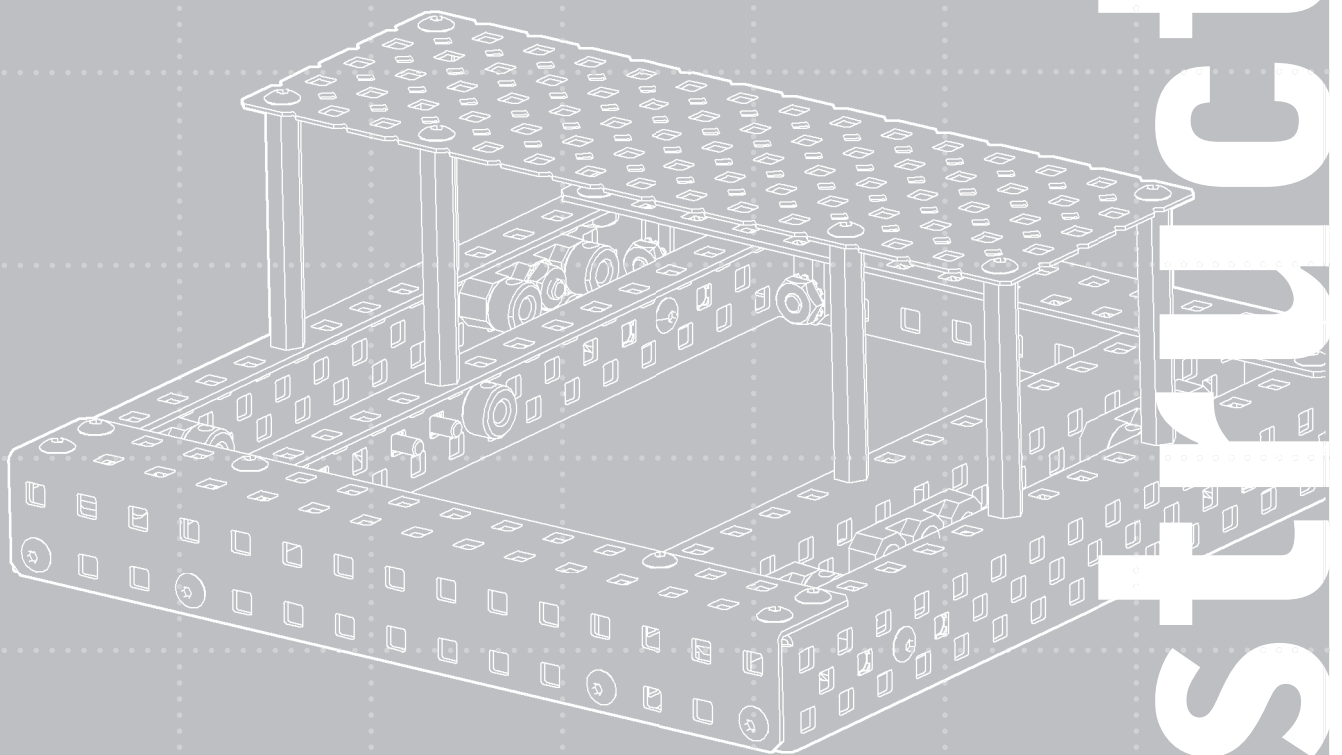


The structural subsystem of the robot is responsible for physical support. It holds everything in place, and is, in effect, the durable “skeleton” of the robot to which all the other subsystems are attached.



structure

structure

table of contents:

squarebot chassis parts and assembly	2.2
concepts to understand	2.27
subsystems interfaces	2.37
structure subsystem inventory	2.38

