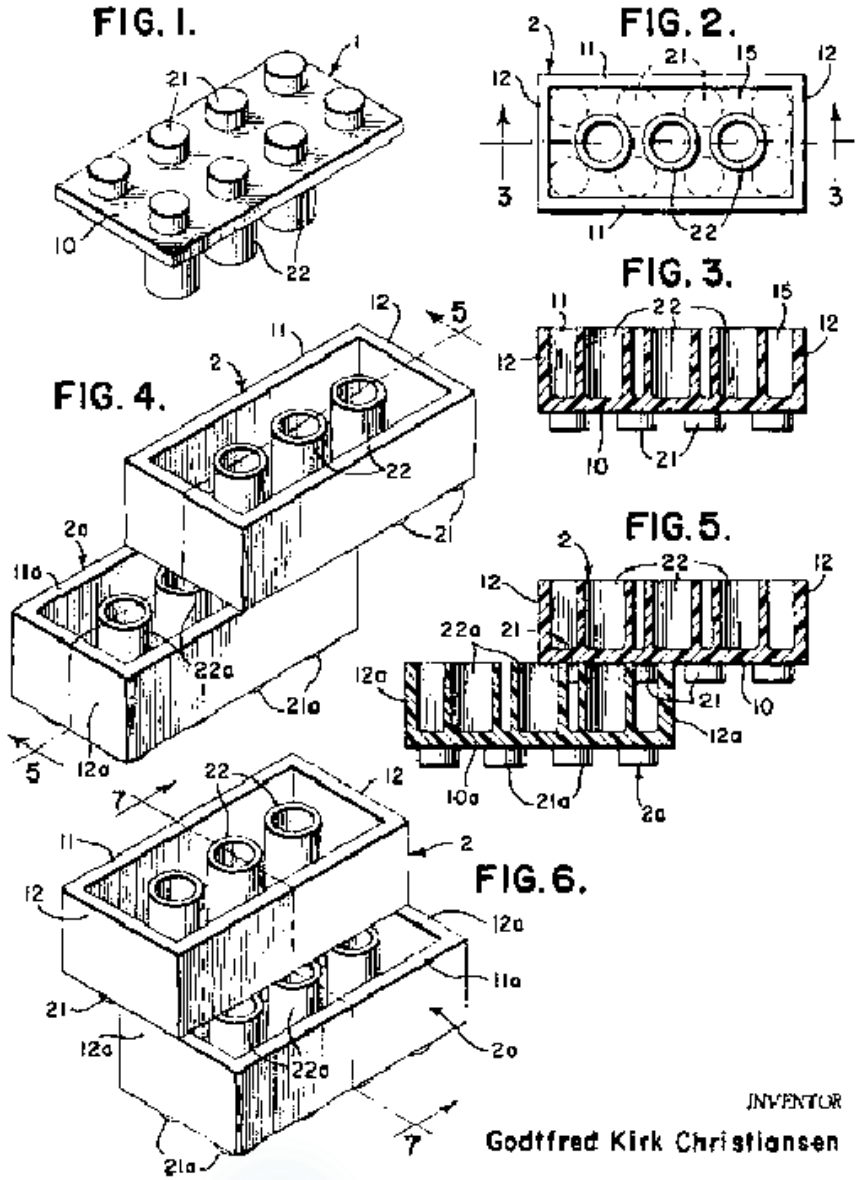
Building with LEGO® Mindstorms® 101

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



UPDATED 7/2016

Required Stuff

- Please do not wander the building.
- Rest Rooms Location.
- Food and Drink.
- Cell phones

- The approximately 2000 LEGO® parts in the kits today are on loan to us. Sorry you cannot keep them.

Introductions

- UME FTC Teams are helping today.
  - The Prototypes #8626
  - Terabytes #11097

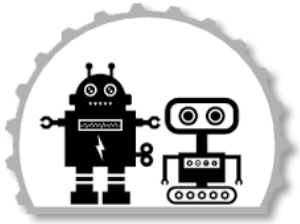
WiFi and Informational Links

SSID: UMEagle

Additional clinics at:

http://www.umepreprobotics.com

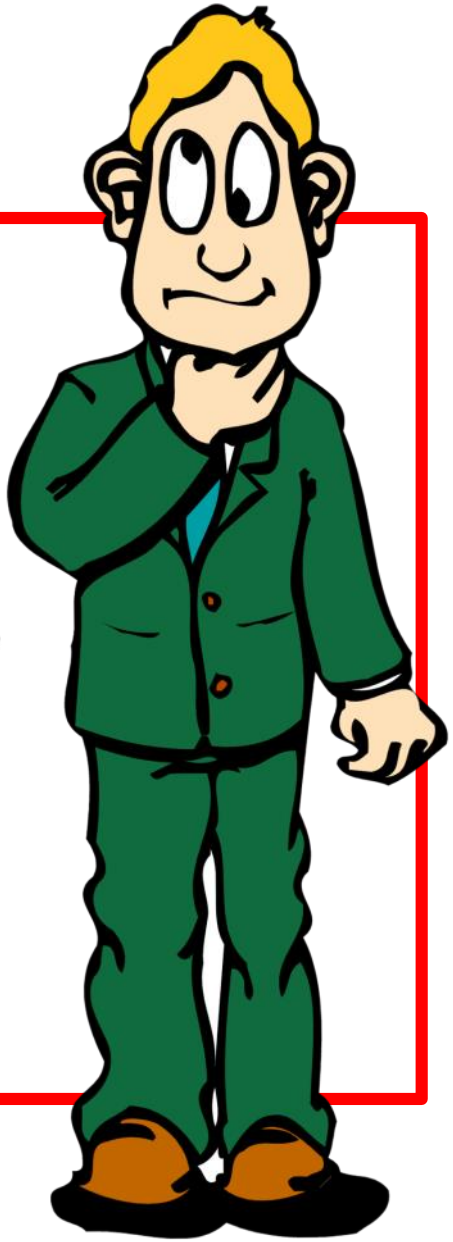
Today presentation available at:



http://www.roboplex.org/fll

WARNING

CHOKING HAZARD – Do **NOT** put 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.



Introduction

- Annual production of Lego bricks averages approximately 36 billion per year, or about 1140 elements per second.
- Since 1958, more than 400 billion Lego® pieces have been produced, or 86 for every person in the world!
- There are roughly 4,200 different Lego® elements in 58 different colors.

Same piece, many different names

Same piece, many different colors

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

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/

Electronic Elements

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

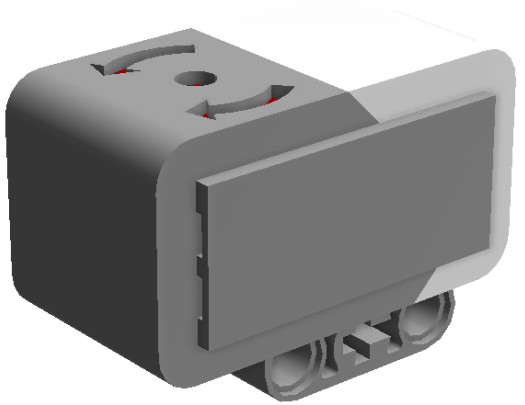
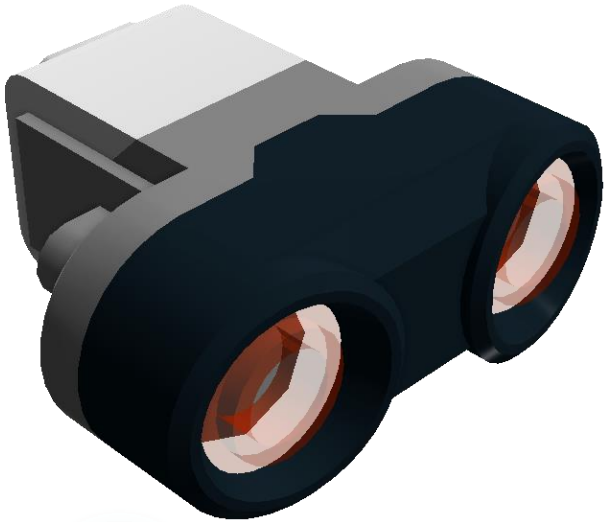
Intelligent Bricks History

- **EV3**
  - Educational released August 1, 2013
  - Commercial released September 1, 2013
- **NXT**
  - Released 2006
- **RCX**
  (Robotic Command eXplorers)
  - Released 1998

Sensors

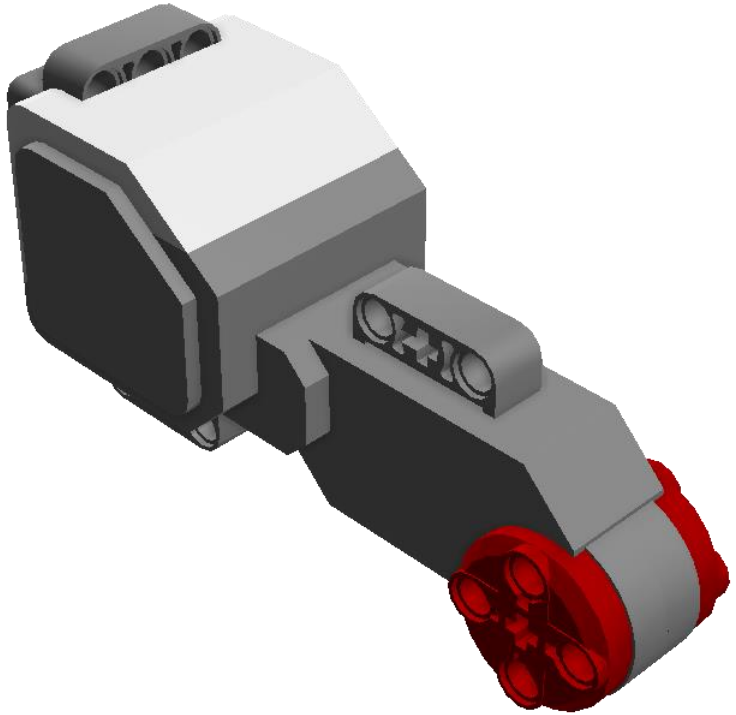
- 6008472: EV3 Touch Sensors (2)
- 6008919: EV3 Color Sensor
- 6008916: Gyro
- 6008924: Ultrasonic Sensor

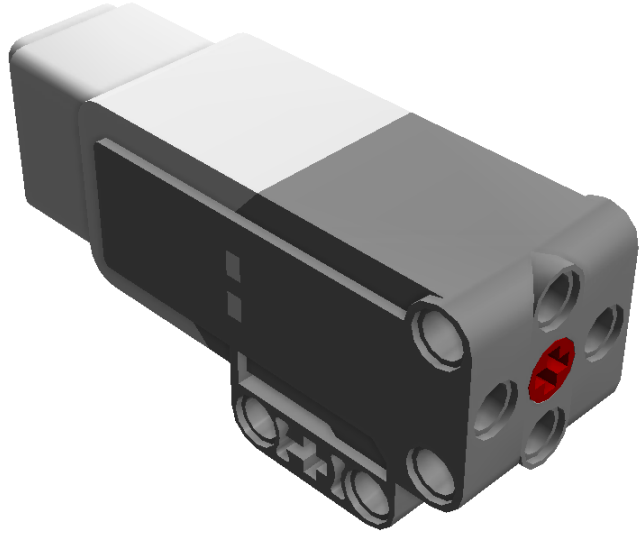


Drive Motors

- 6009430: EV3 drive motor
- 6008577: Medium motor





Beams

- STRAIGHT BEAMS
- ANGULAR BEAMS
- FRAMES
- THIN BEAMS

Beams - Straight

- Beams are measured by counting the number of holes.
  - Beams come in odd numbers when counting the holes, with one exception.
  - Beams start with15 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

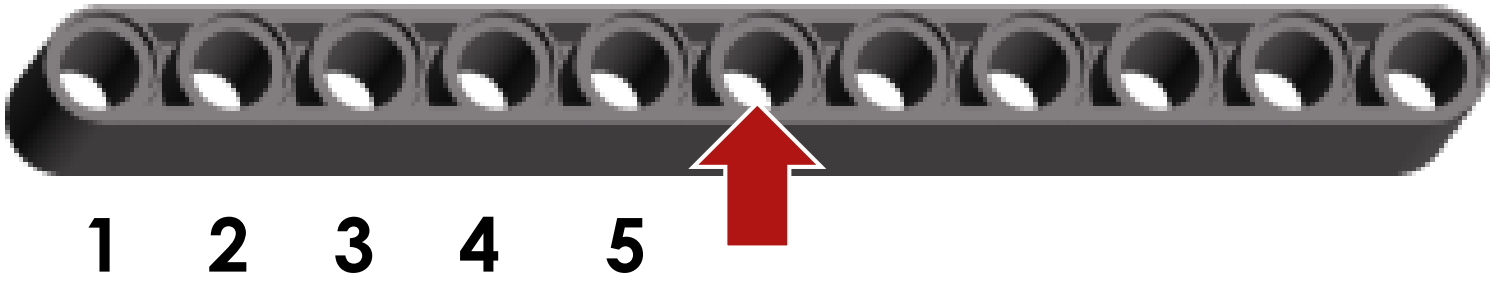
- 11M Beam

- 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

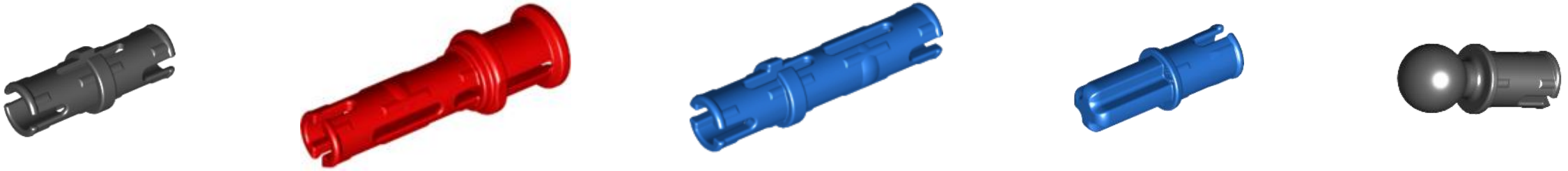
- 6008527: Horizontal to Vertical Beam 90 Degrees
- 6006140: Beam 1X2 with Cross And Hole
- 4538007: Cross Block 3X2

