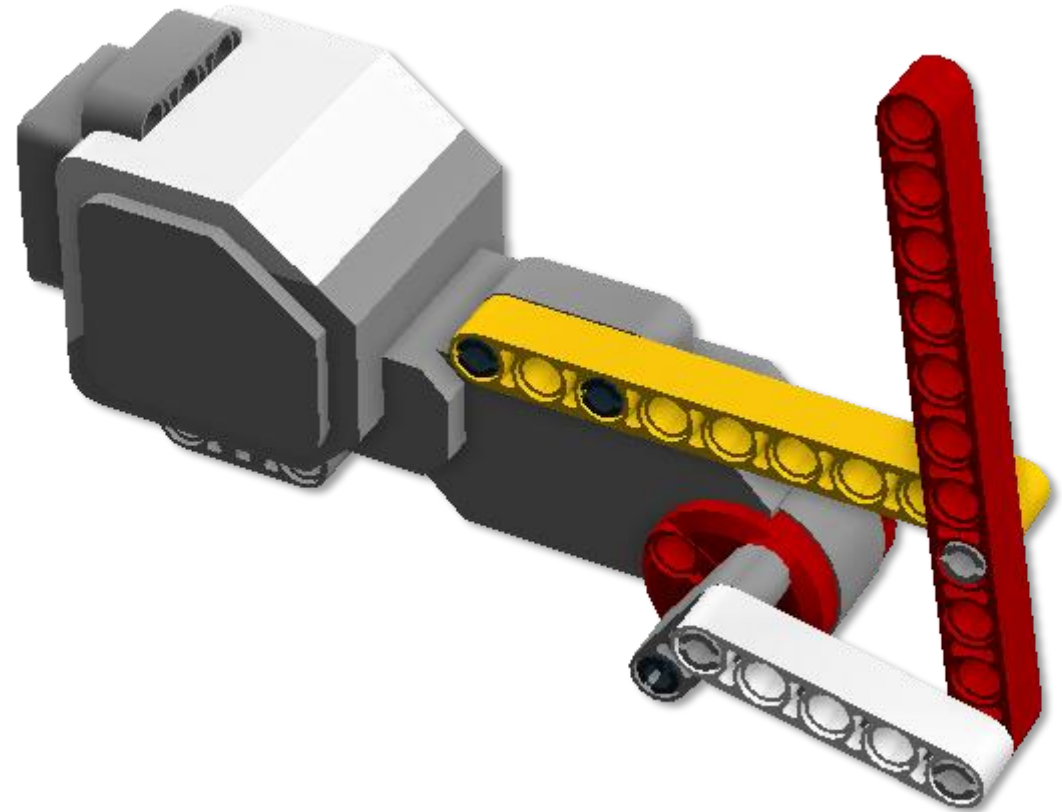
Motion Transfer: Testing

- ▶ Rotate the handle (5M axle).
- ▶ What happens to the forward (red) 11M beam?