squarebot chassis parts and assembly

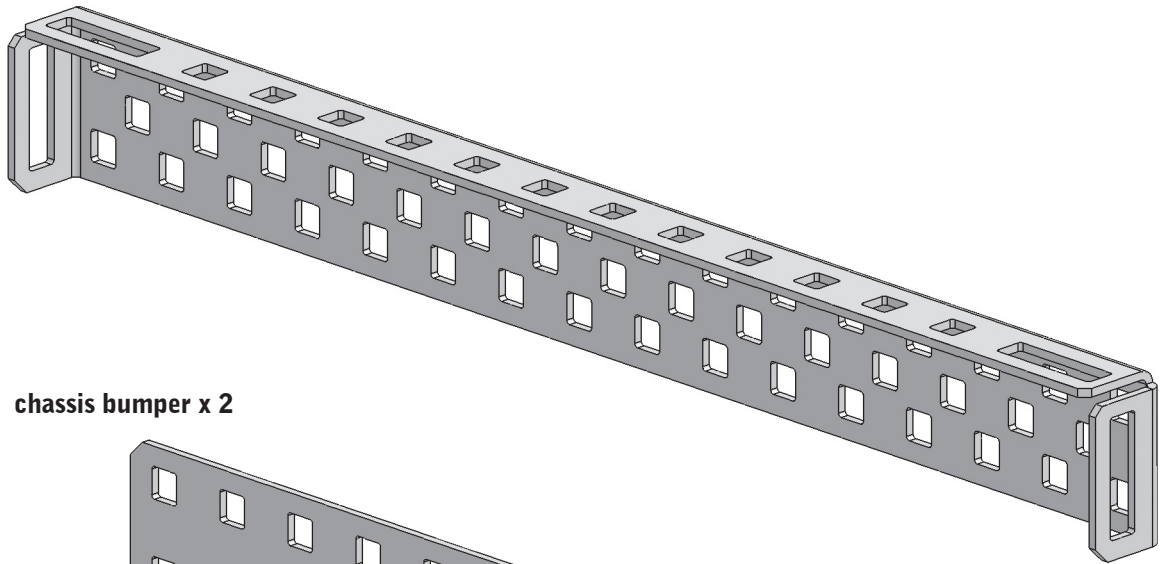
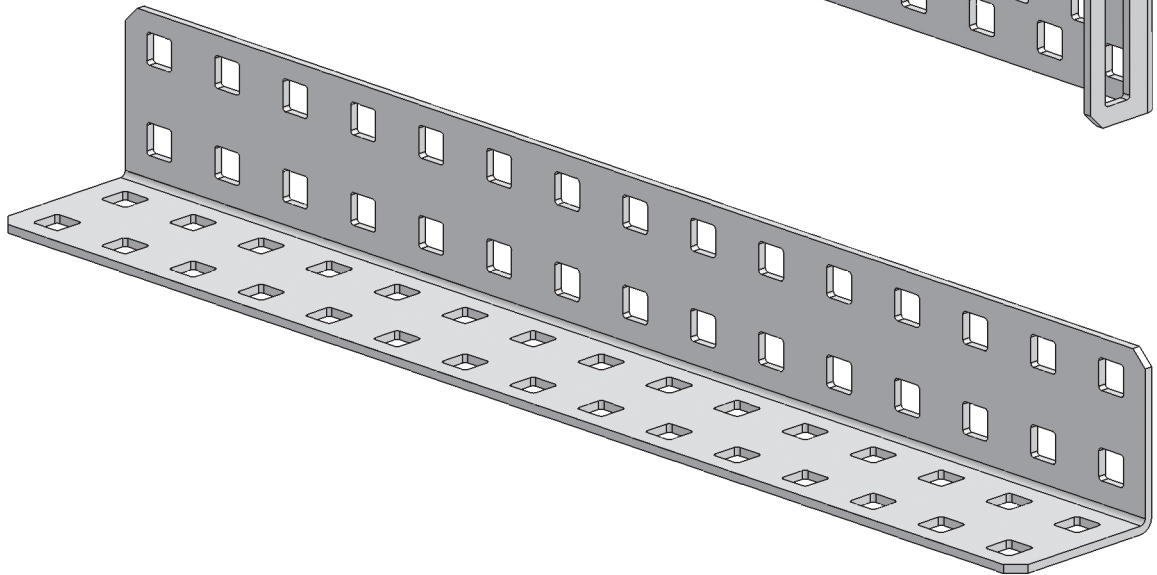
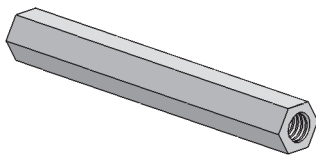
The Structure and Motion subsystems are very tightly integrated to form the chassis of the Squarebot.

The chassis assembly instructions refer to components from both the Structure and Motion sections.

Follow the steps in this section to build the chassis.

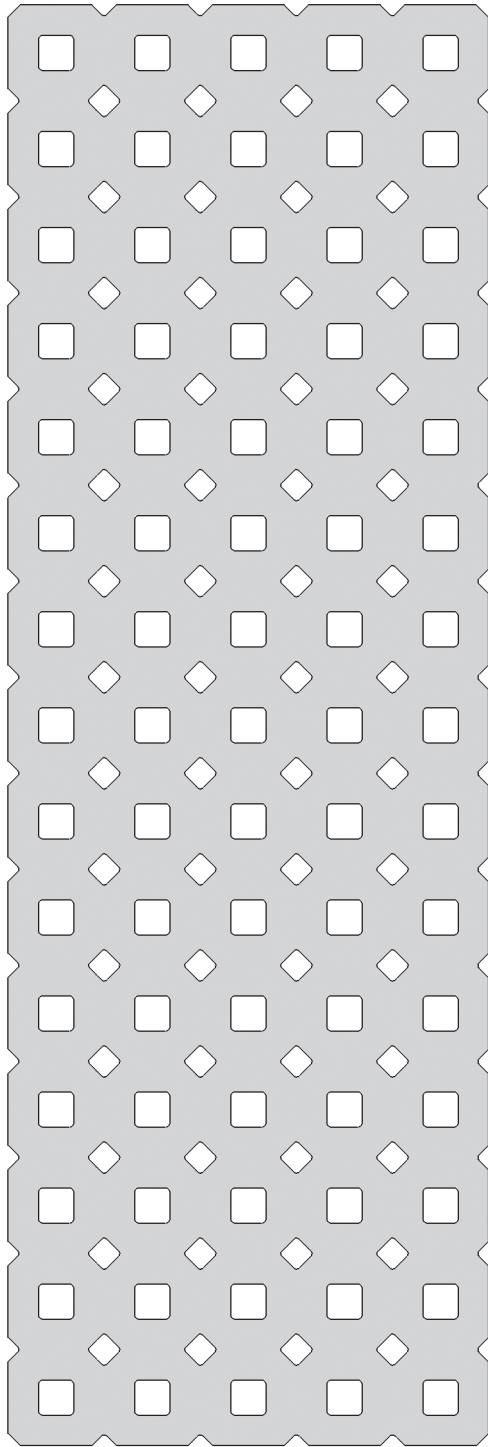
1 Collect and identify the parts from the list of materials below:

	materials	qty
structure subsystem	bearing flat	12
	panel	1
	chassis rail	4
	chassis bumper	2
	partially threaded beams, 2"	4
	keps nut	38
	8-32 hex screw, 1/4"	26
	8-32 hex screw, 1/2"	20
motion subsystem	motor	2
	2.75" removable tire	4
	1.895" detachable hub	4
	36-tooth gear	4
	60-tooth gear	2
	collar w/ threaded set screw	10
	square bar, 2"	2
	square bar, 3"	4
	6-32 hex screw, 1/2"	4