Pegs and Axle Pegs

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

Pegs and Axle Pegs – Friction

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

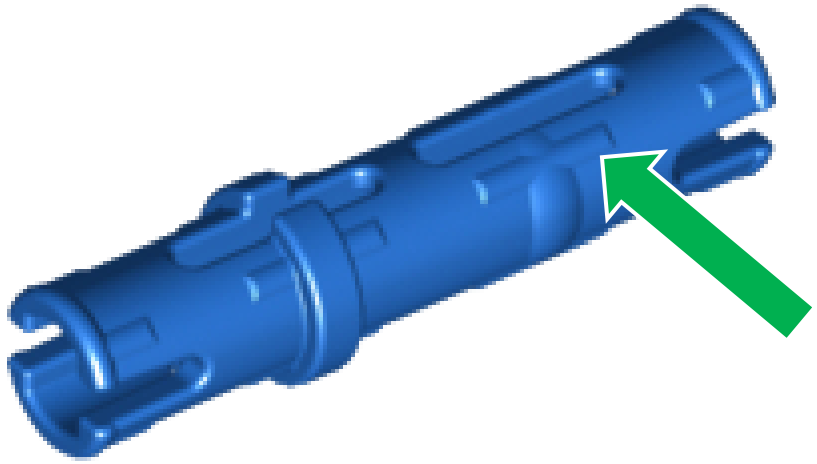


Pegs and Axle Pegs – Non-friction

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

Identifying friction and non-friction pegs

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

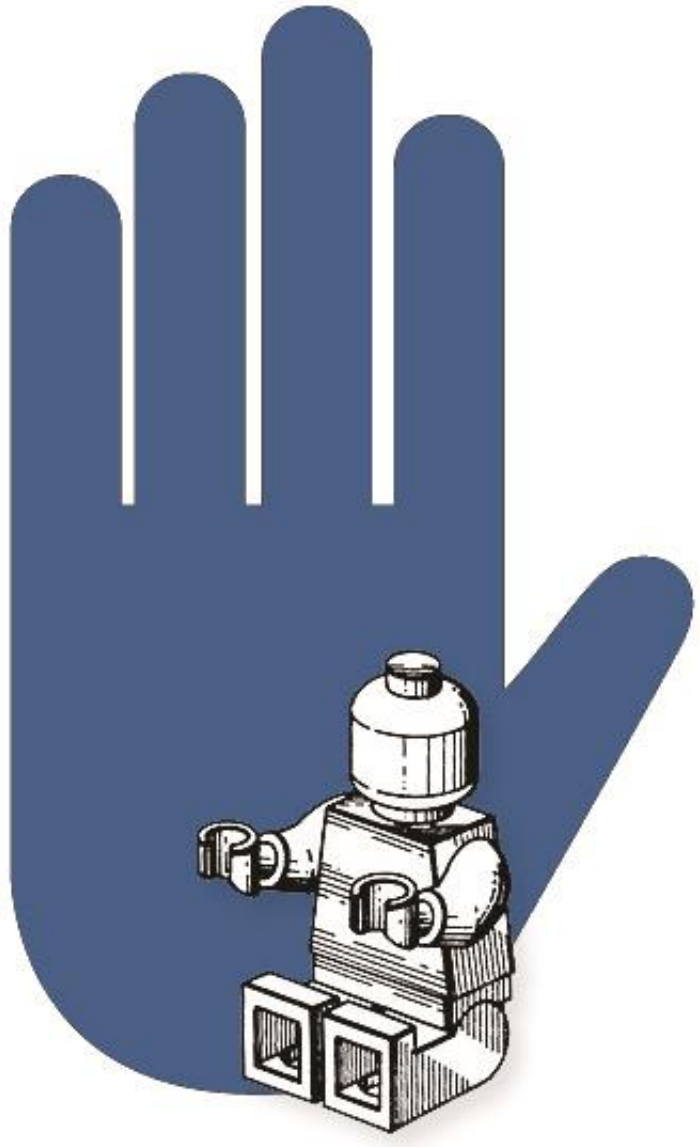


Beams and “snap” combinations

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

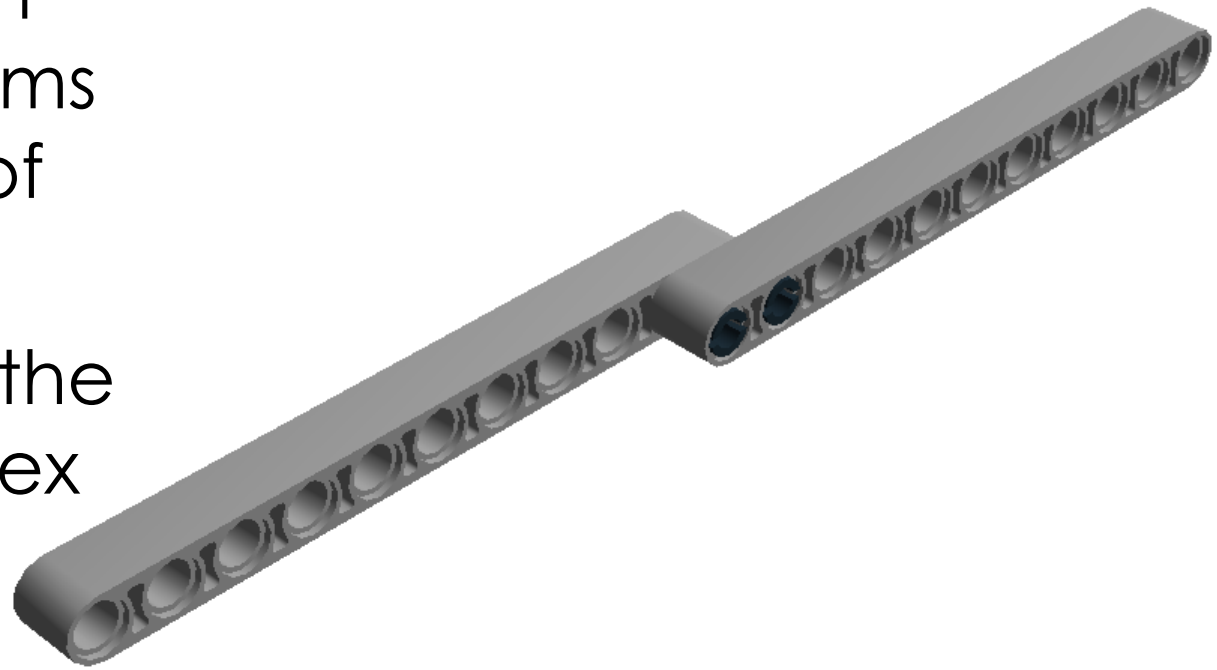
Using Beams and Pegs

- Hands-on activity



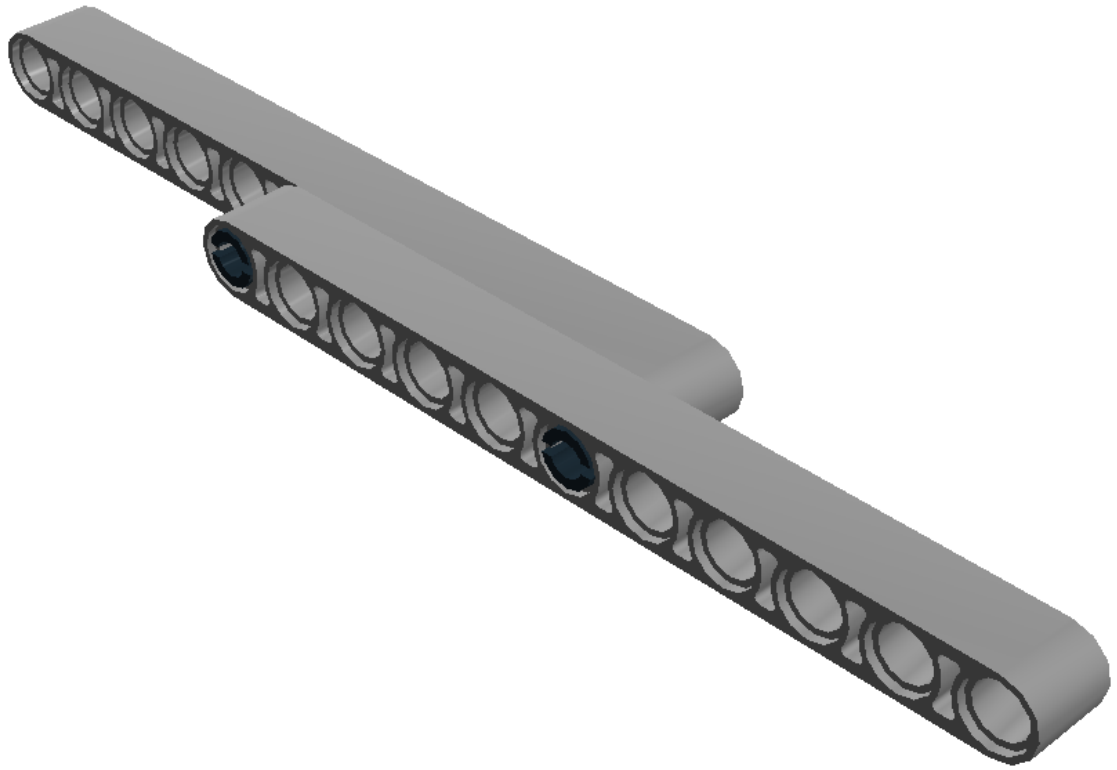
Extending Beams

- Using two black pegs with friction 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

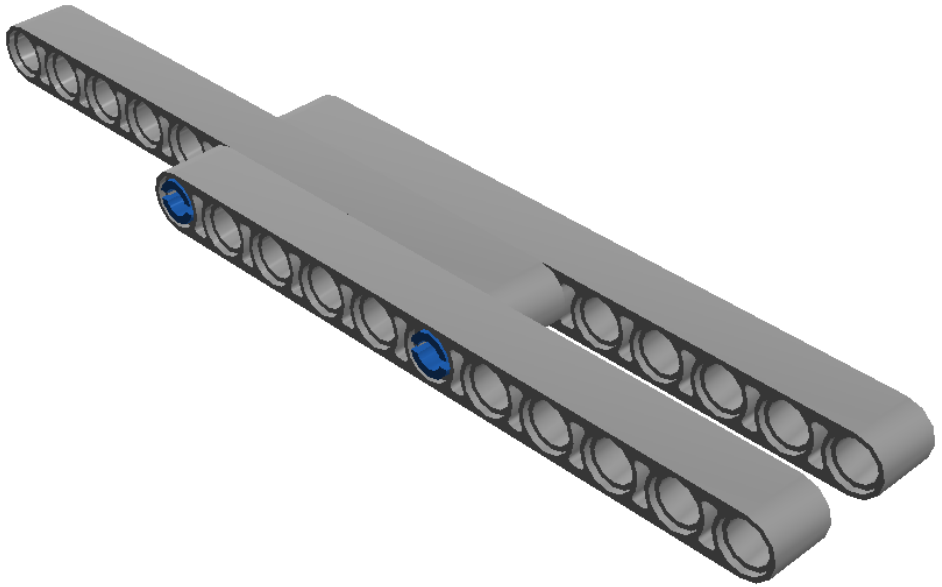
- Using the same two black pegs with friction, overlap the beams five holes.
- Test: Holding the ends of the extended beam gently flex it.
- Result: Structure is more rigid.

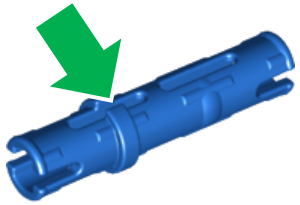


Note: Adding additional black pegs will hold the beams together better, but not required for strength.

Increasing Strength by Making Wider

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

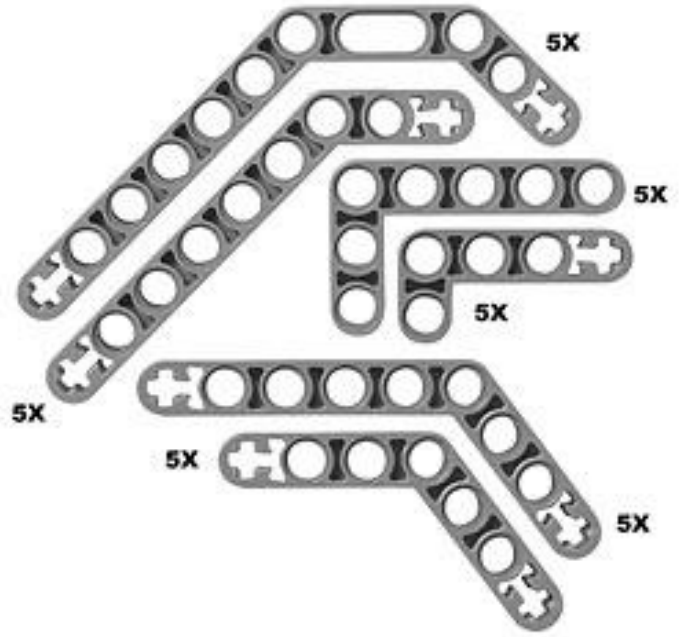




Note: Alternate the direction of the 3M blue peg ridge to reduce separation. Peg ridge can be used to help in keeping pegs in place when removable attachments.

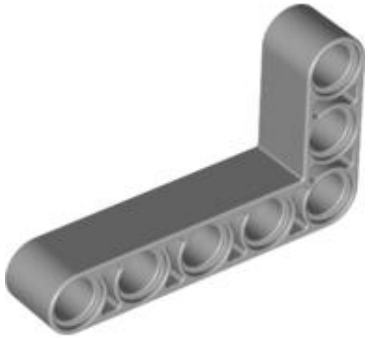
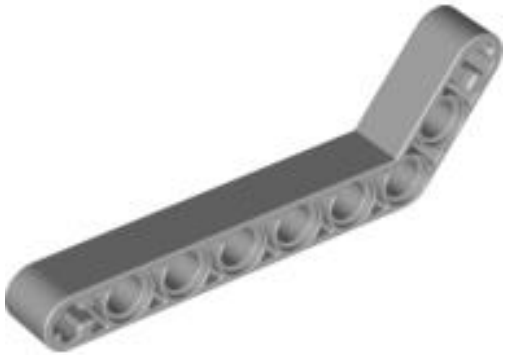
Angular beams

- 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 hole at the other.
- All other angular beams have cross holes at the ends.



Angular beams

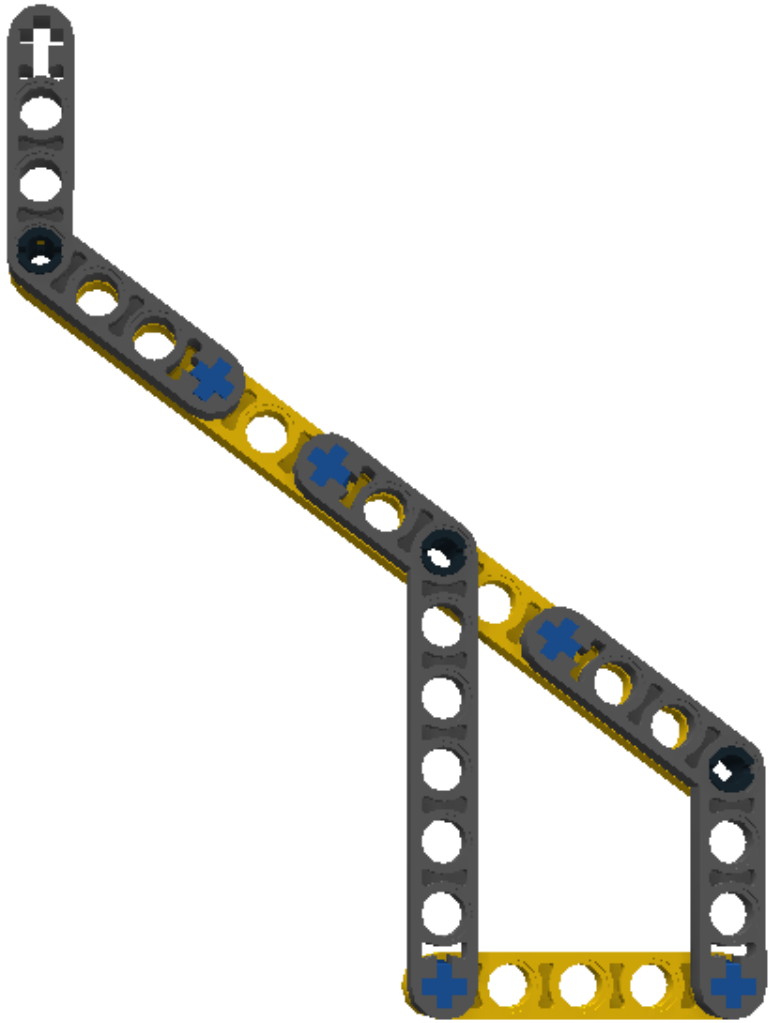
- 4141270: Angular Beam 4X2 90°
- 4211713: Angular Beam 3X5 90° (Med. Grey) / 4585040 (White)
- 4211624: Angular Beam 3X7
- 4509912: Angular Beam 4X4

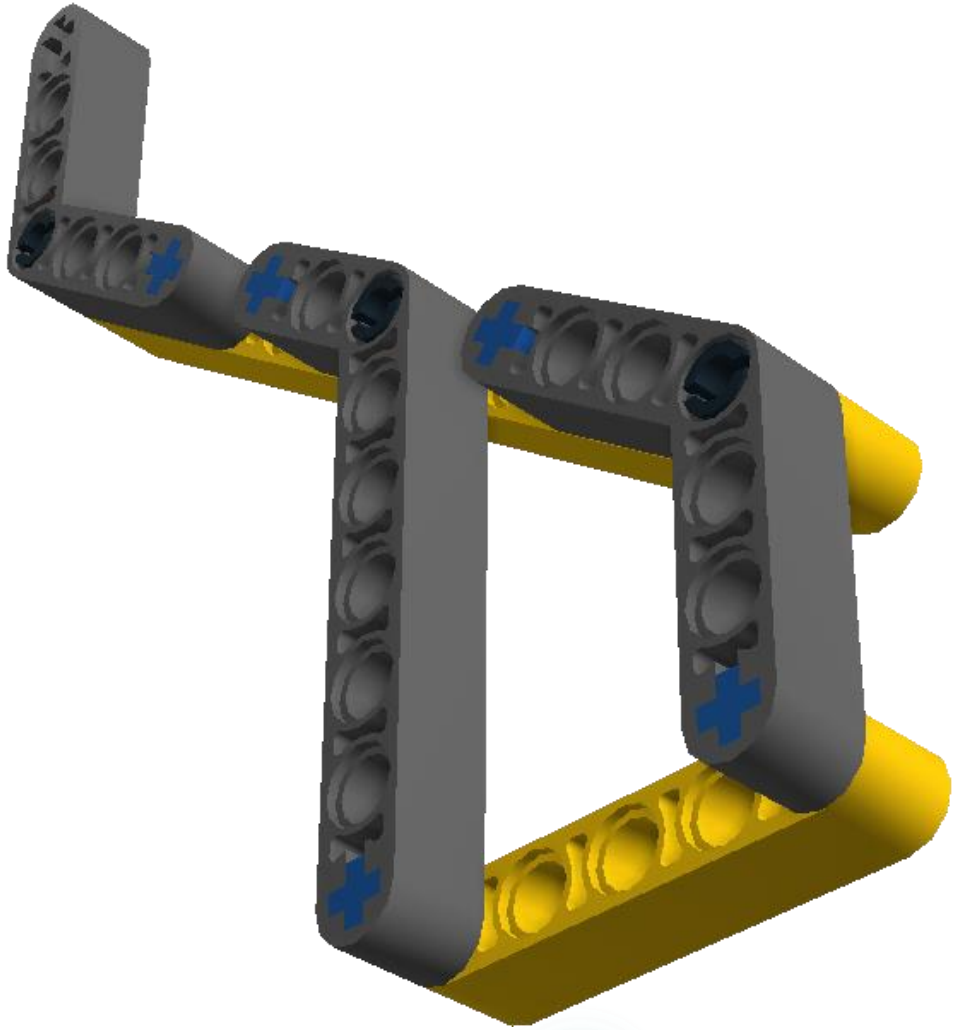





Angular beams

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

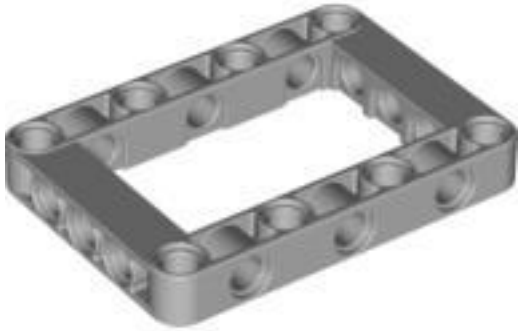
Angular combinations





Frames

- Frames are referred to based on their shape:
  - O frame
  - H frame
- Frames 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