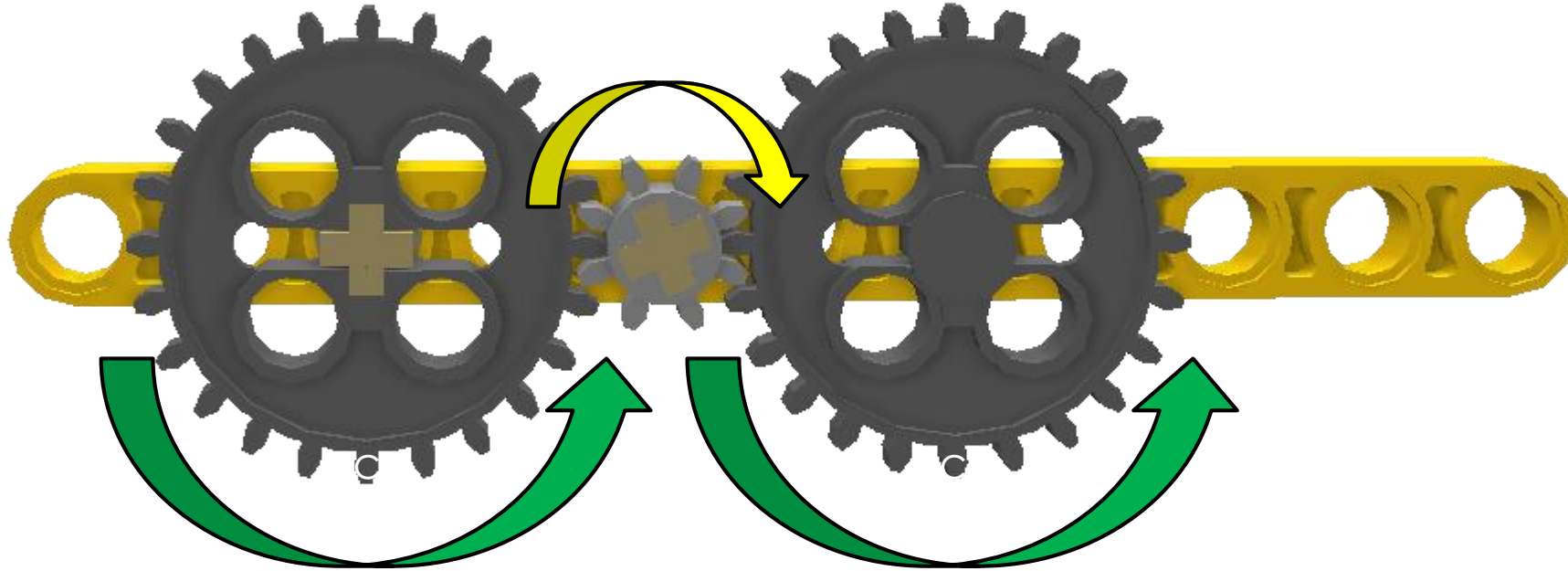


Linear Motion with a motor

- ▶ Adding a motor to drive linear motion is simple.
- ▶ The 24z gear and drive motor both have three holes.



Gear Trains - Direction



- ▶ An idler gear is one between two or more gears to change the direction of the output axle without changing the gear ratio.

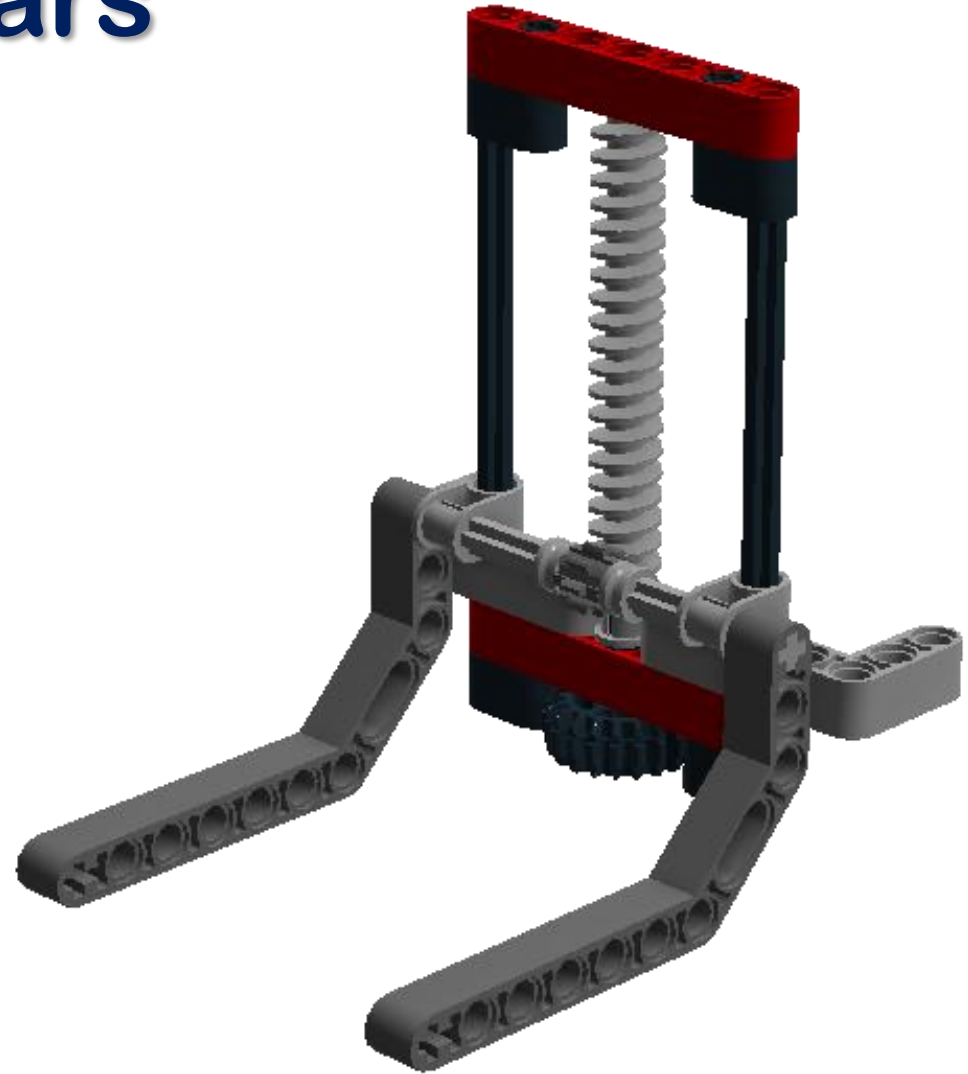
Gear Trains - Ratio



$$(1:3) \times (3:1) = 3:3 \text{ or } 1:1$$

Gears: Using worm gears

- ▶ Worm gears can be used to create linear motion too. This Forklift attachment is one example.
- ▶ Rotating the gear causes the forklift arms to travel up and down.
- ▶ Notice that the 8z gear does not rotate.