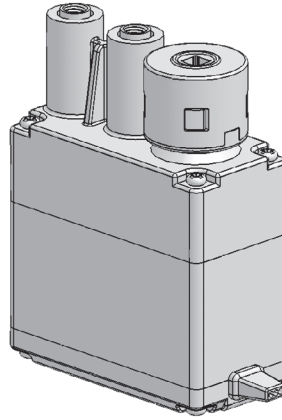
squarebot chassis parts and assembly, continued**chassis rail x 4****chassis bumper x 2****2" partially threaded beam x 4****8-32 hex screw, 1/4" x 26****keps nut x 38****8-32 hex screw, 1/2" x 20****6-32 hex screw, 1/2" x 4**

squarebot chassis parts and assembly, continued

panel x 1



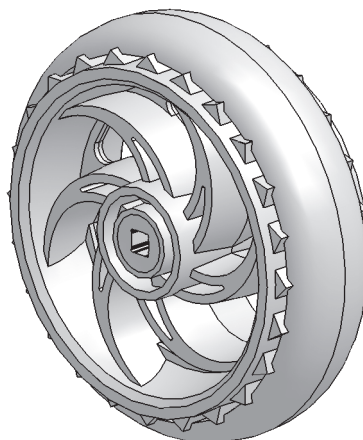
motor x 2

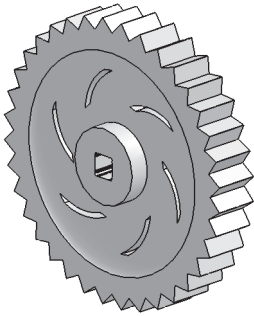
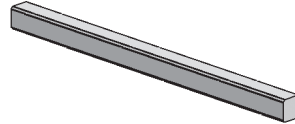
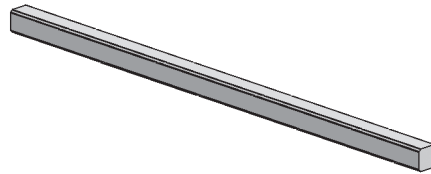
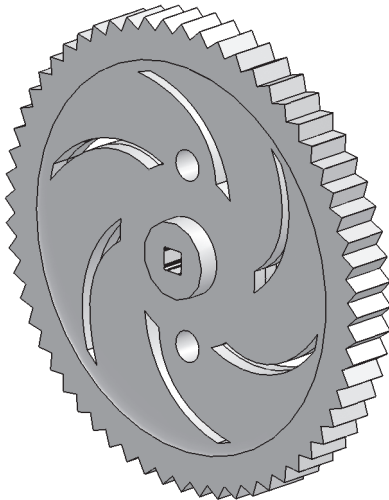
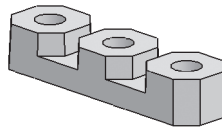


2.75" removable tire x 4



1.895" detachable hub x 4

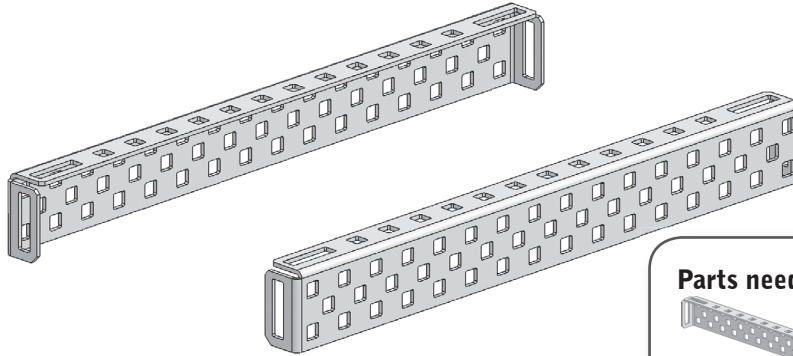


squarebot chassis parts and assembly, continued**36 tooth gear x 4****collar w/threaded set screw x 10****square bar, 2" x 2****square bar, 3" x 4****60 tooth gear x 2****bearing flat x 12**

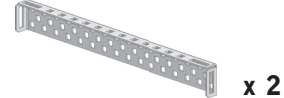
squarebot chassis parts and assembly, continued

2 Inner chassis rails

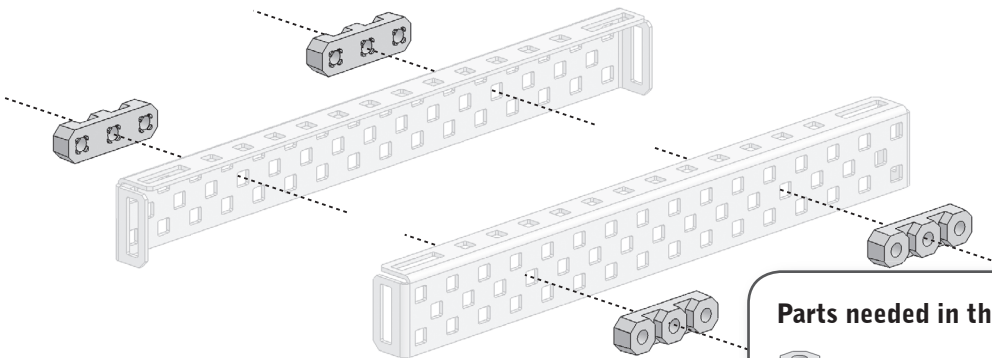
You will need two chassis rails, one for the right side and one for the left side. Orient them as shown, so that the narrow face is pointing up and the “open” sides are facing each other.