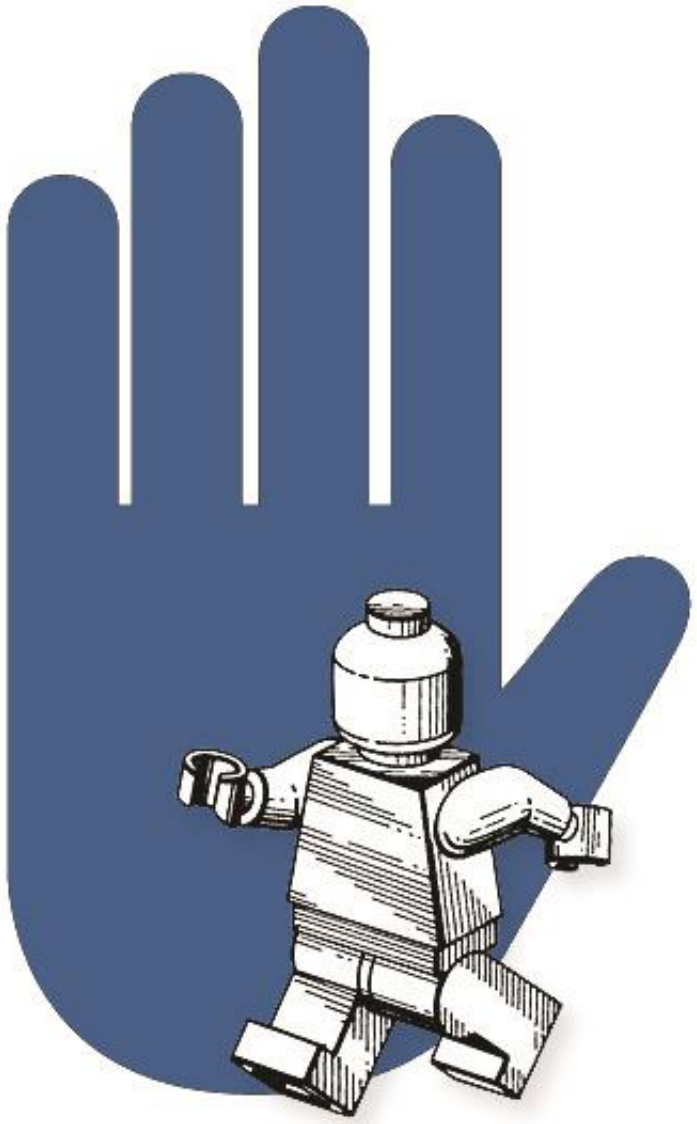
4142236: Lever 1X4, Without Notch

4112287: Technic Lever 3X3M, 90*

4503417: Technic 5M Half Beam*

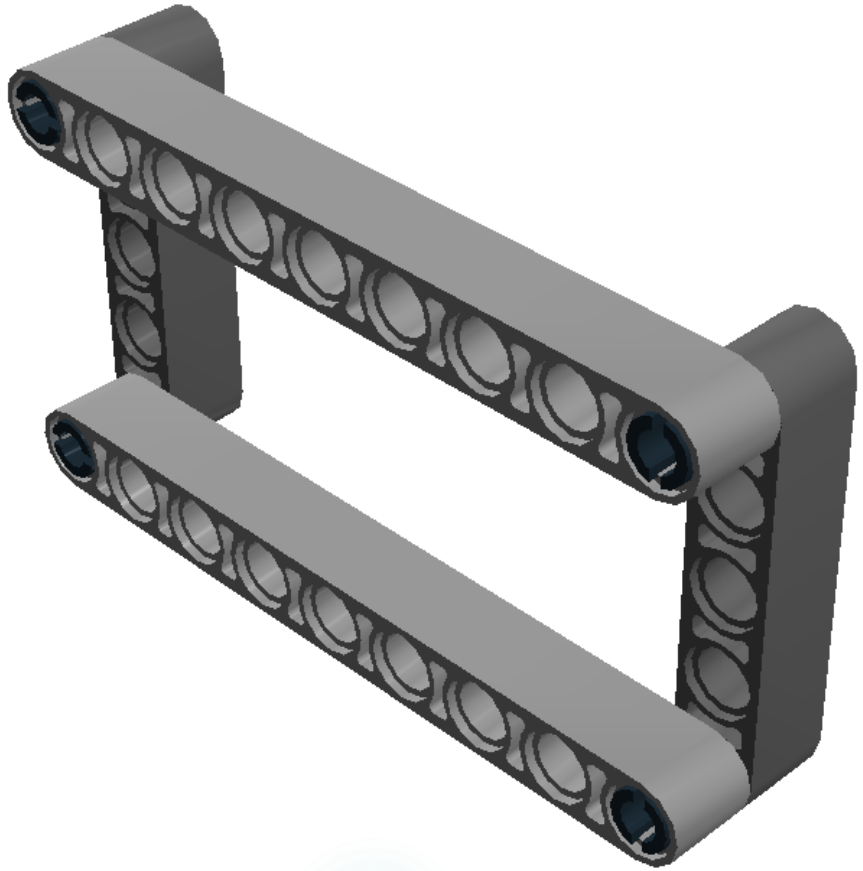
Structural frames

- Hands-on activity

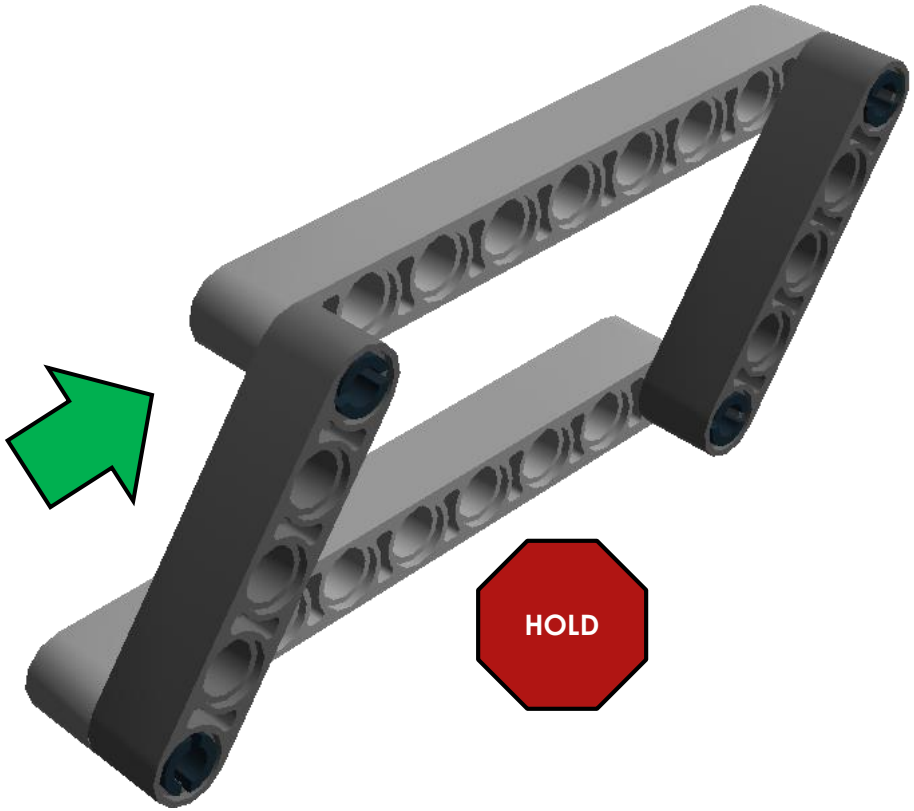


Make a Structural Frame

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



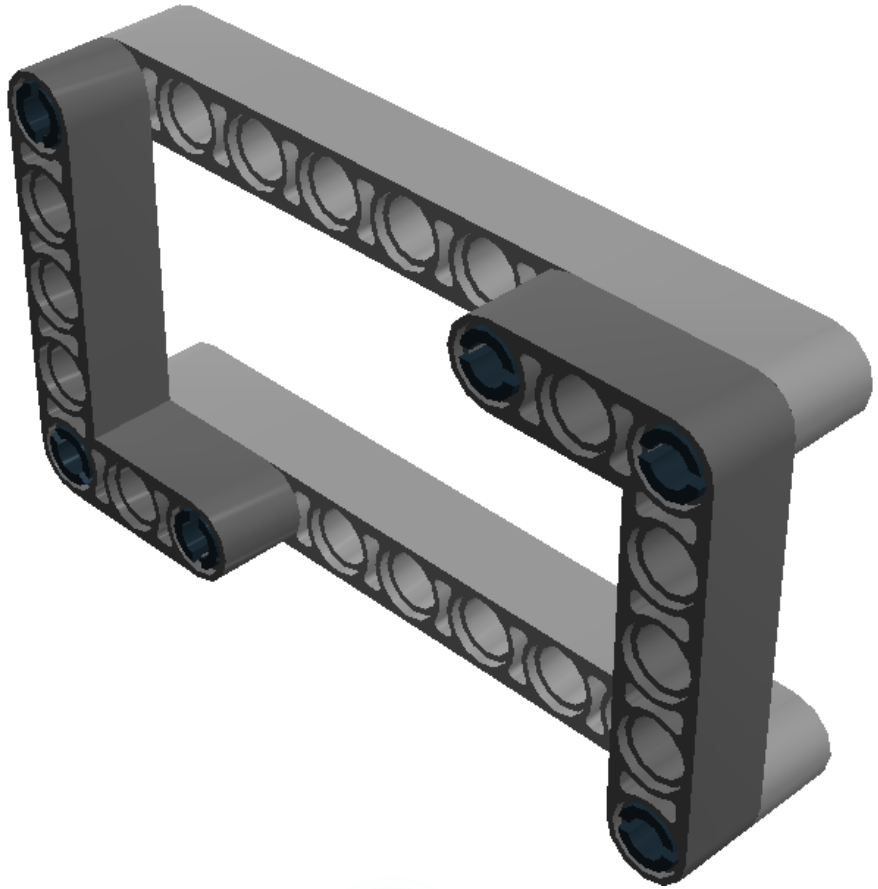
Strength Test of Structural Frame



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

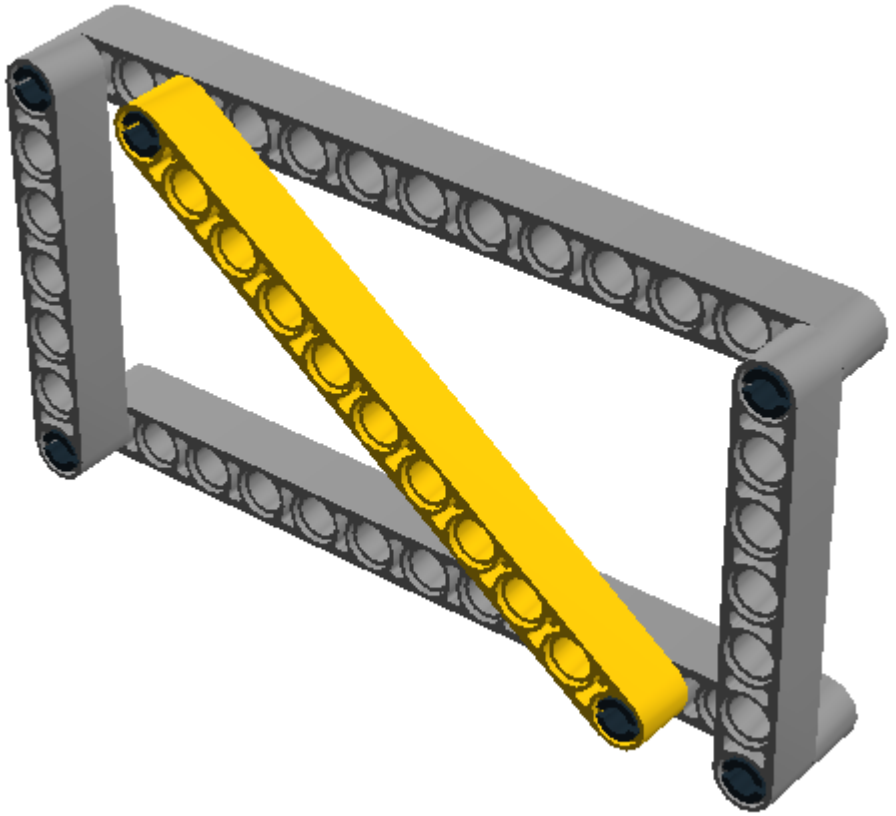
Adding Strength to the Structural Frame

- 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.

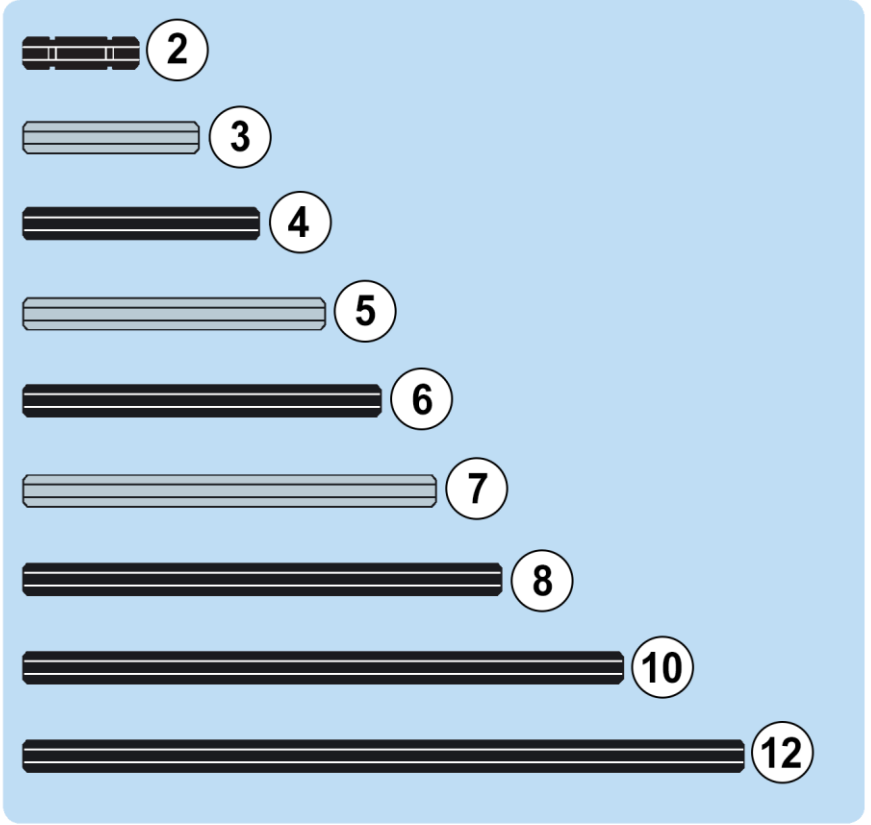


Axles and connectors

■ 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).



Specialty Axles

- Axle with end stop
- Cross axle with end stop
- Cross axle with end knob

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: Half Bushing for Cross Axle
- 4211622: Bushing for Cross Axle
- 4560175: Double Bushing 3M

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

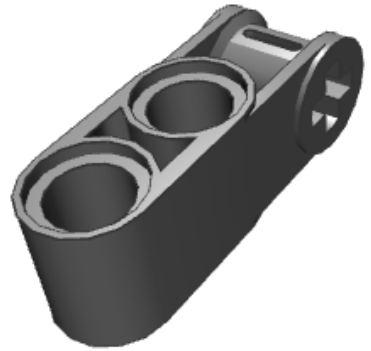
Cross blocks




- 4173668 - Cross Block 90
- 4121667 - Double Cross Block
- 4140430 - Technic Cross Block 2X1 (Mickey)
- 4162857 - Technic Cross Block Fork 2X2 (Minnie)
- 4210857 - Technic Cross Block 90, 2X3

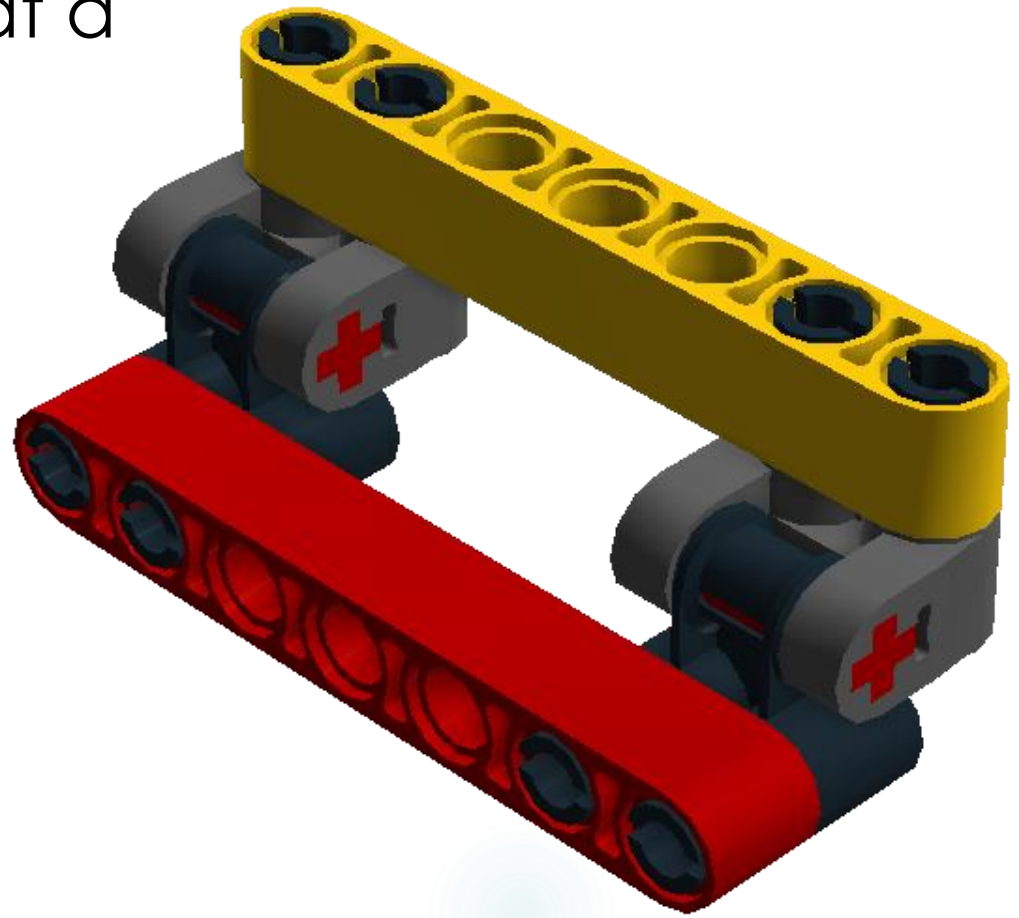






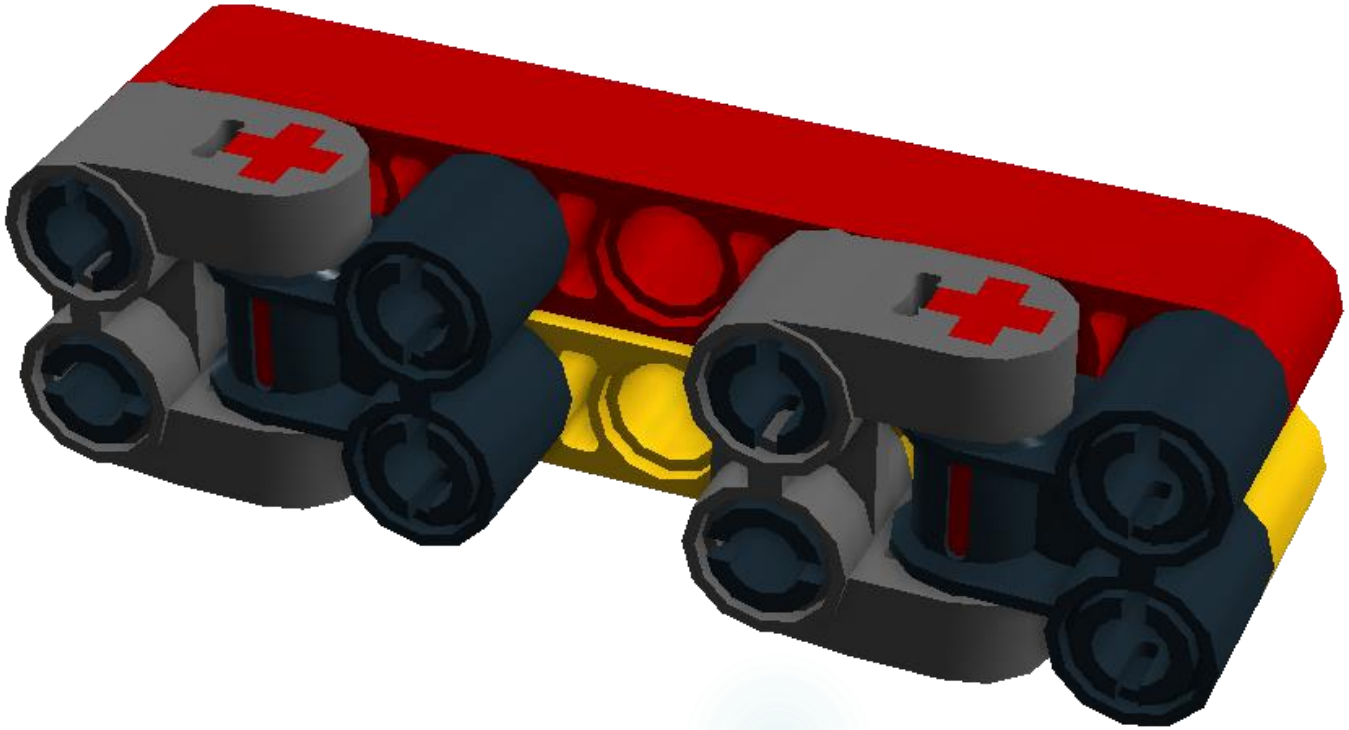
Cross blocks combinations

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



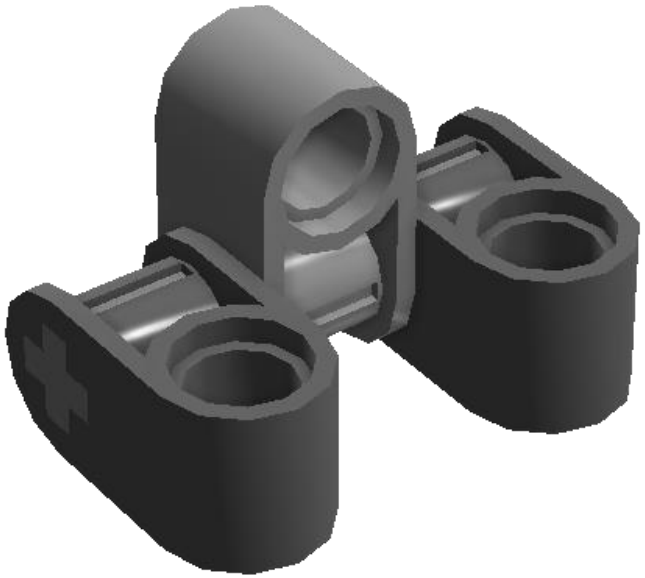
Cross blocks combinations

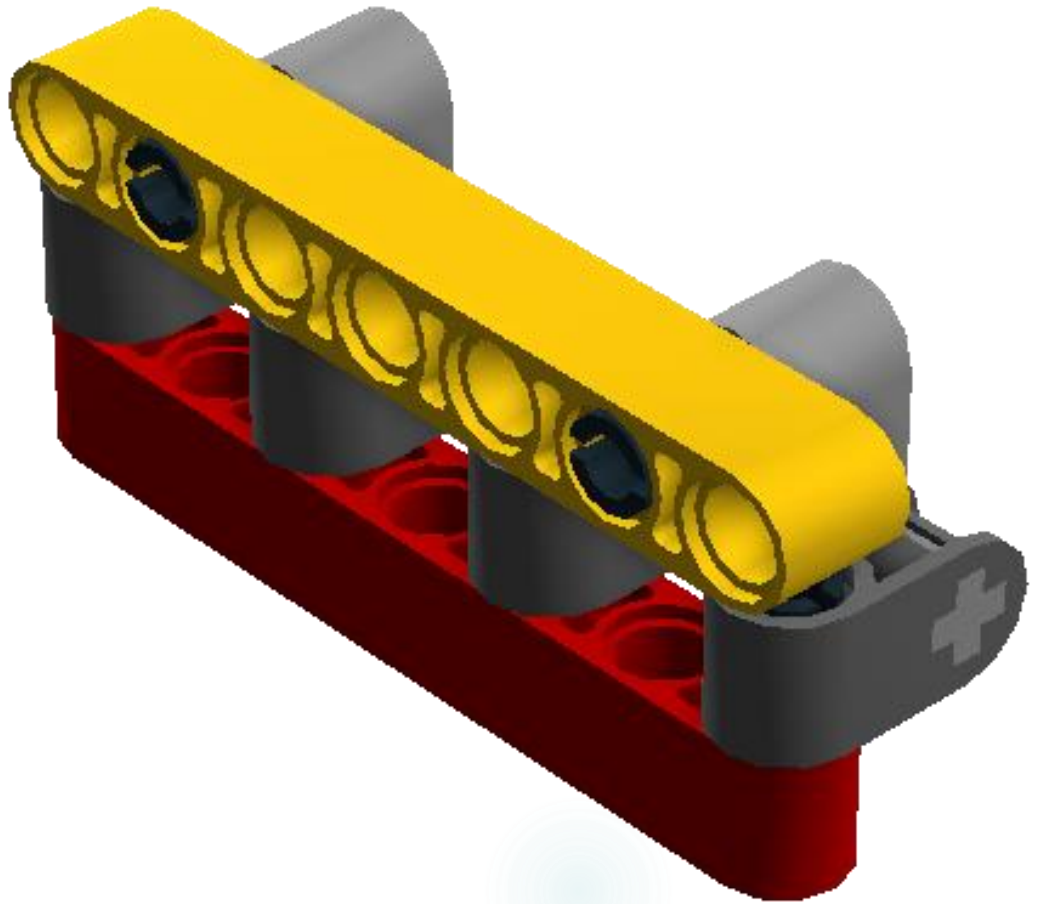
- This cross block combination allows two beams to be mounted smooth sides together.