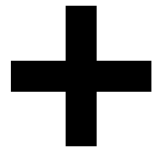


Caster, Wheels, and Miscellaneous



Caster

- ▶ 6023956: LEGO® Steel Ball
- ▶ 4610380: Power Joint



Wheels (Tyres), Rims, and Tracks

- ▶ The LEGO® Group is one of the world's largest tyre manufacturers.



6035364: Tyre Low
Wide 56 X 28



4634091: Rim Wide
43.2 X 26 with
6 Holes



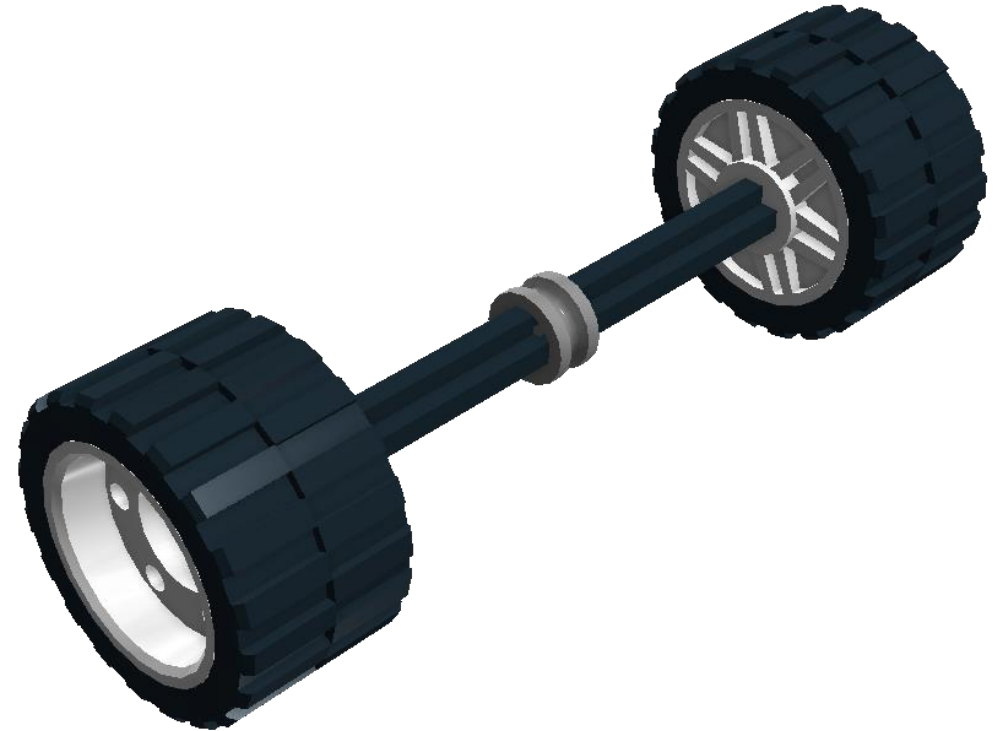
6014648: Track
Element, 5X1.5



4582792:
Sprocket, Ø, 40,7

Simple Wheel Matching

- ▶ Assemble the two wheels on an axle with a bushing in the middle.
- ▶ Align the bushing with the line on a slight slope with the axle at 90° to the line.
- ▶ Let the wheel assembly roll down the slope and watch if the bushing moves off the line.



Miscellaneous

- ▶ 4652236 Upper Part For Turntable 28z
- ▶ 4587275: Wedge-Belt Wheel Ø24
- ▶ 6028041: Tyre For Wedge-Belt Wheel
- ▶ 4173941: Bionicle Eye
- ▶ 4563044: 2X1X3 Steering Knuckle Arm



Upper Part For
Turntable 28z



Wedge-Belt
Wheel Ø24



Tyre For
Wedge-Belt Wheel



Bionicle Eye



2X1X3 Steering
Knuckle Arm

Decorative elements

- ▶ Are just that. Have been used for a number of things.



4566251 Left
Panel 3X5



4566249 Right
Panel 3X5



4541326 Left
Panel 5X11



4566249 Right
Panel 3X5



Disassembly Time

- ▶ Please take apart the project and put the **all** the LEGOS® in the plastic bag.
- ▶ Remember, we need the LEGOS® pieces for the next class.

How many?



- ▶ Take six eight-stud LEGO bricks (2x4) – how many ways can they be combined?
- ▶ With the aid of computers, the exact number of combinations has been calculated as 915,103,765!
- ▶ Just so you know, two eight-stud LEGO bricks can be combined in 24 different ways and three eight-stud LEGO bricks in 1,060 ways.

Everything is awesome!

- Emmet Brickowski



Corrections and Comments: james.brodnick@gmail.com