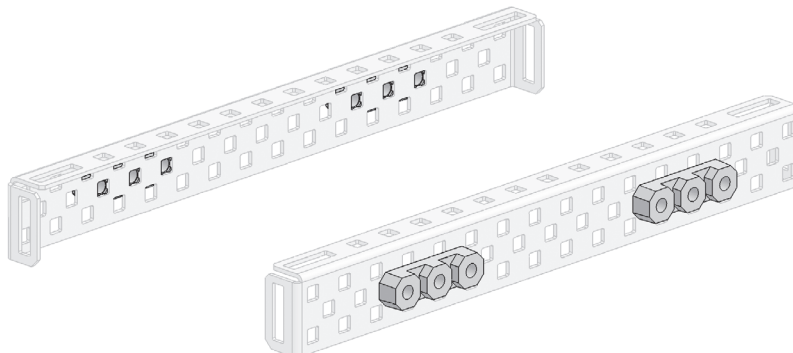
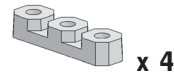
Parts needed in this step:



Add four bearing flats to the chassis rails (two per rail, on the outward-facing sides). Be sure to position the bearing flats such that the central hole of each bearing flat is aligned with the fourth hole from the respective end of the chassis rail, as shown.



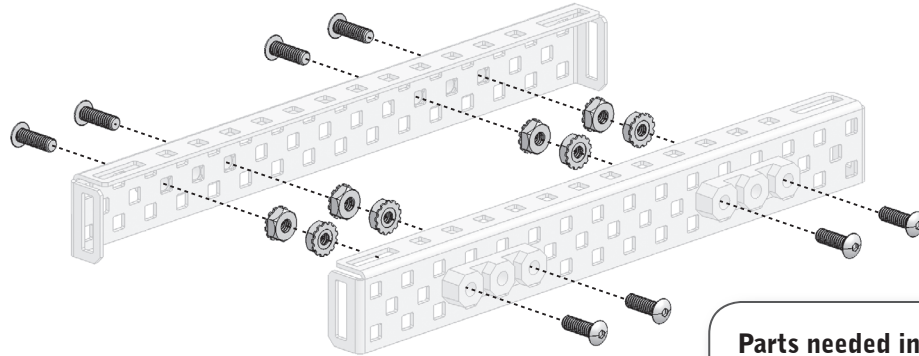
Parts needed in this step:



squarebot chassis parts and assembly, continued

2 Inner chassis rails, continued

Secure the bearing flats to the chassis rails using two $\frac{1}{2}$ " 8-32 screws and two keps nuts per bearing flat, as shown.



Parts needed in this step:

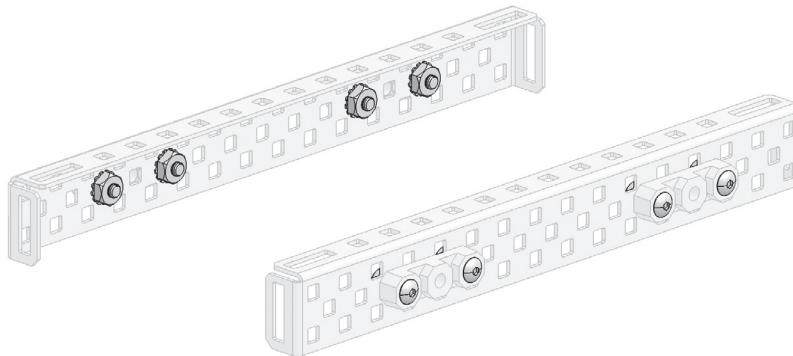


$\frac{1}{2}$ "
x 8



x 8

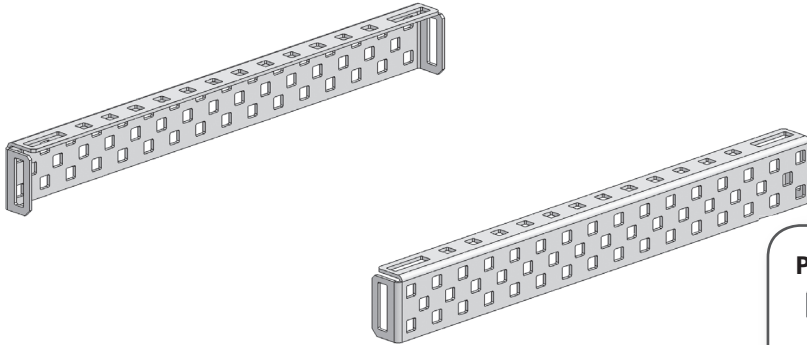
Your completed inner chassis rails should look like this when you're done:



squarebot chassis parts and assembly, continued

2 Outer chassis rails

Position two more chassis rails as shown, just as you did for the inner chassis rails.