Cross block combinations

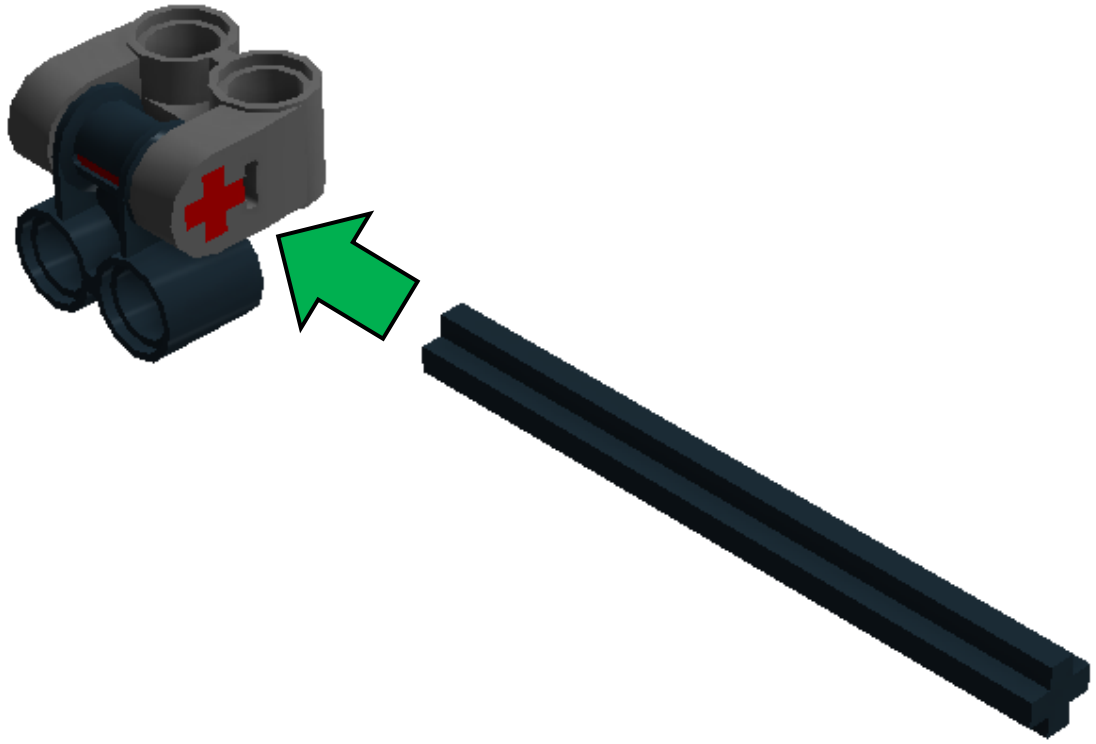
- This combination of cross blocks also allows mounting two beams at a right angle.





Tip for removing small cross axle connector

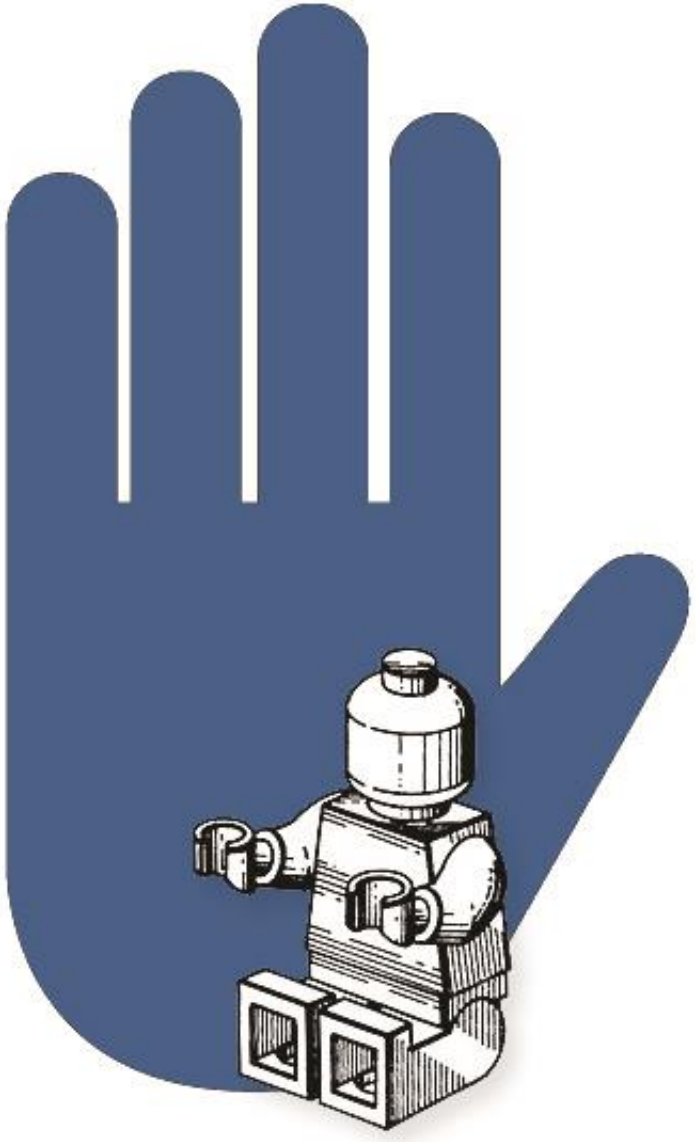
- Use long axle to push small axle through.



601172 Brick Separator

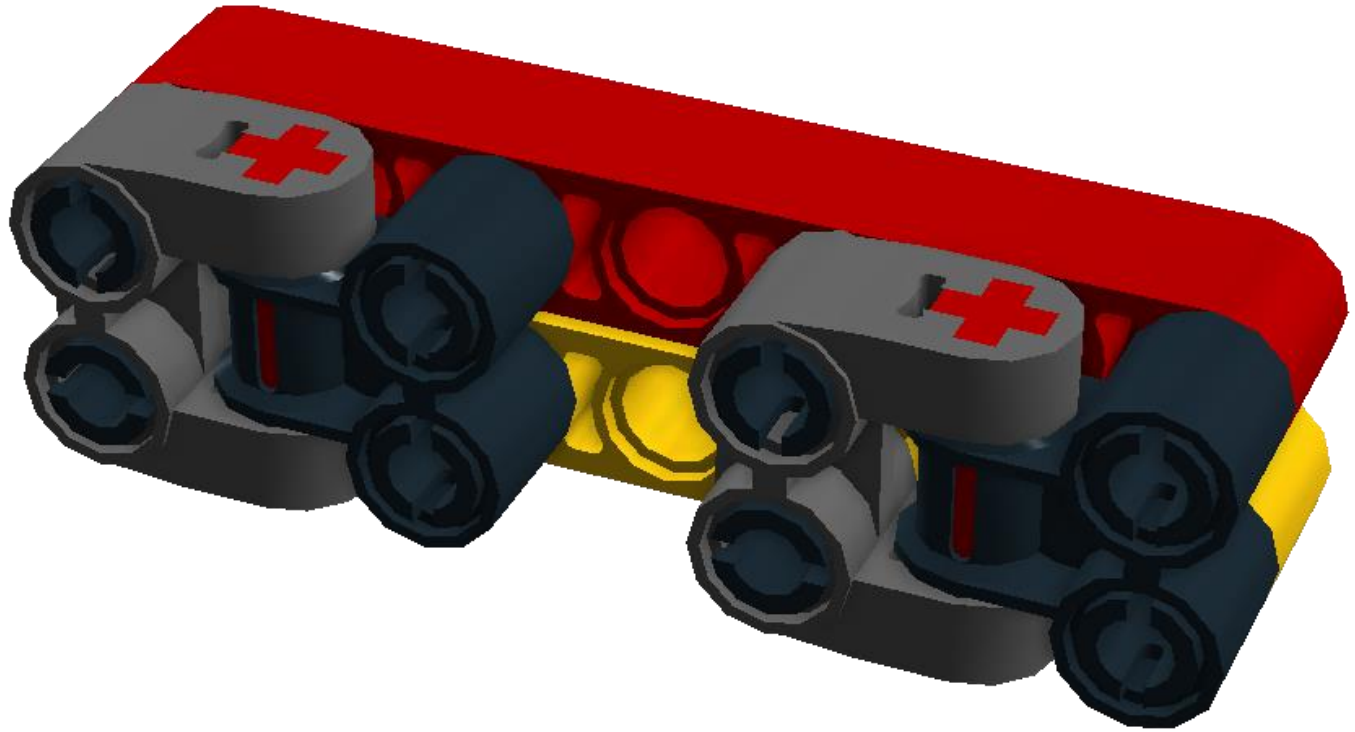
Cross blocks

- Hands-on activity



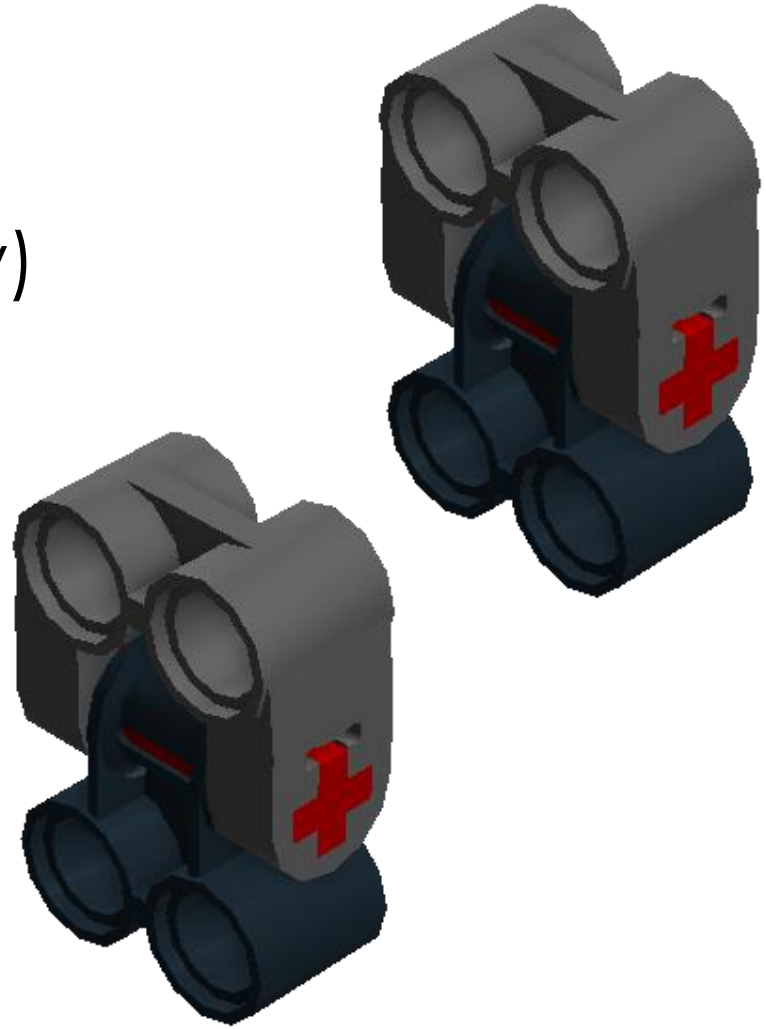
Cross blocks: Hands-on parts needed

- 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)



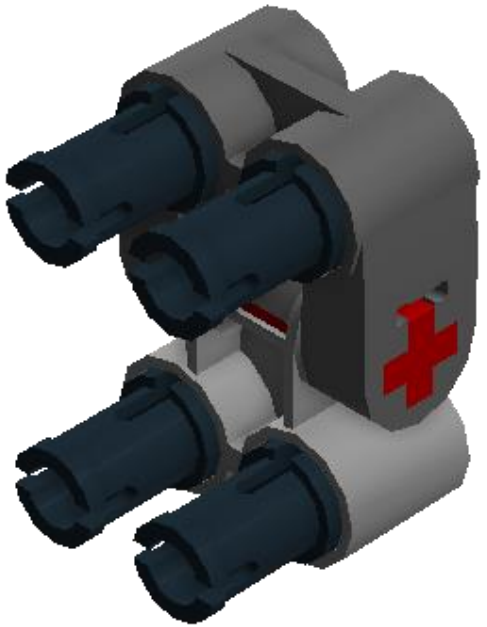
Cross block building instructions

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



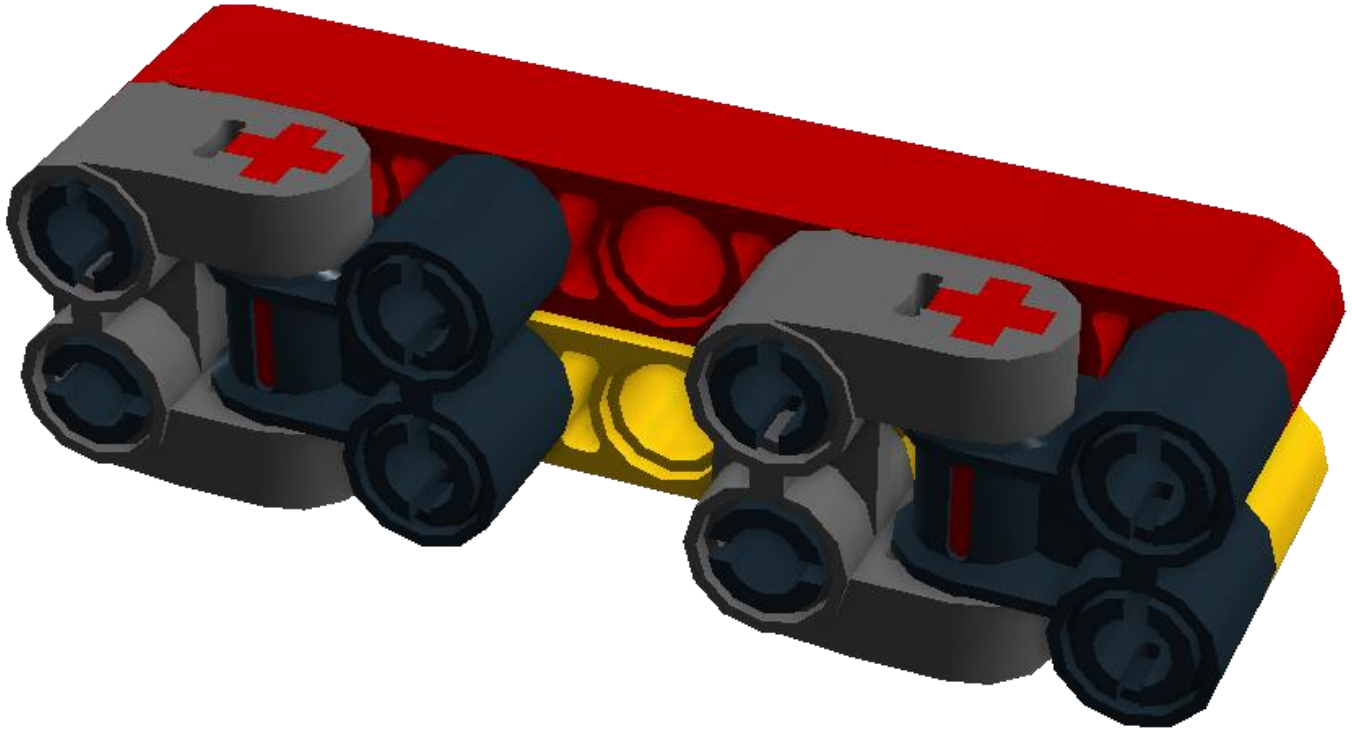
Cross block building instructions

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



Cross blocks building Instructions

- Place two 7M beams on cross blocks.

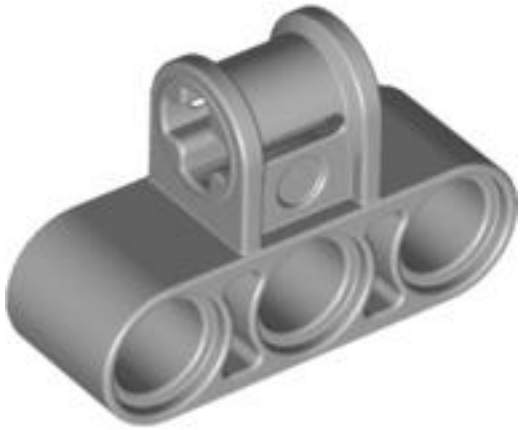


Bracing

- 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 is bracing.
- Bracing can add strength with minimum weight increase.

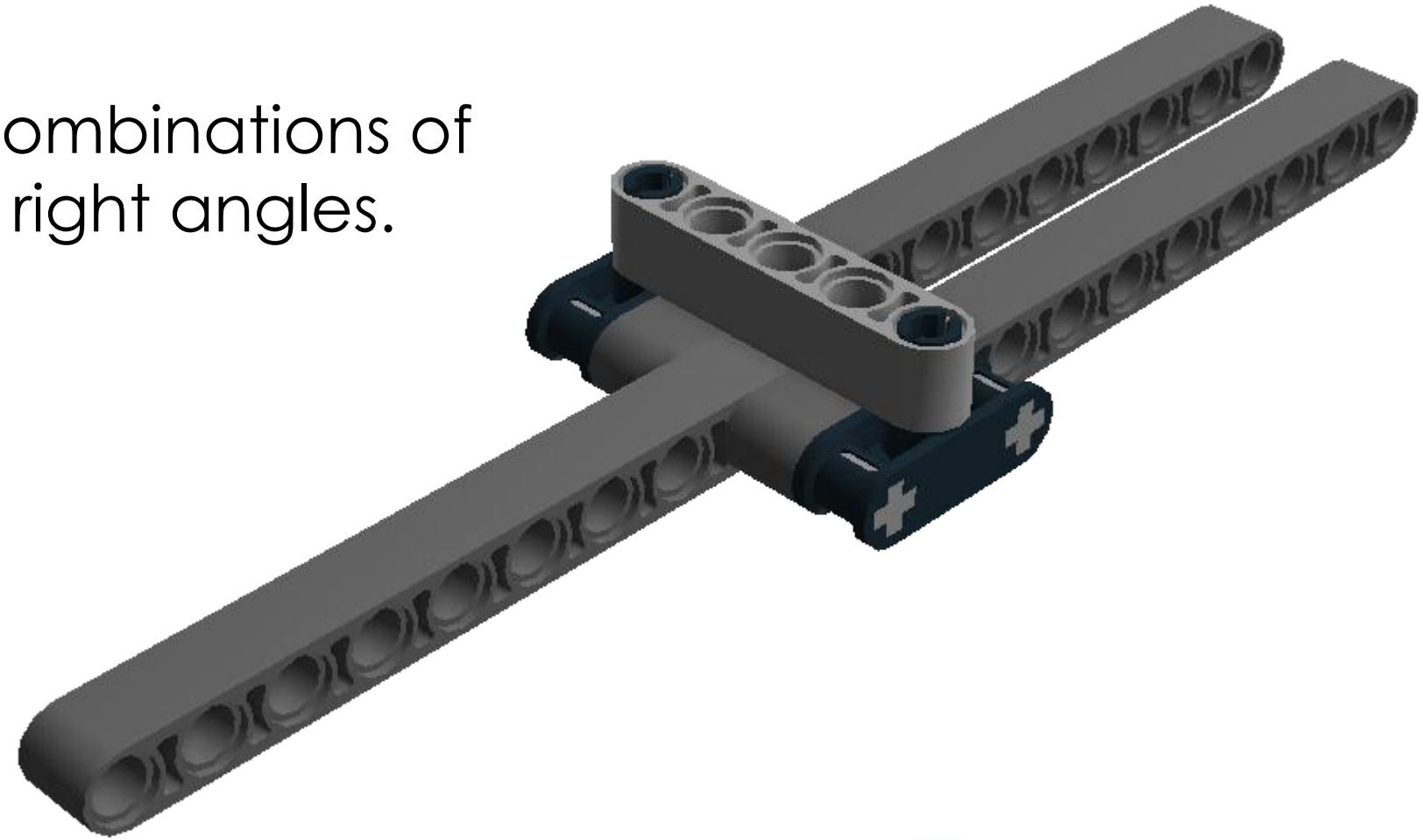
Additional cross blocks

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

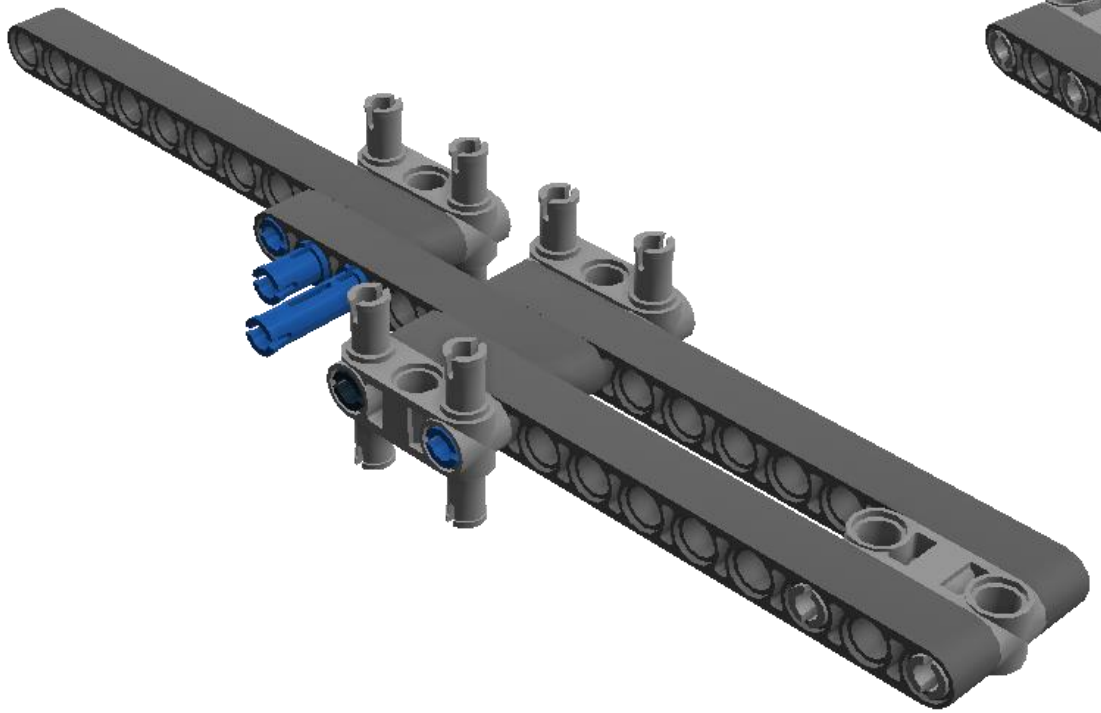


Bracing – Sample 1

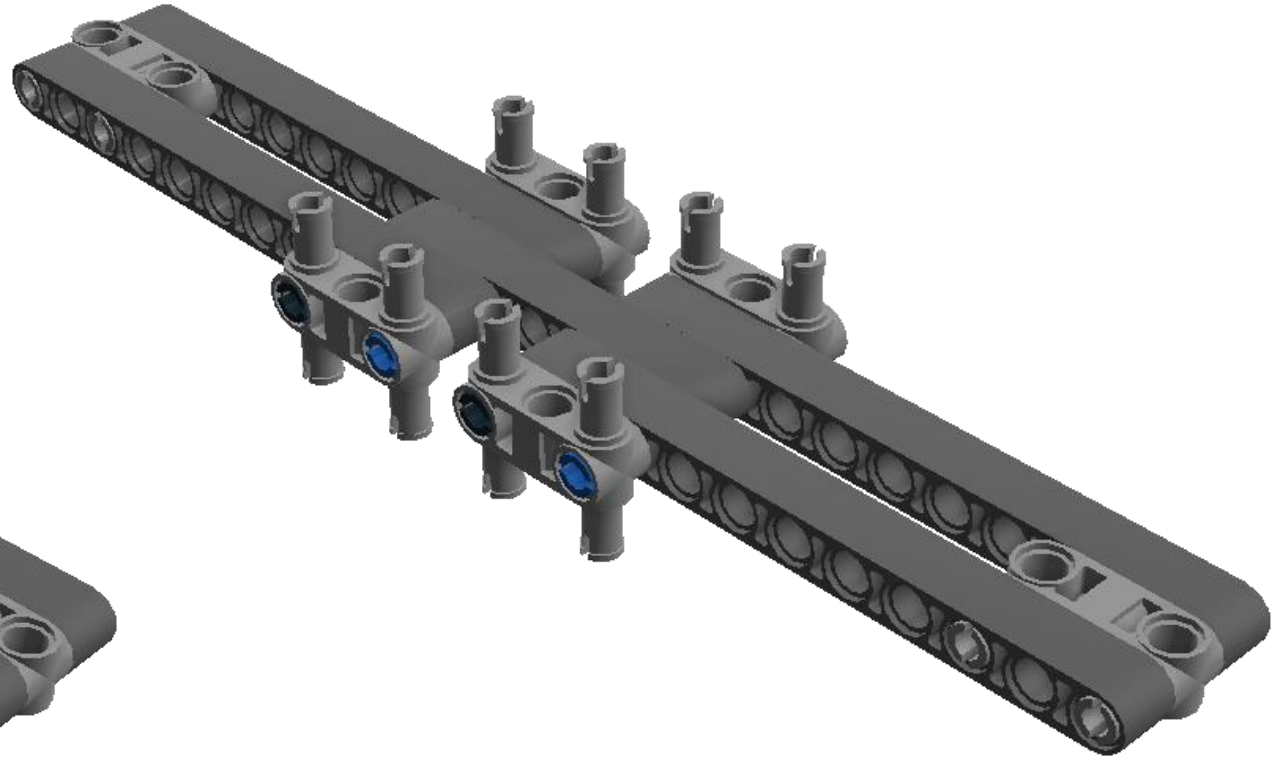
- Bracing uses combinations of LEGO® part at right angles.



Bracing – Sample 2

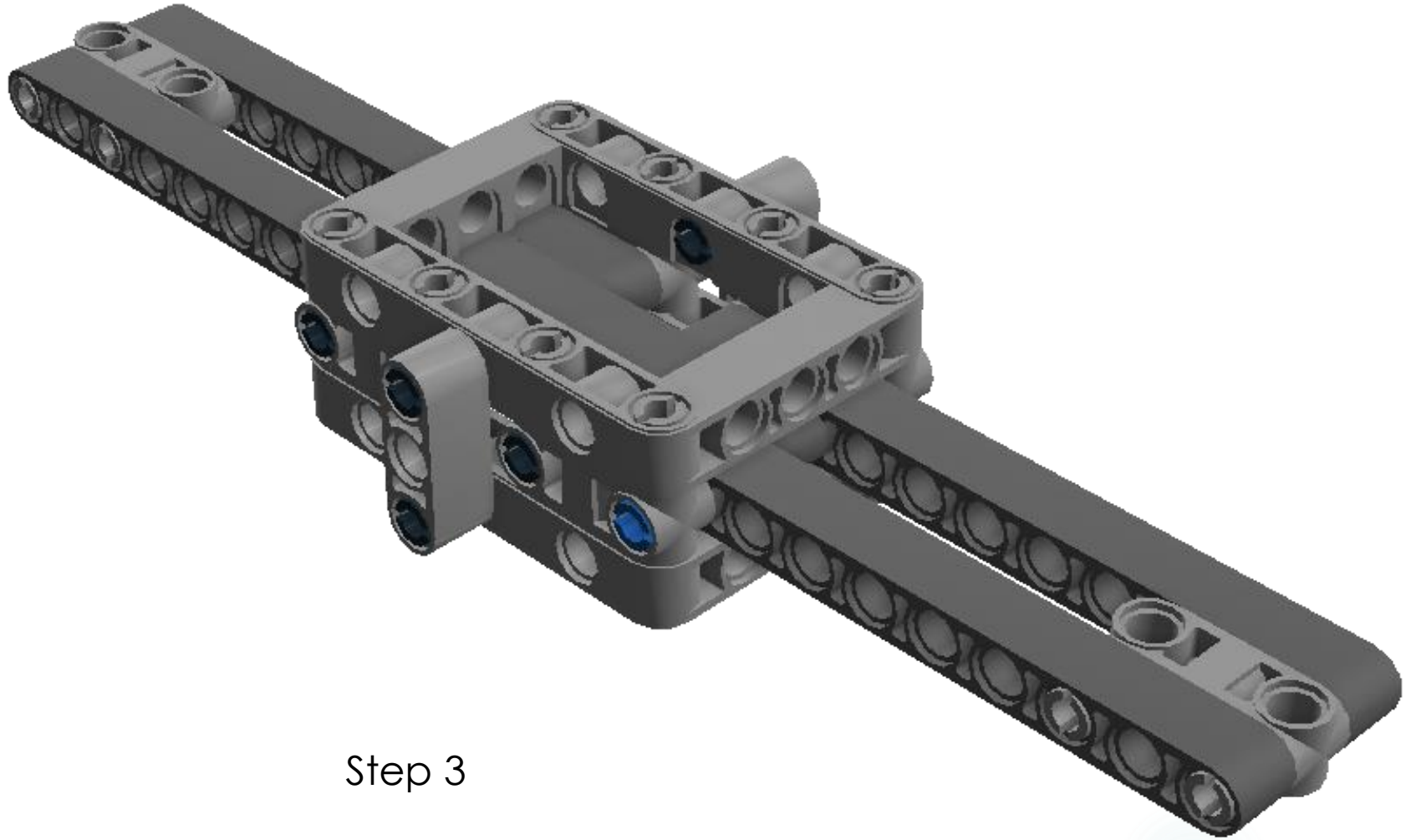


Step 1



Step 2

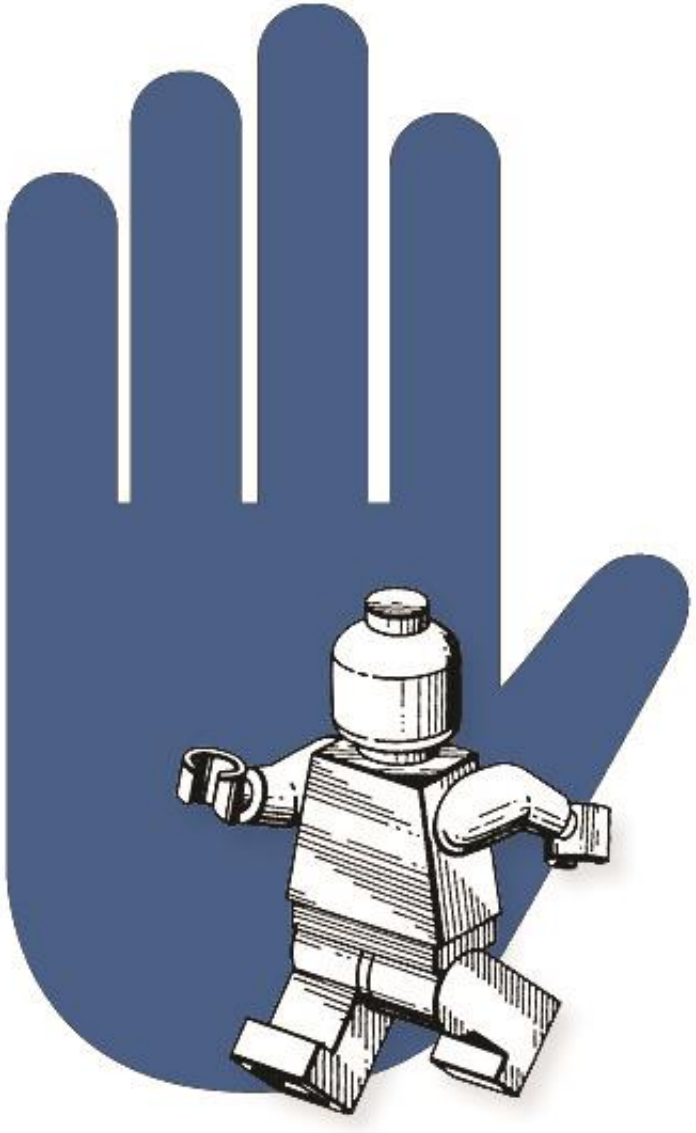
Bracing – Sample 2



Step 3

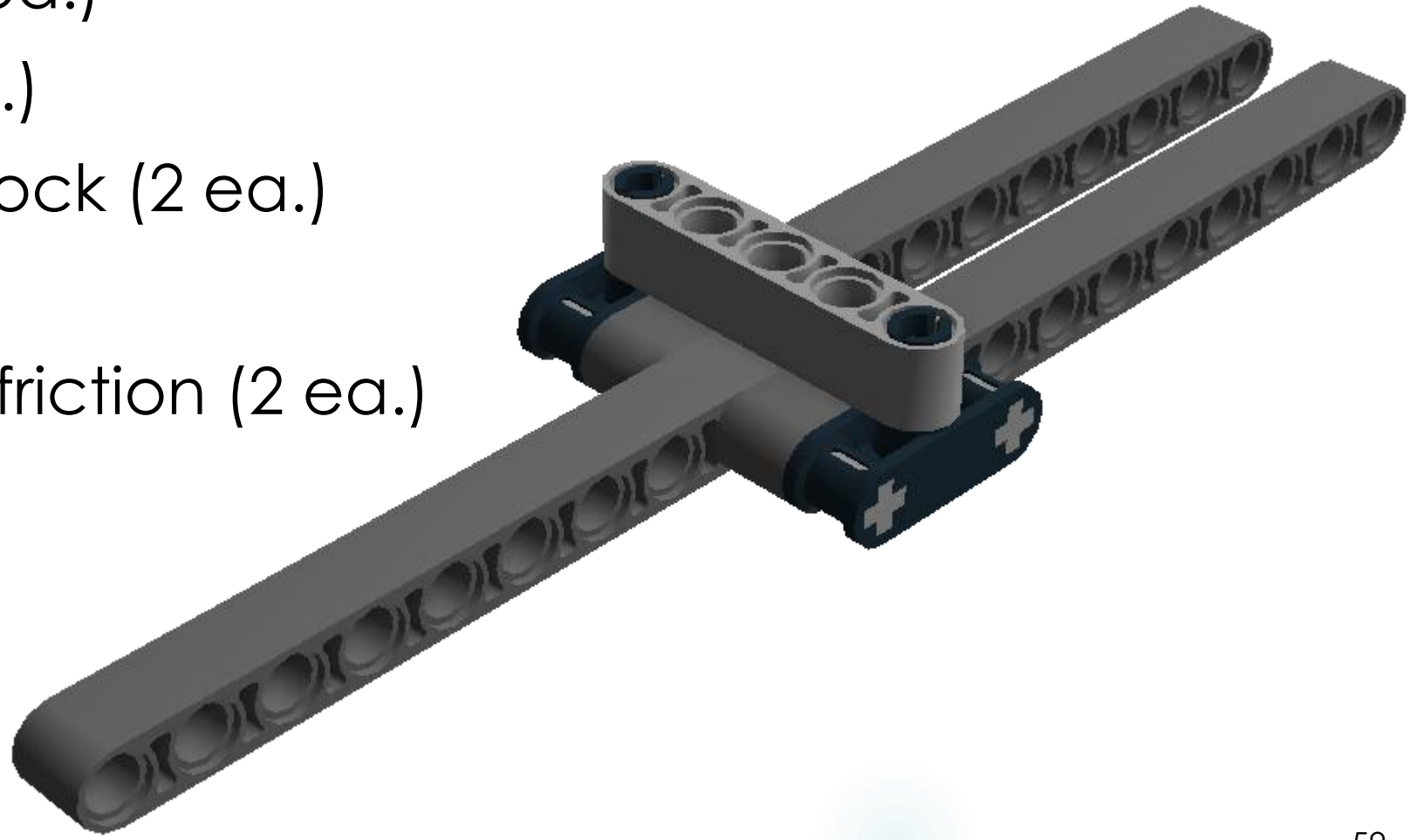
Bracing

- Hands-on activity

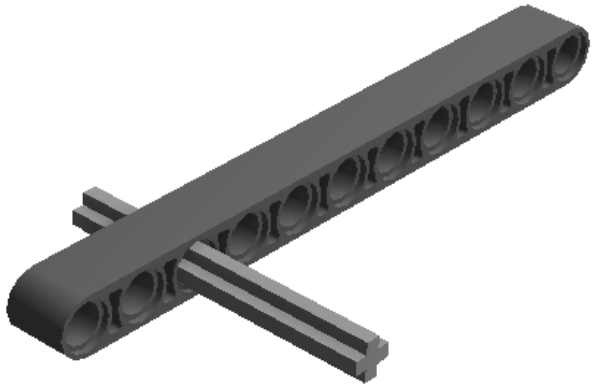


Bracing: Hands-on parts needed

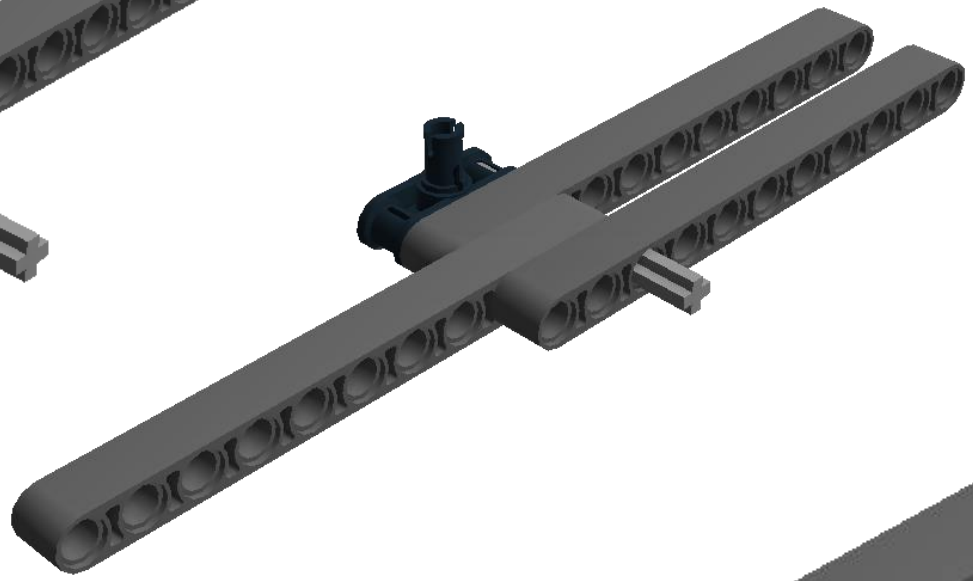
- 11M beams (3 ea.)
- 5M beam (1 ea.)
- Double cross block (2 ea.)
- 5M axle (2 ea.)
- Black peg with friction (2 ea.)