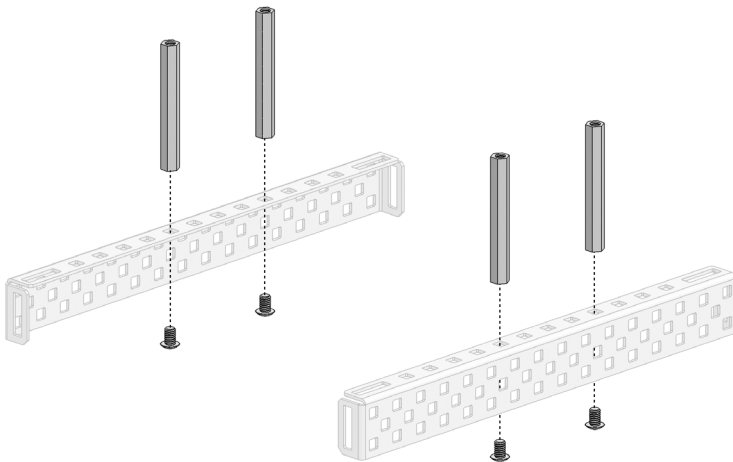


Parts needed in this step:

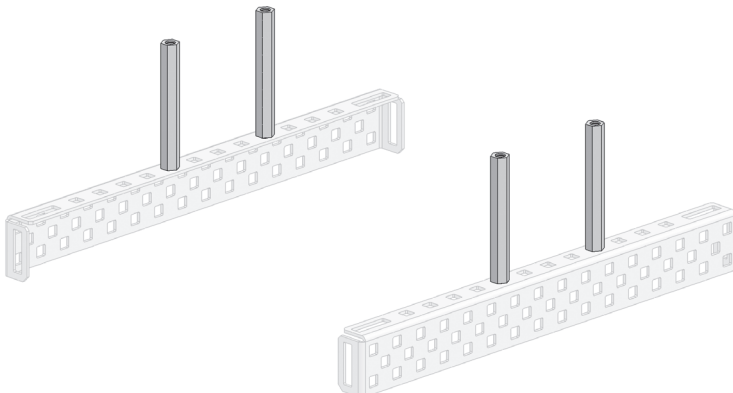


x 2

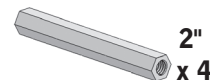
Connect two 2" partially threaded beams to each of the rails, using a $\frac{1}{4}$ " 8-32 screw for each beam. Position the rear beam on the fourth square hole from the back end of the chassis rail, and the front beam on the fifth square hole from the front end of the chassis rail.



12	□	12
11	□	11
10	□	10
9	●	9
8	□	8
7	□	7
6	□	6
5	●	5
4	□	4
3	□	3
2	□	2
1	□	1



Parts needed in this step:



2"
x 4



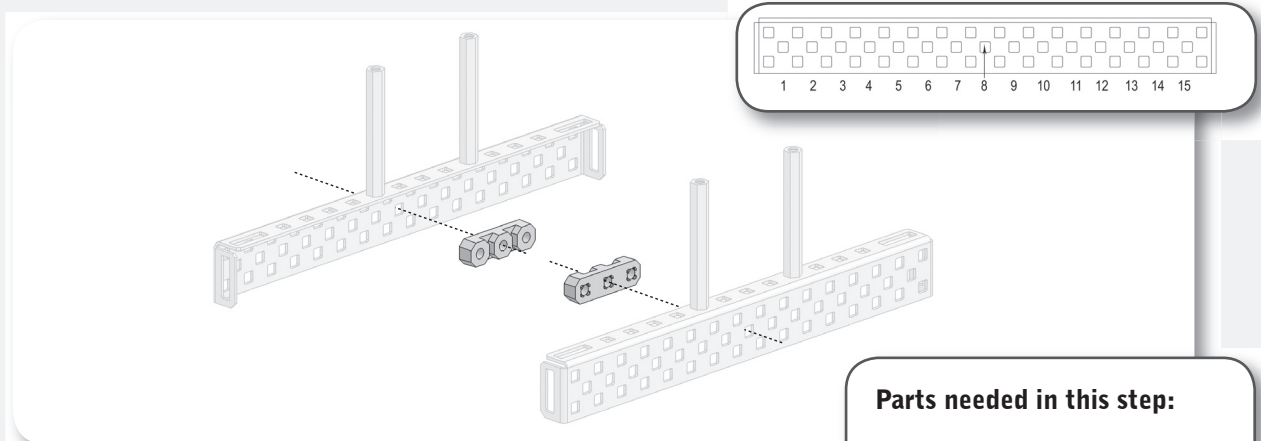
$\frac{1}{4}$ "
x 4

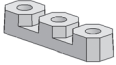
squarebot chassis parts and assembly, continued

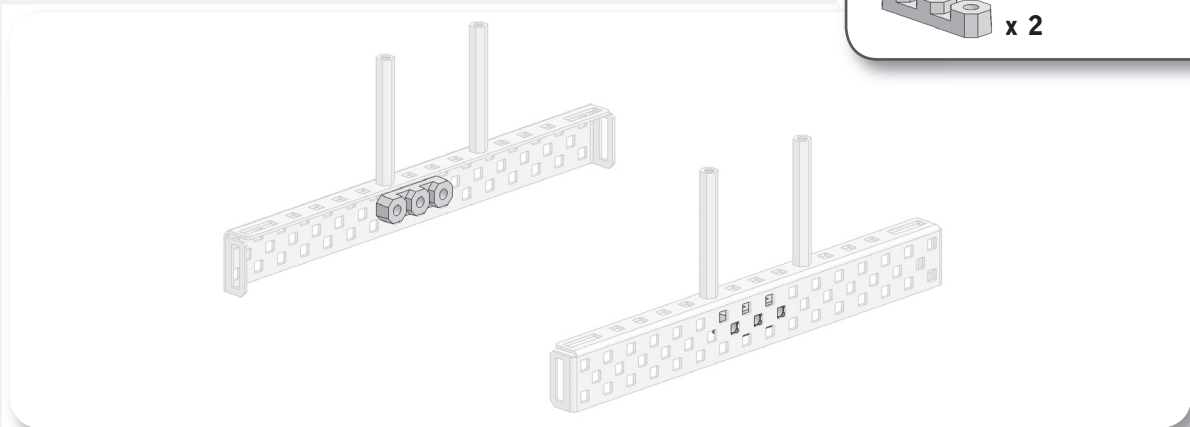
2 Outer chassis rails, continued

Add bearing flats to the inner faces of the two chassis rails.