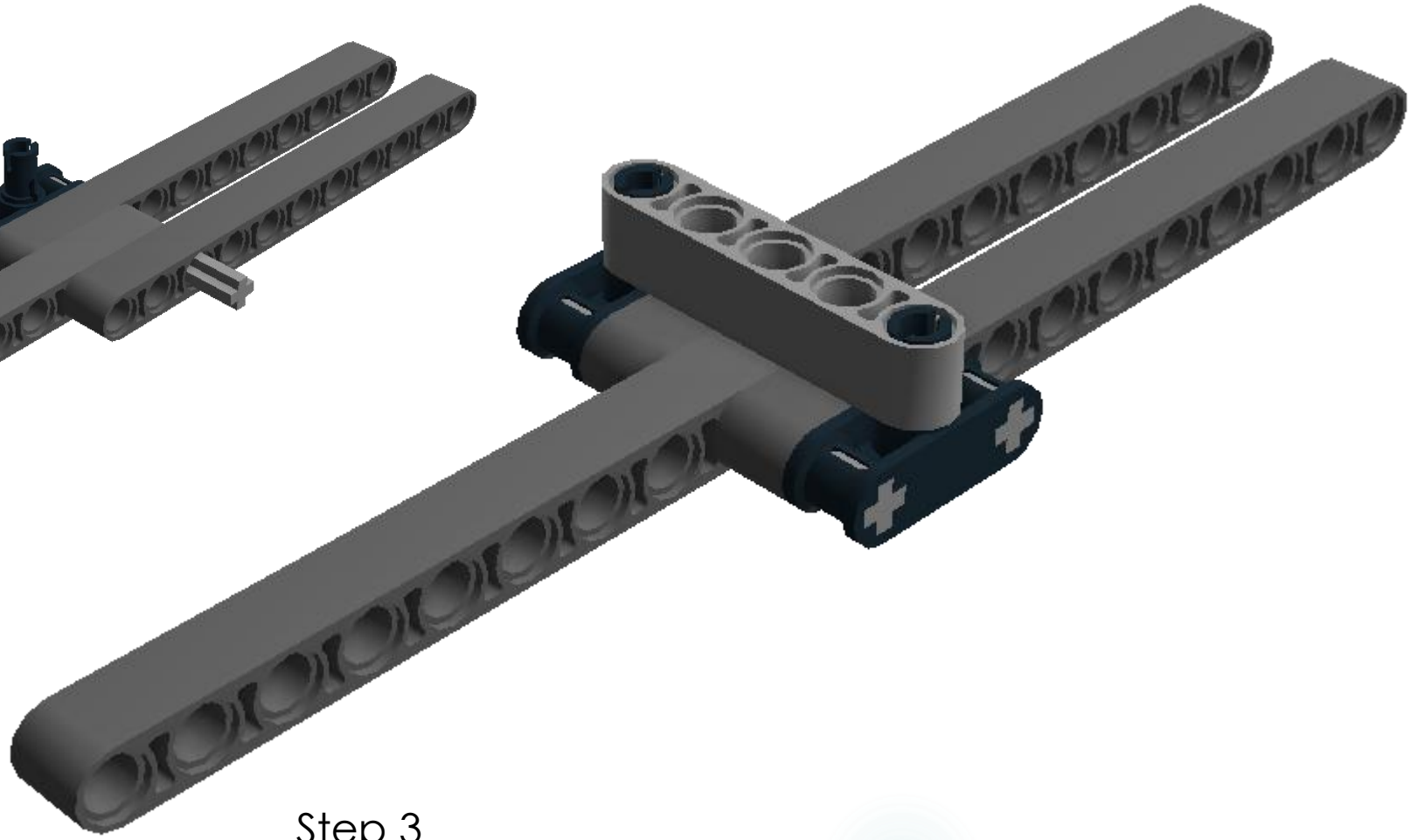
Bracing: Hands-on



Step 1



Step 2



Step 3

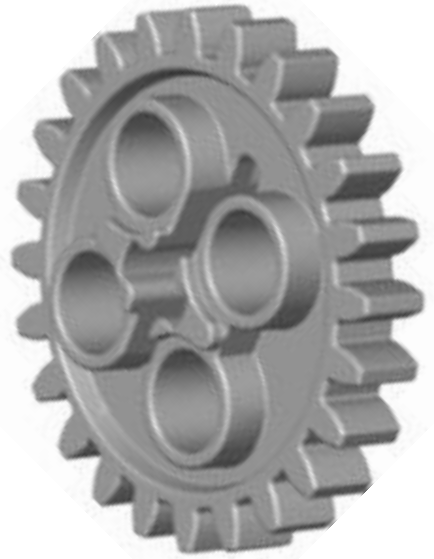
Axle connectors

- 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

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

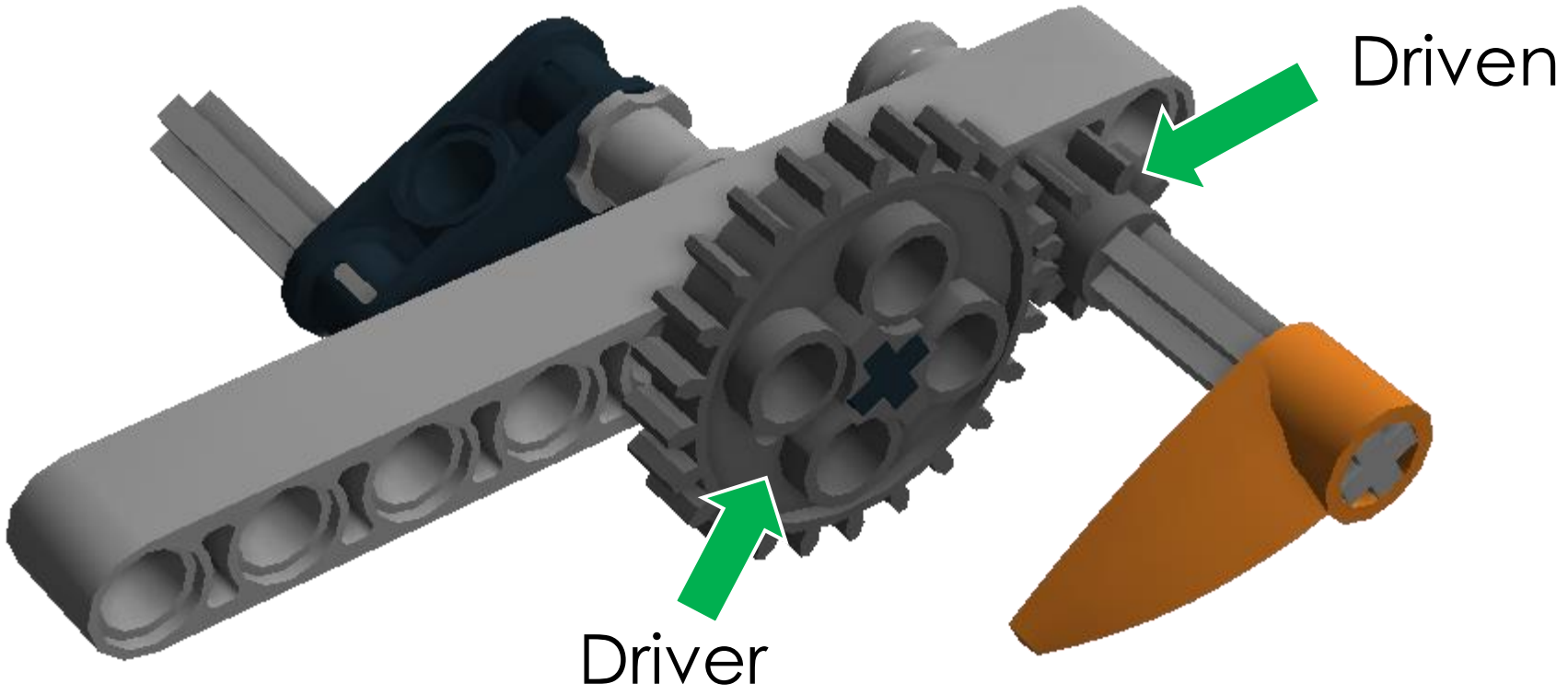




Gears

- 4565452 - Conical Wheel 12z
- 4640536 - Gear Wheel 16z
- 4177430 - Double Conical Wheel 20z 1M
- 4211510 - Worm gear
- 4255563 - Double Conical Wheel 36z

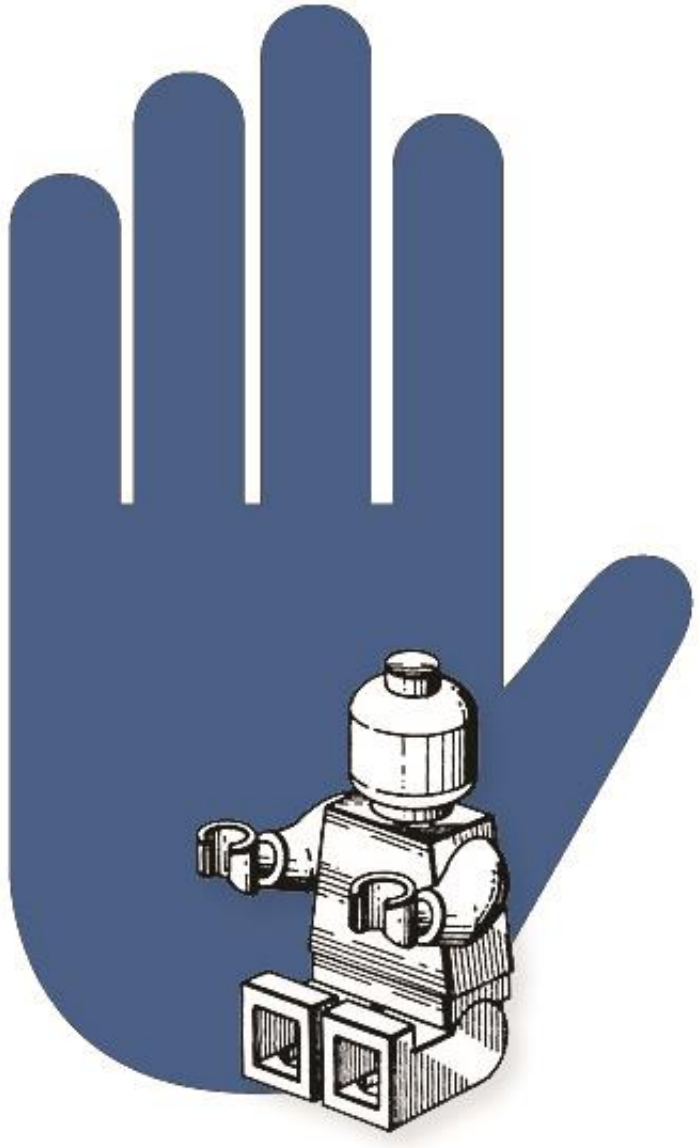
Gears



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

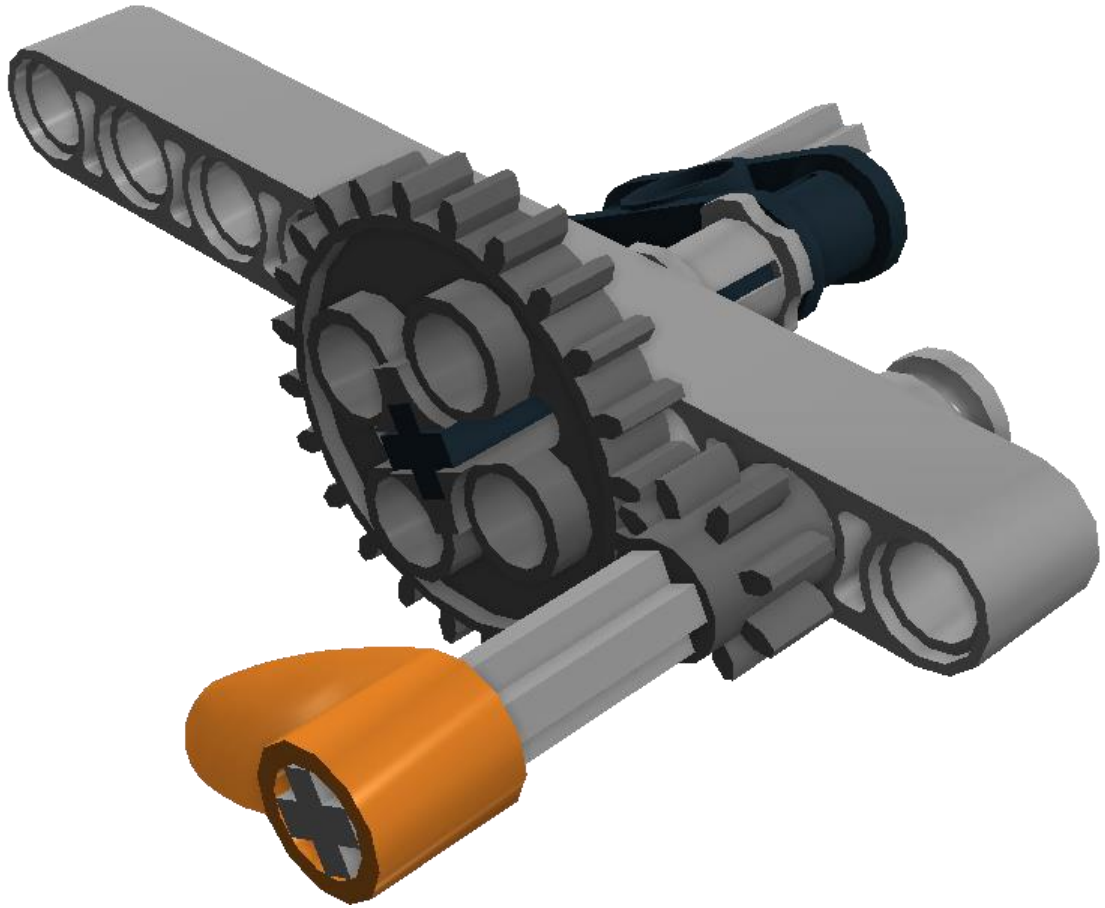
Gears

- Hands-on activity



Gears: Hands-on parts needed

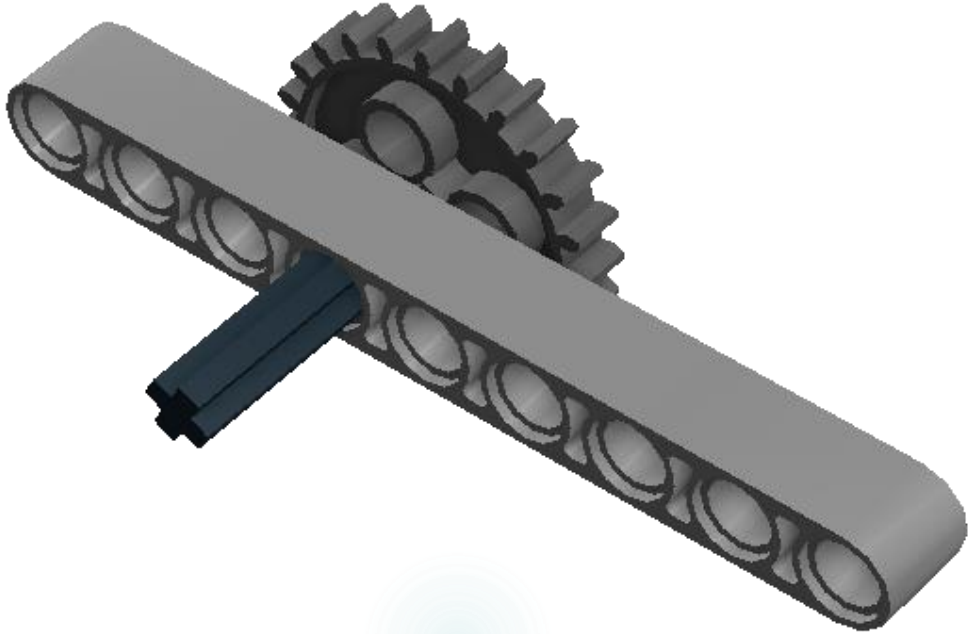
- 24z gear
- 8z gear
- 3m axle
- 4m axle
- 5m axle
- Double Cross Block
- Bionicle Eye
- Half-bushing
- bushing



Gears: Building instructions

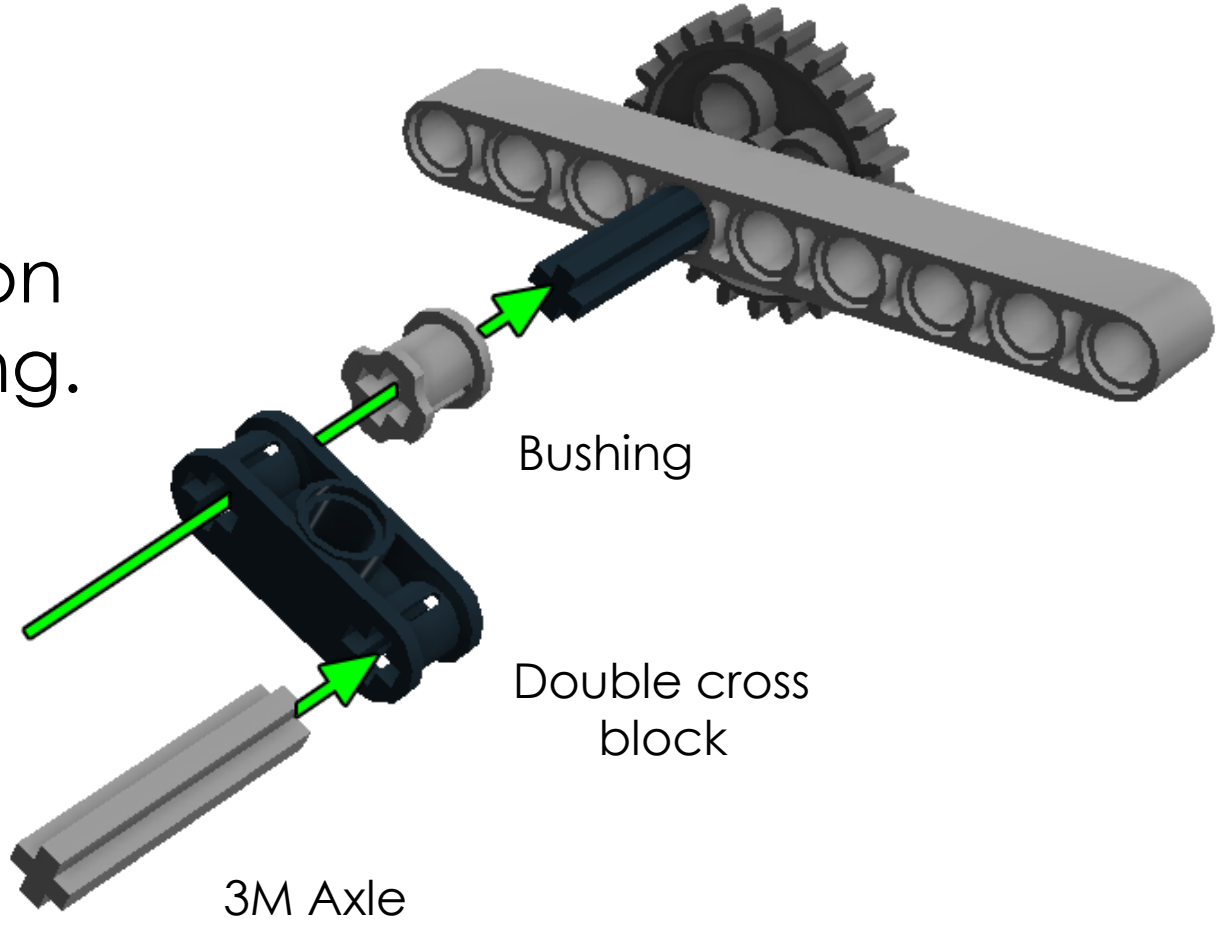
- Insert 4M axle into the 24z gear.

- Insert the gear assembly through the fourth hole in the beam.



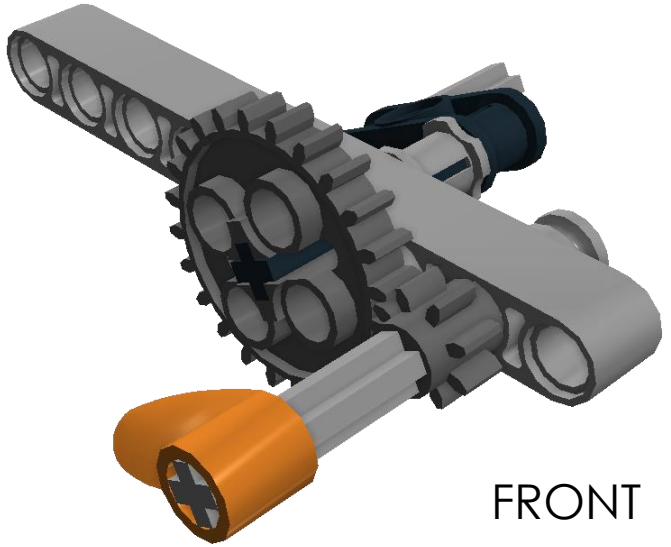
Gears: Building instructions

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

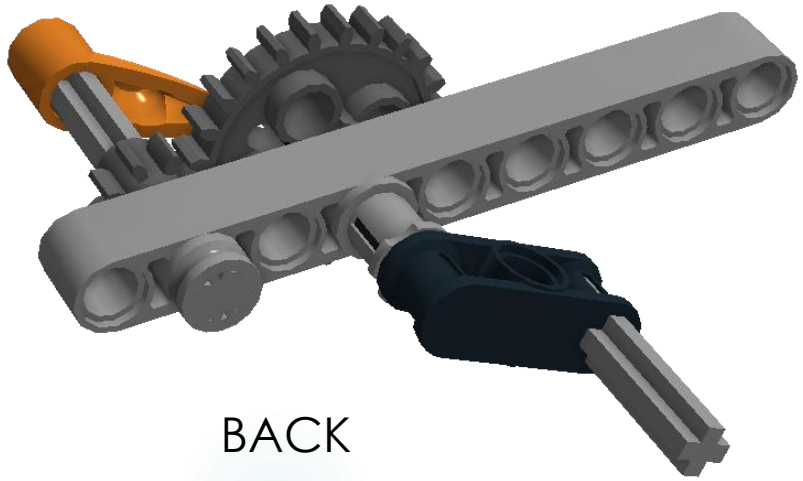


Gears: Building instructions

- Insert the 5M axle into the 8z gear.
- Insert the gear assembly into the second hole in the beam.
- Install the half-bushing onto the other side of the 5M axle.
- Install the orange bionicle eye on the other end.



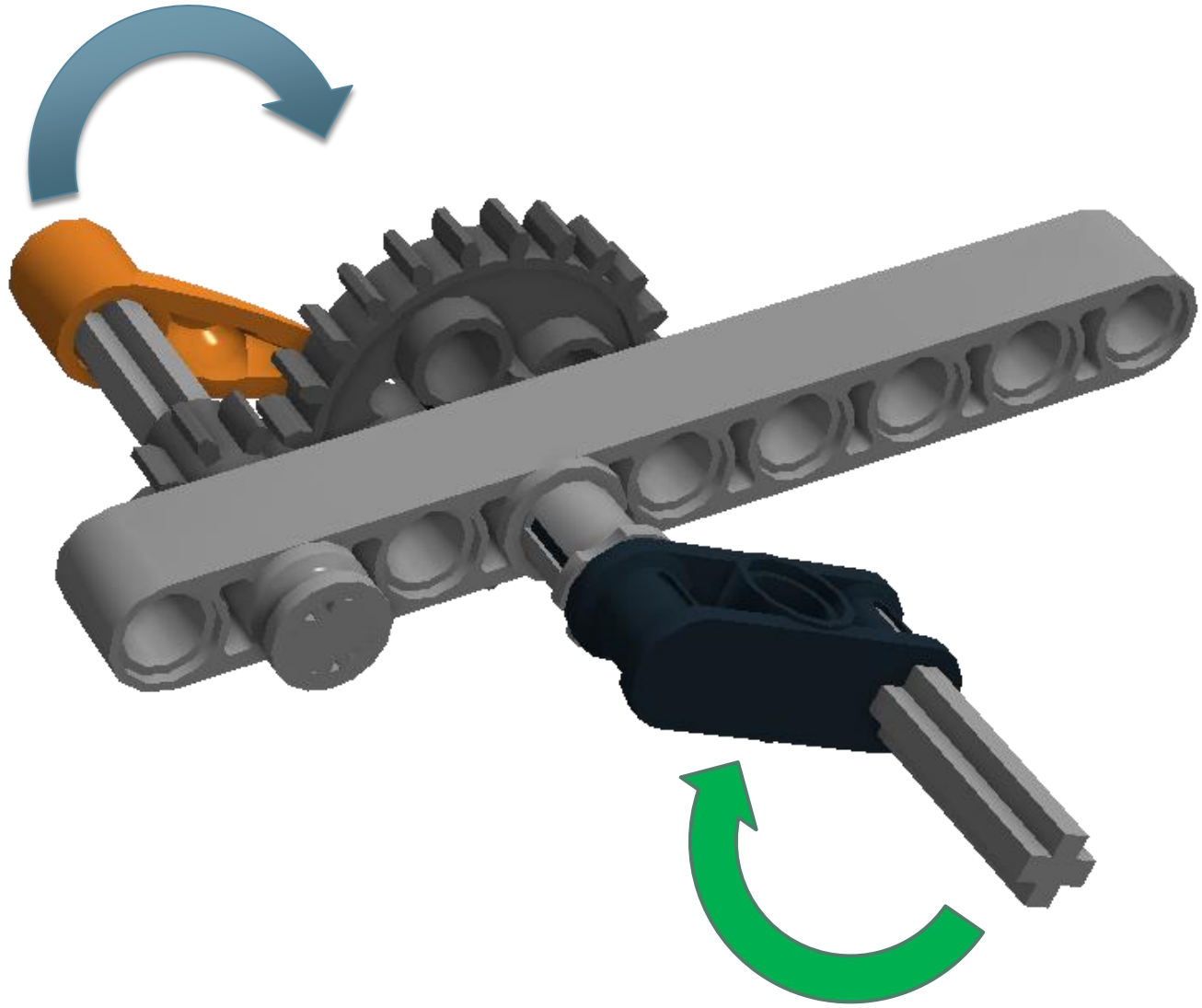
FRONT



BACK

Gear: 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?

- Switch the crank and bionicle eye. Repeat the test.

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

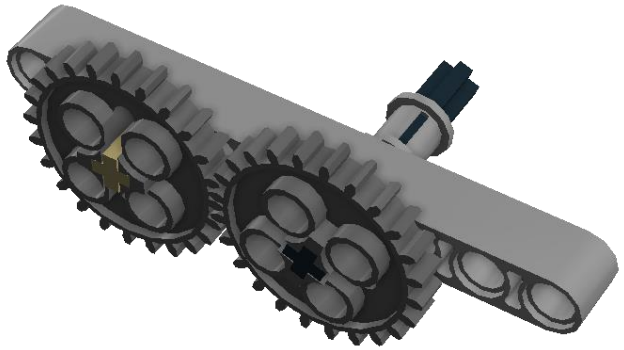
Stable combination

Unstable combination

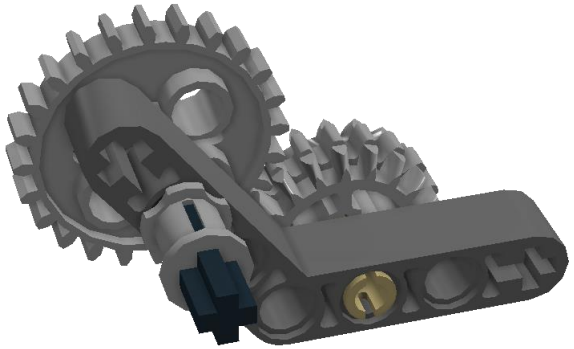
Unknown Combination

Gear combinations

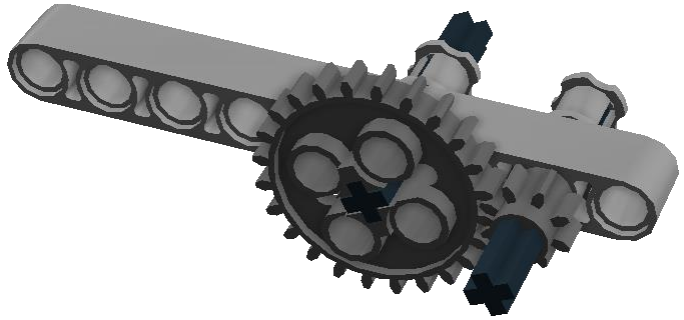
http://gears.sariel.pl/



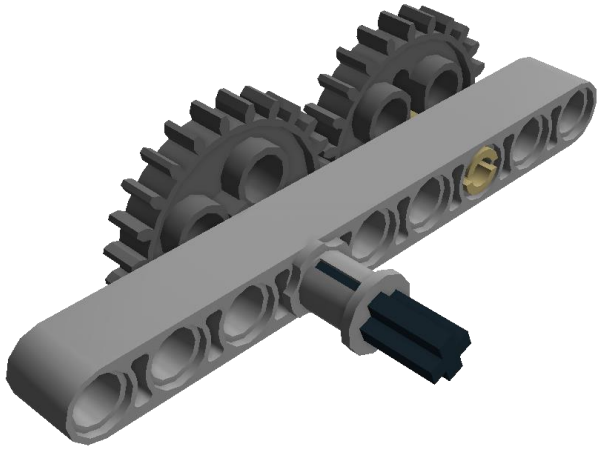
24z to 24z (1:1)

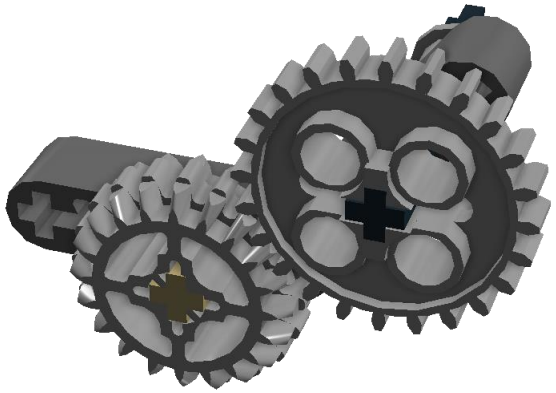


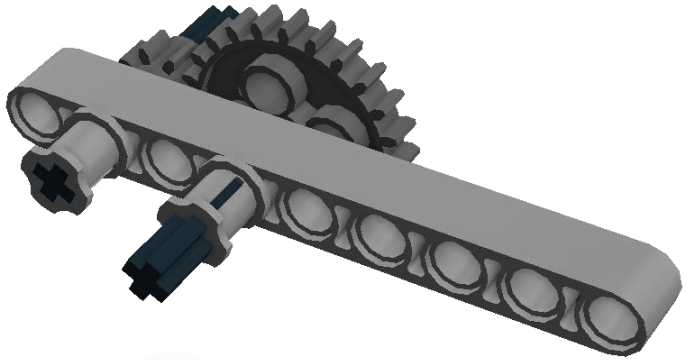
20z to 24z (5:6)



24z to 8z (3:1)





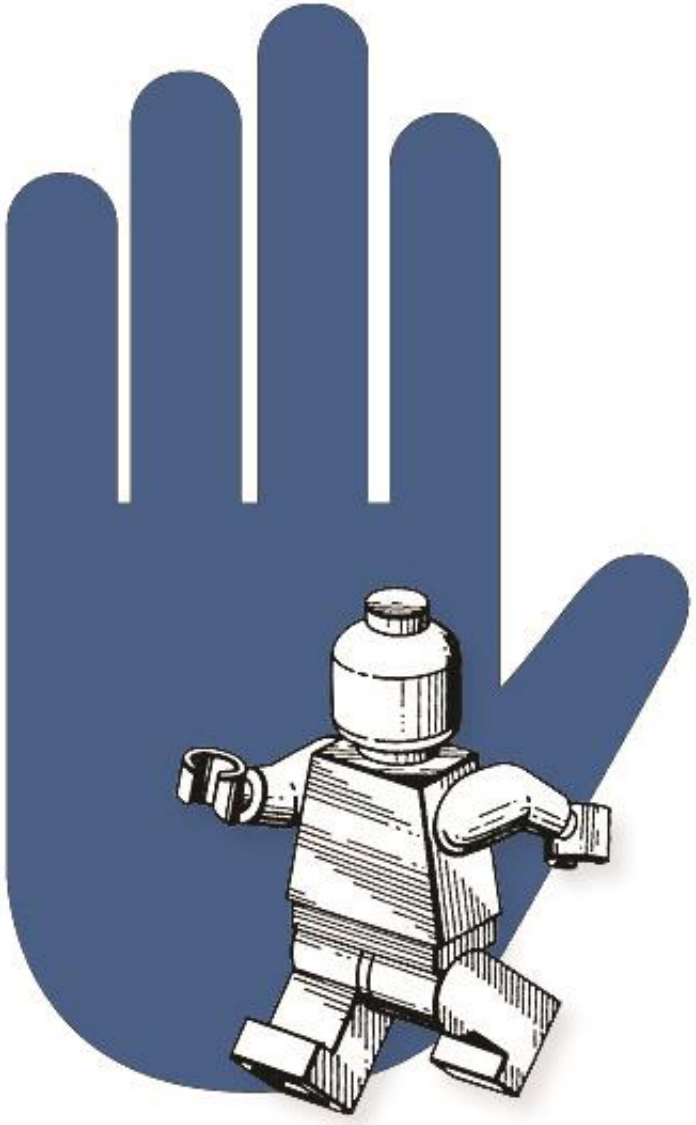


Gears: Motion Transfer

- How can you achieve linear motion?

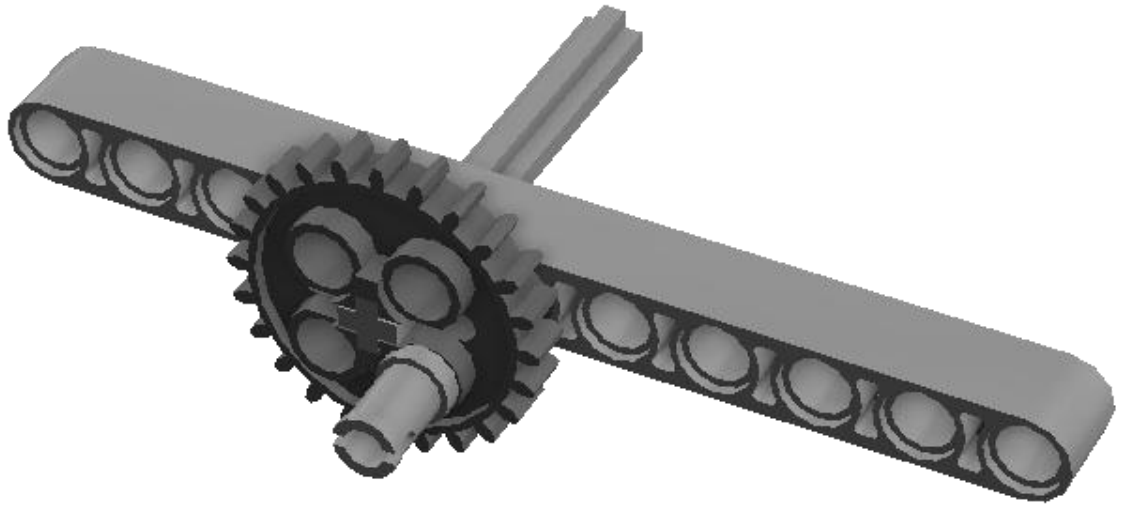
Motion Transfer

- Hands-on activity



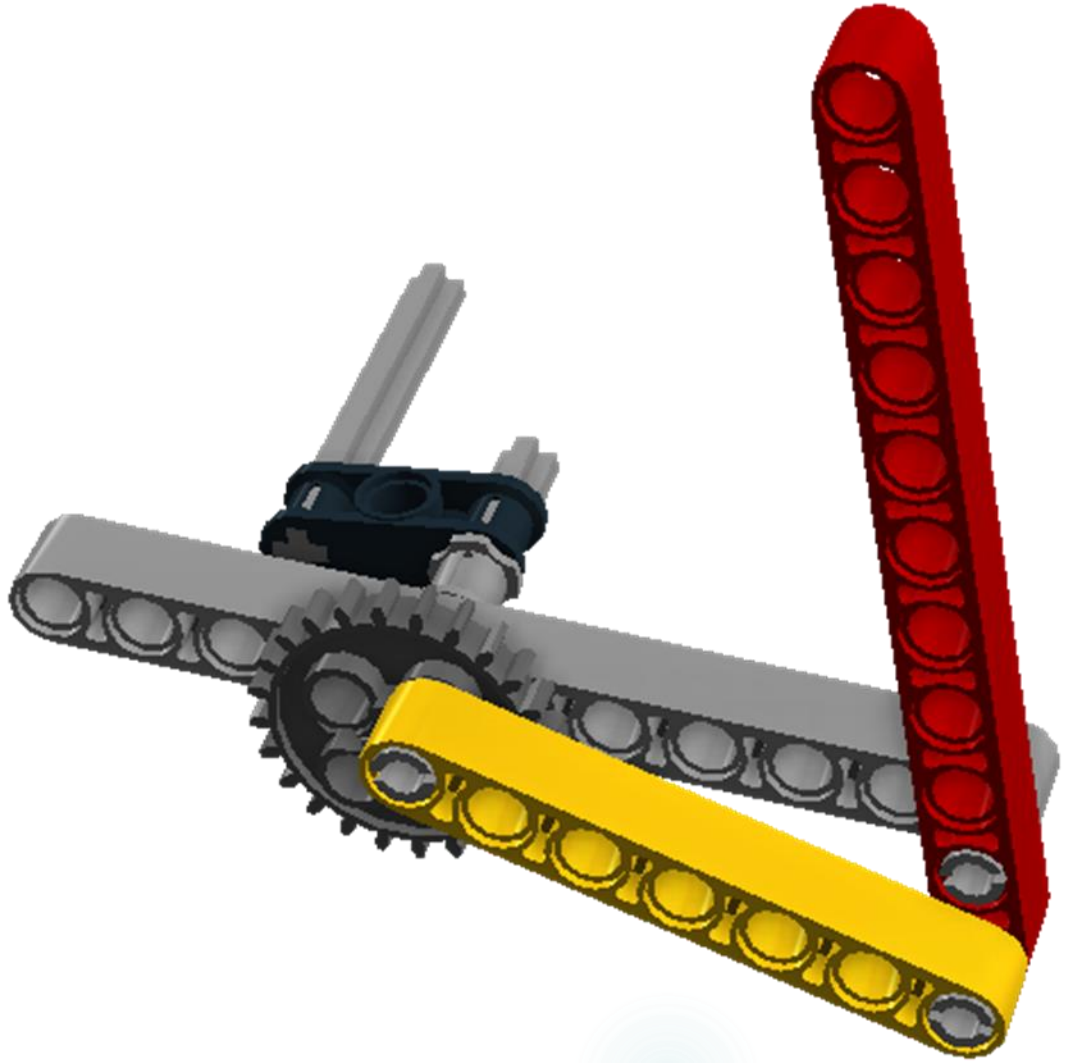
Motion Transfer: Building instructions

- Place 5M axle in 24z gear.
- Insert gear into fifth hole in an 11M beam.
- Insert gray non-fraction peg into hole on gear.