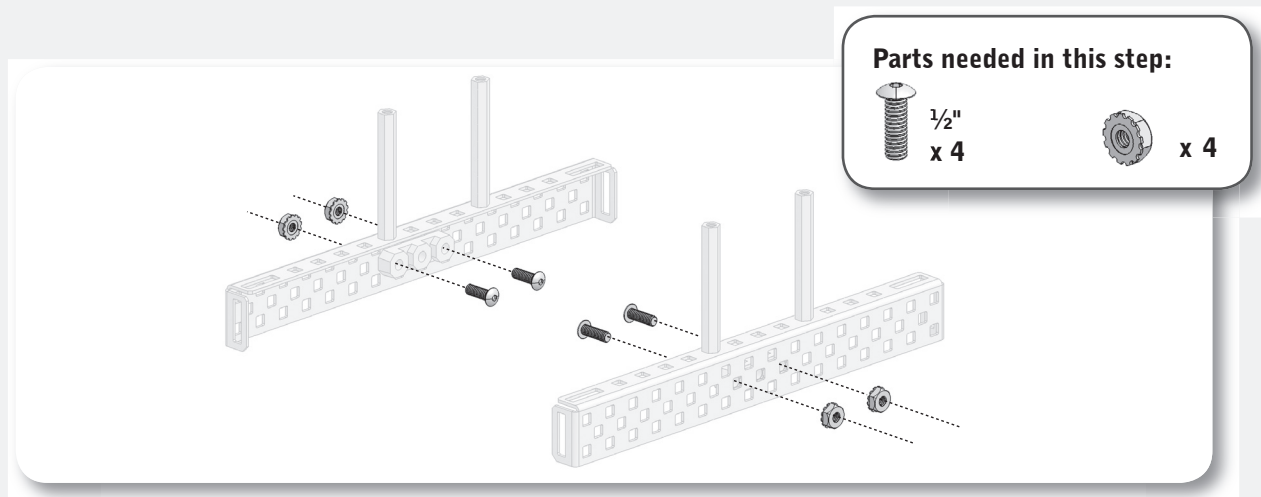
The center hole of the bearing flat should be aligned with the eighth hole from the front end of the chassis rail, in the middle row of holes.



 x 2



Secure each bearing flat with two $\frac{1}{2}$ " 8-32 screws and two keps nuts.



 $\frac{1}{2}$ "
x 4

 x 4

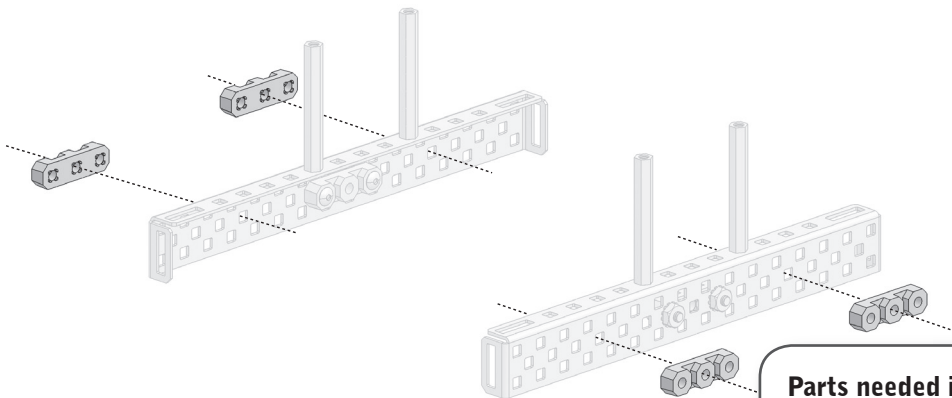
squarebot chassis parts and assembly, continued

2 Outer chassis rails, continued

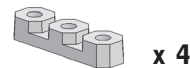
Your outer chassis rails should now look like this:



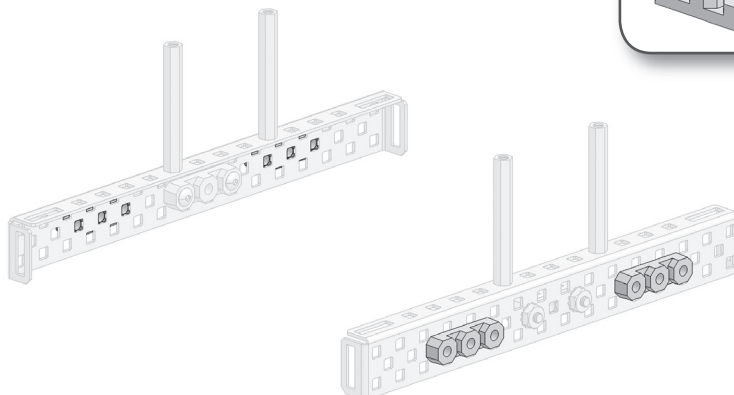
Now add two bearing flats to the outer surface of each chassis rail, so the center hole of each bearing flat is over the fourth hole from the respective end of the chassis rail, as shown. These are the same positions as the bearing flats you put on the inner chassis rails earlier.



Parts needed in this step:



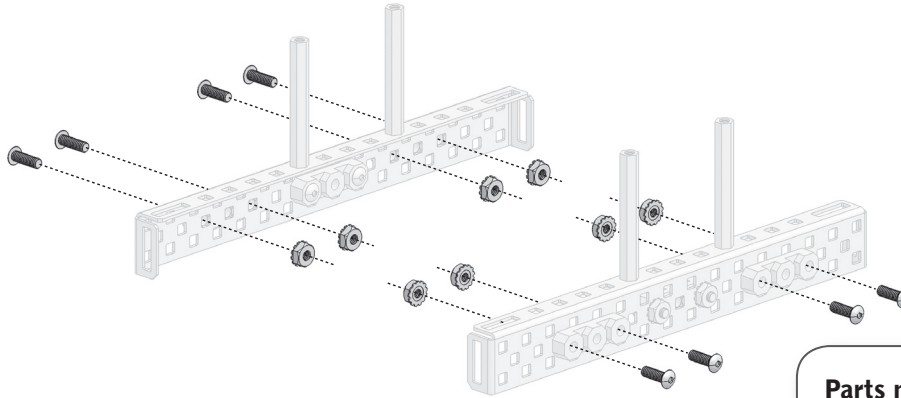
x 4



squarebot chassis parts and assembly, continued

2 Outer chassis rails, continued

Again, secure the bearing flats to the chassis rails using two $\frac{1}{2}$ " 8-32 screws and two keps nuts per bearing flat.



Parts needed in this step:

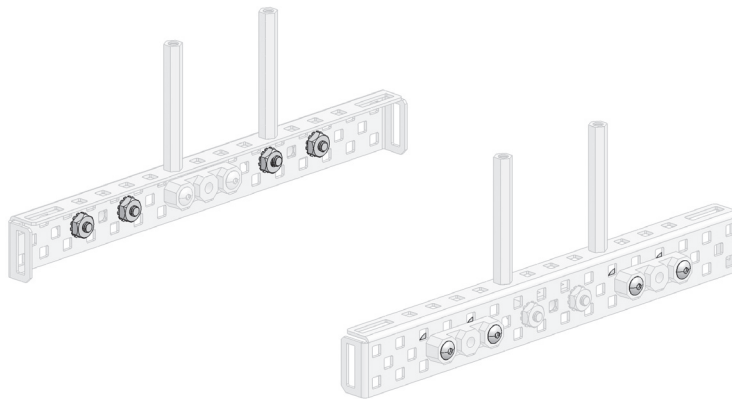


$\frac{1}{2}$ "
x 8



x 8

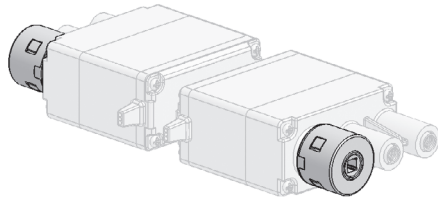
Your outer chassis rails should now look like this:



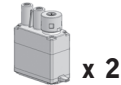
squarebot chassis parts and assembly, continued

3 Motor Subassembly

Before starting on the motor subassembly, make sure that the clutch is installed in the motor, as shown.

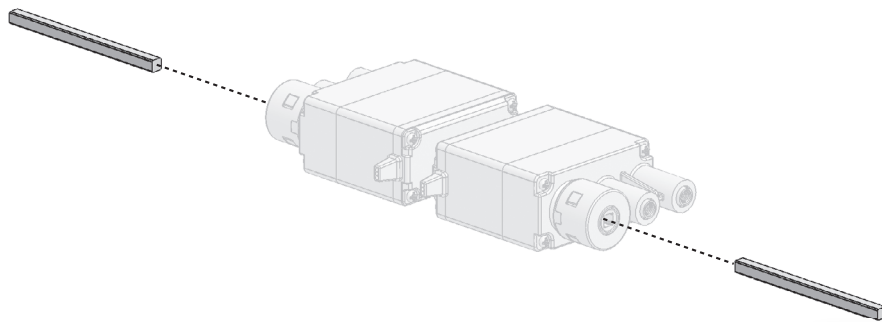


Parts needed in this step:

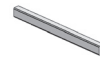


x 2

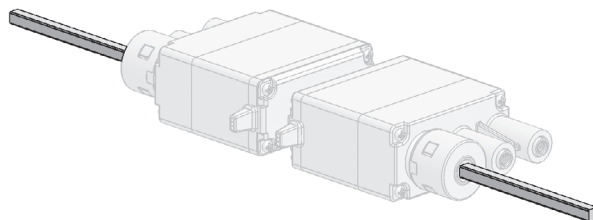
Insert a 2" square beam into each clutch, making sure that they seat firmly. The square bar will act as the motor's drive shaft.



Parts needed in this step:



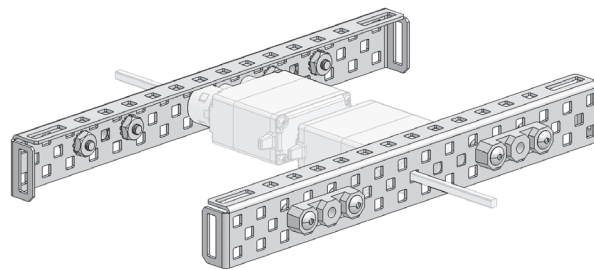
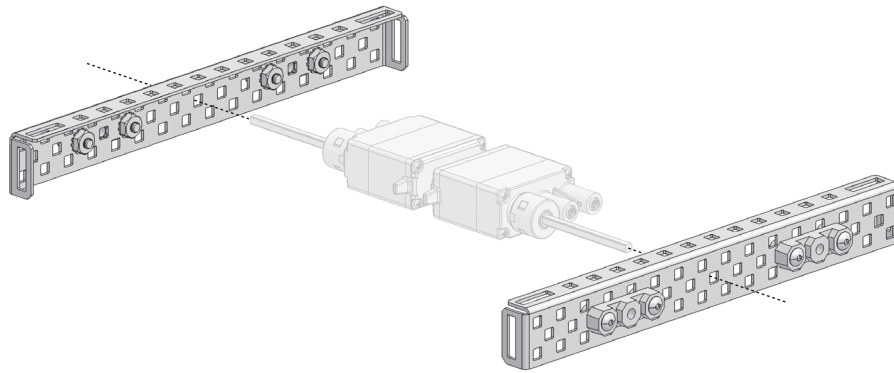
2"
x 2