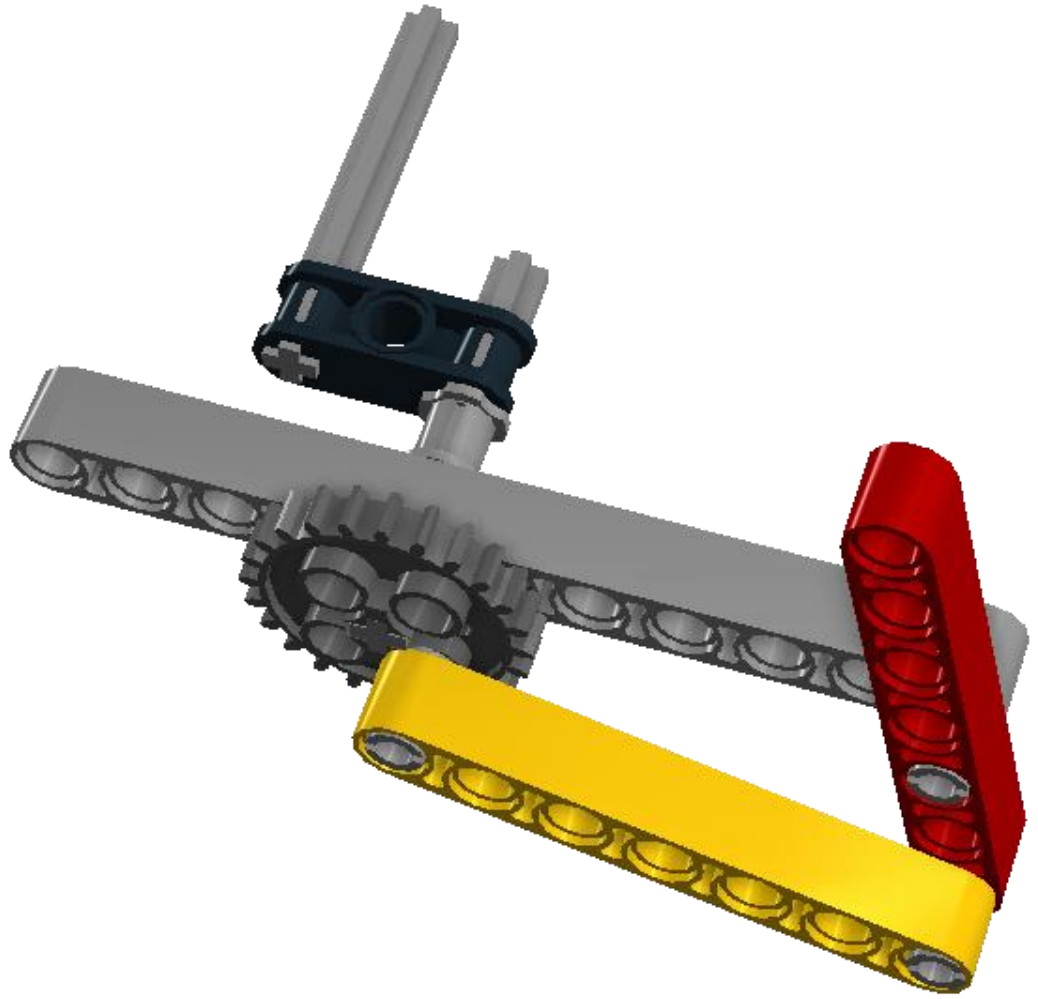
Motion Transfer: Building instructions

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



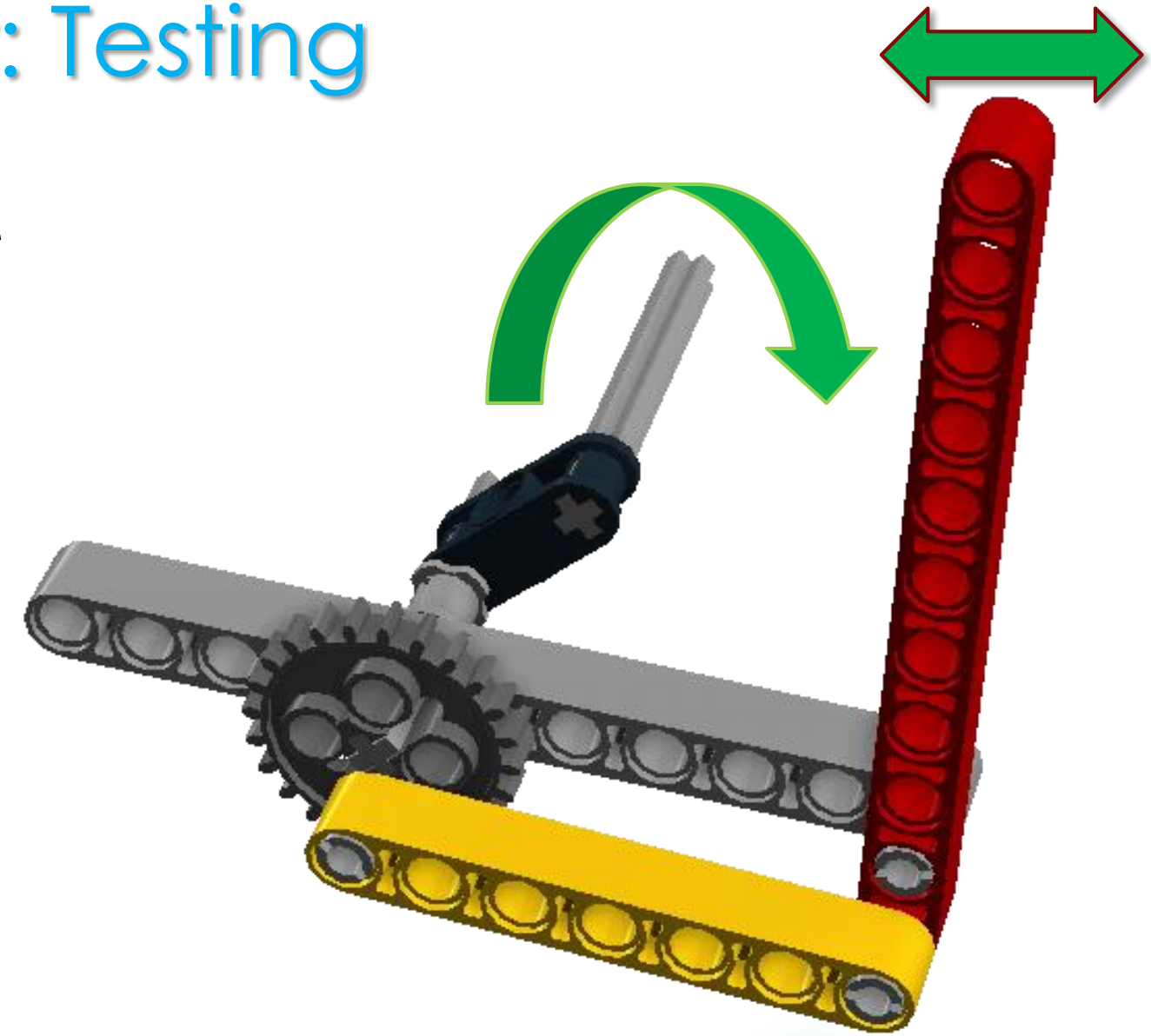
Motion Transfer: Building instructions

- 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.



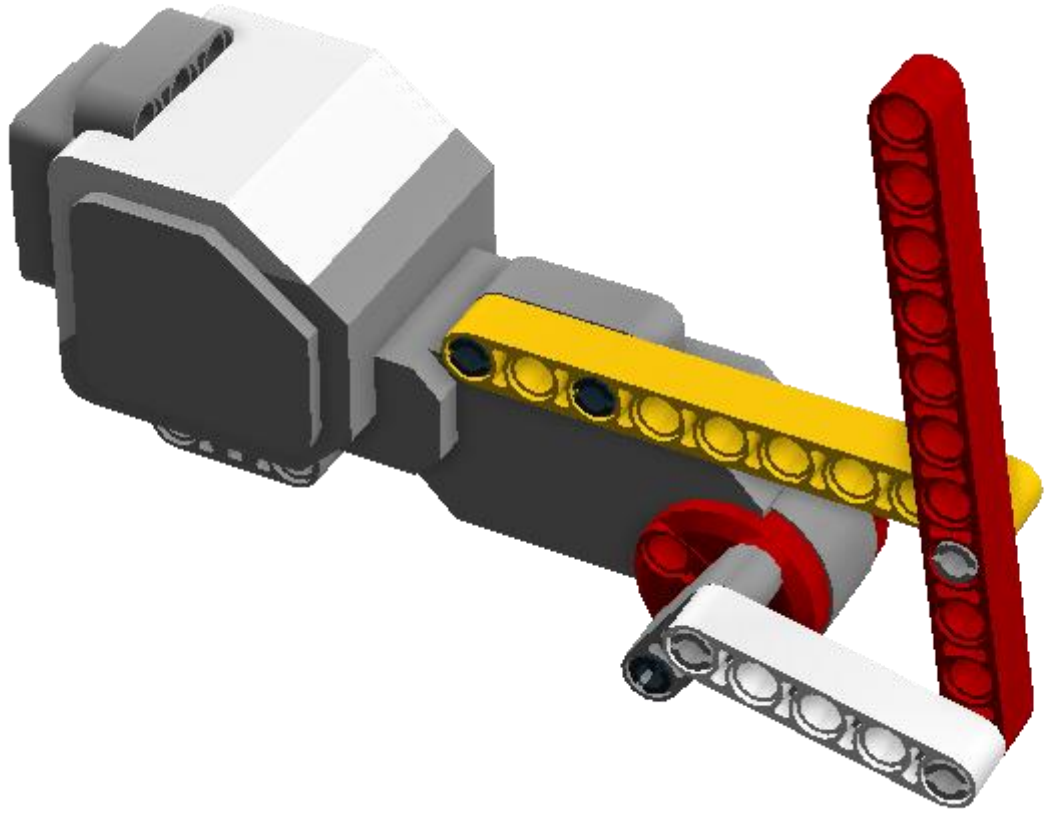
Motion Transfer: Testing

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

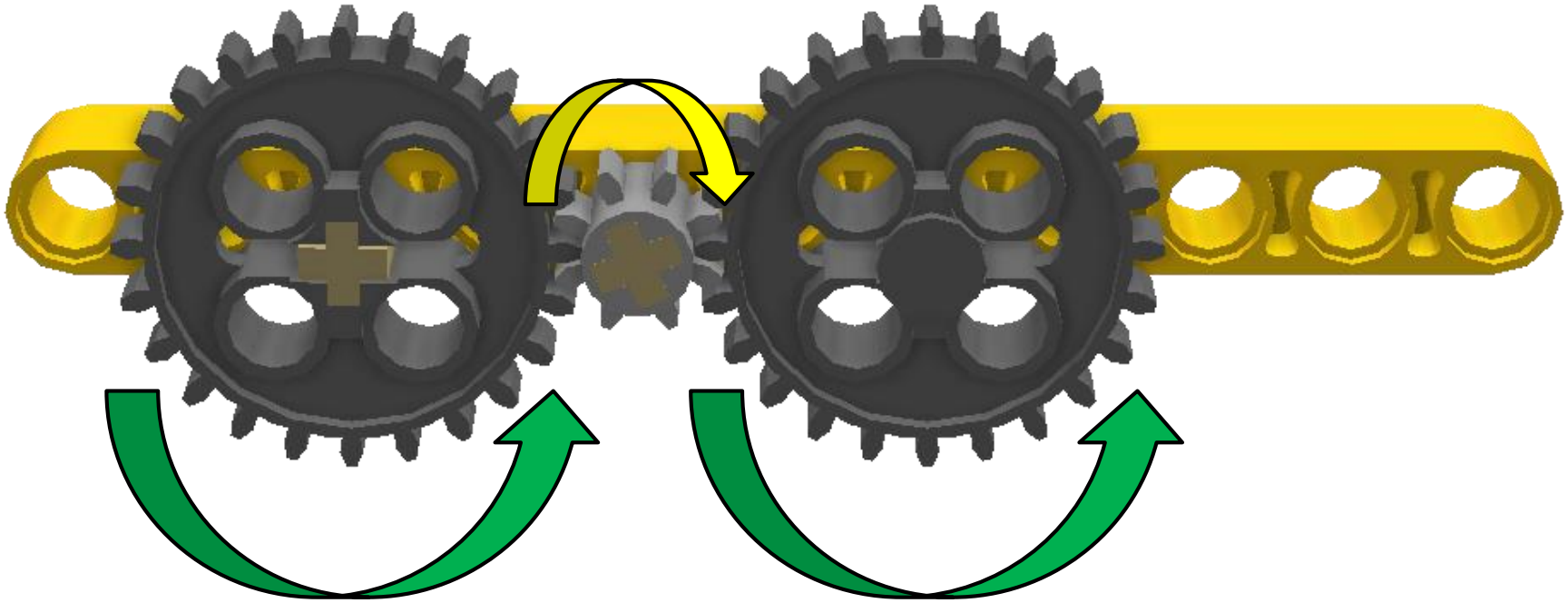


Linear Motion with a motor

- 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

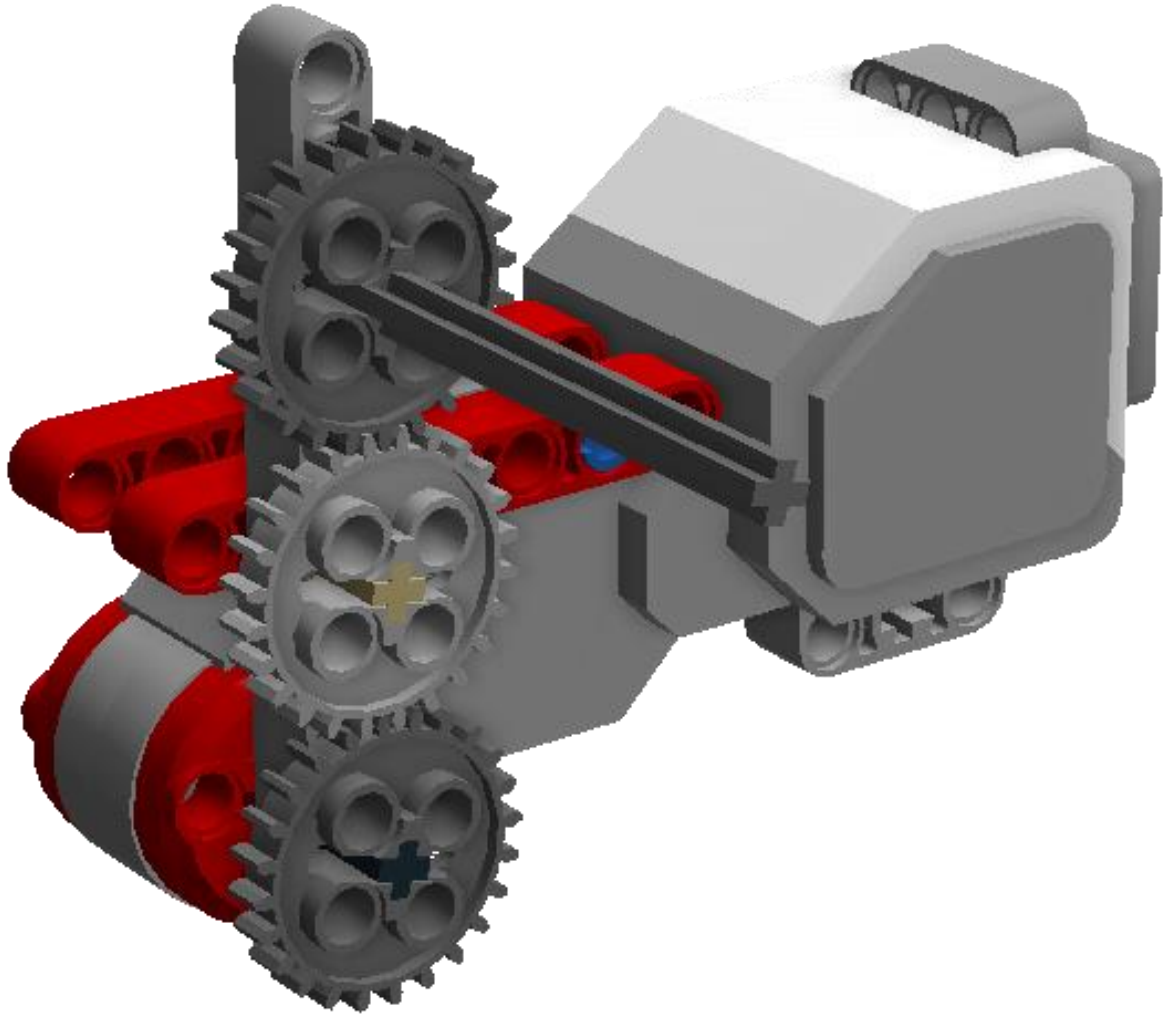
Gear 24z

Gear 24z

Gear 8z

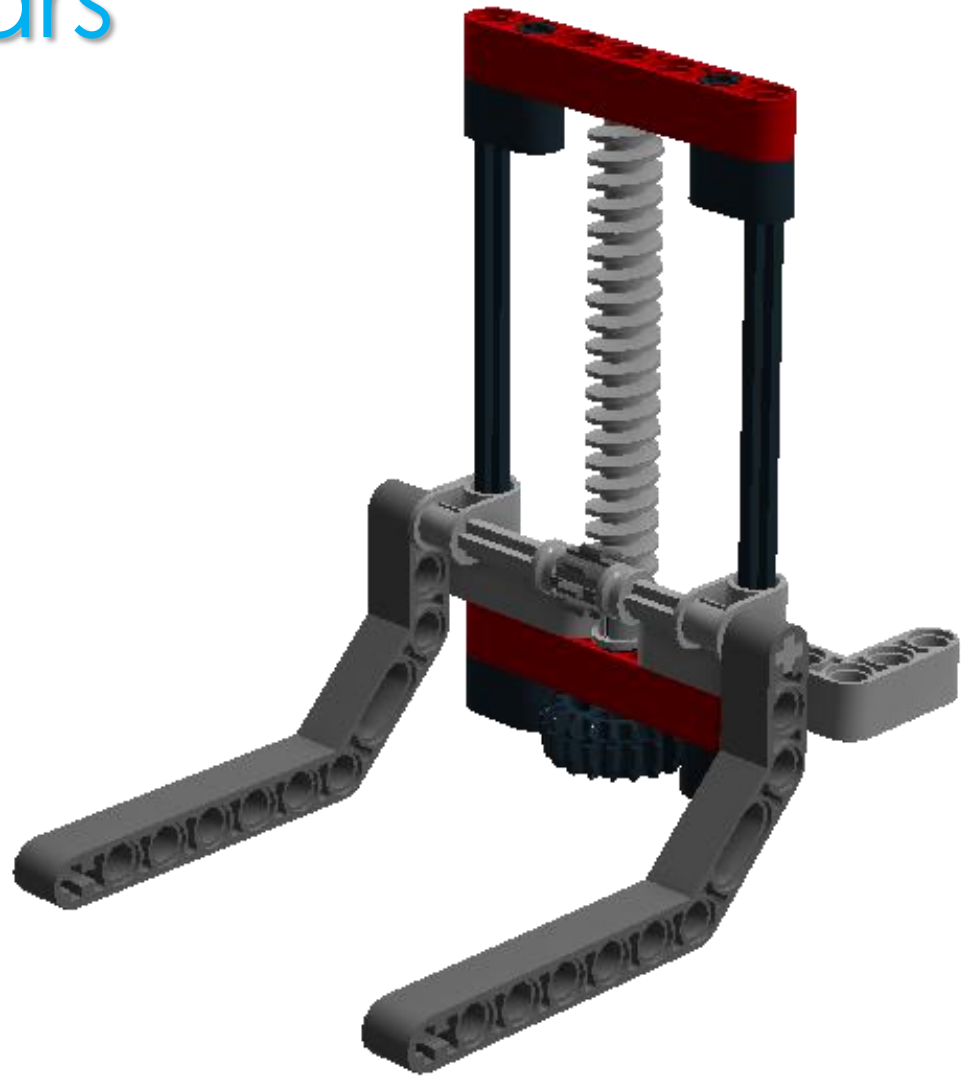
(1:3) x (3:1) = 3:3 or 1:1

Gears and Motors



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

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

Caster, Wheels, and Miscellaneous

Wheels (Tyres), Rims, and Tracks

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

6035364: Tyre Low Wide 56 X 28

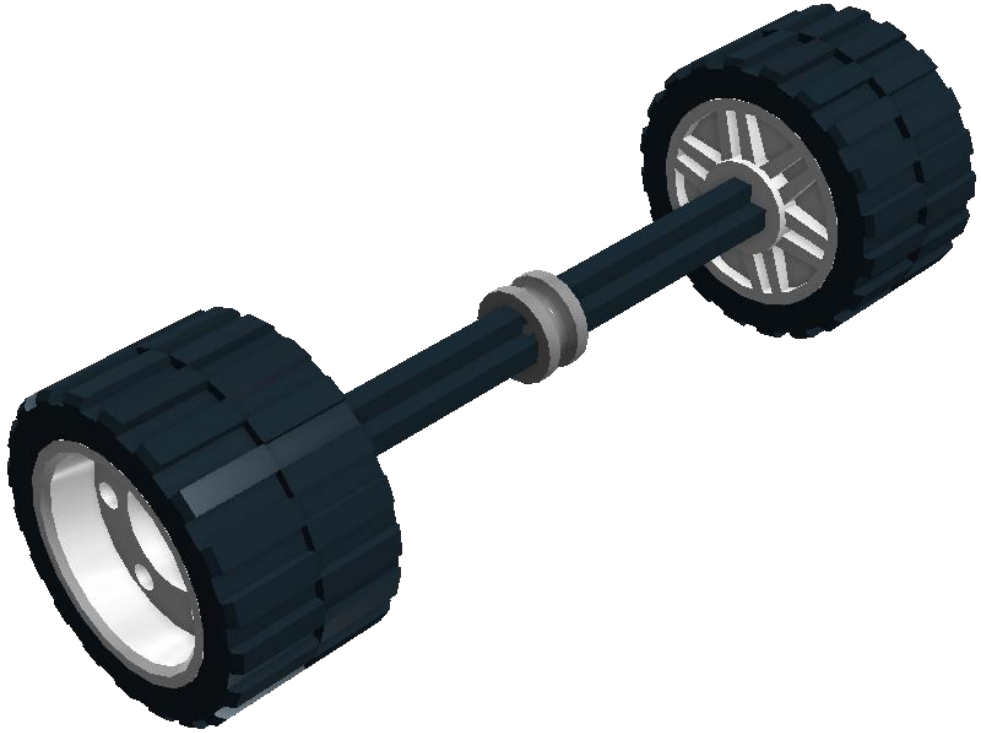
4634091: Rim Wide 43.2 X 26 with 6 Holes

6014648: Track Element, 5X1.5

4582792: Sprocket, Ø¸40,7

Simple Wheel Matching

- Assembly 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
- 417394:1Bionicle Eye
- 4563044: 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

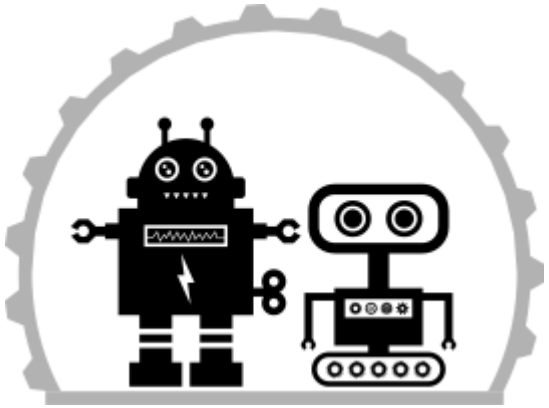
4541326 Left Panel 5X11

4566249 Right Panel 3X5

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.

Presentation available at:



http://www.roboplex.org/fll