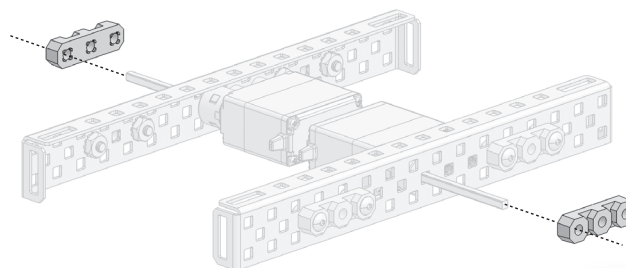
squarebot chassis parts and assembly, continued

3 Motor Subassembly, continued

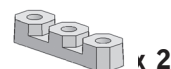
Slide the pre-assembled inner chassis rails onto the square bar motor shafts, so that the shafts go through the middle hole in the middle row of each rail.



Install one bearing flat on the outward-facing side of each chassis rail, with the front hole of the bearing flat sliding onto the motor shaft as shown.



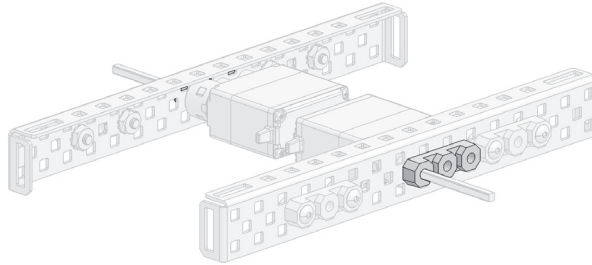
Parts needed in this step:



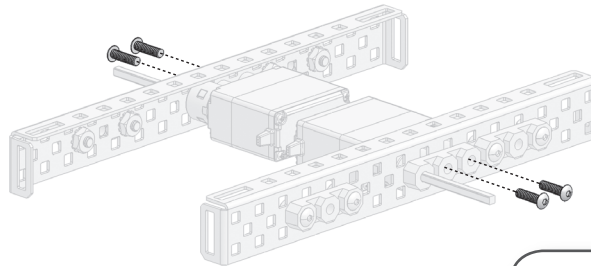
squarebot chassis parts and assembly, continued

3 Motor Subassembly, continued

Your assembly should now look like this:



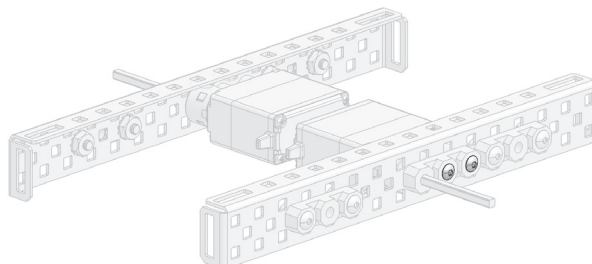
Secure the bearing flat to the inner chassis rail and motor using two $\frac{1}{2}$ " 6-32 screws per motor. Note that these are the thinner screws, not the usual 8-32 ones.



Parts needed in this step:

 $\frac{1}{2}$ "
x 4

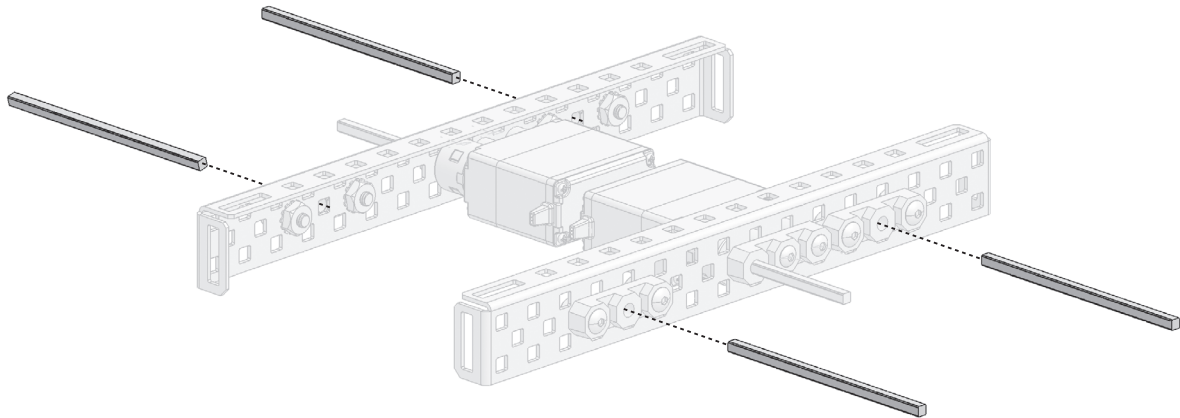
Your assembly should now look like this:



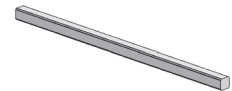
squarebot chassis parts and assembly, continued

3 Chassis Subassembly

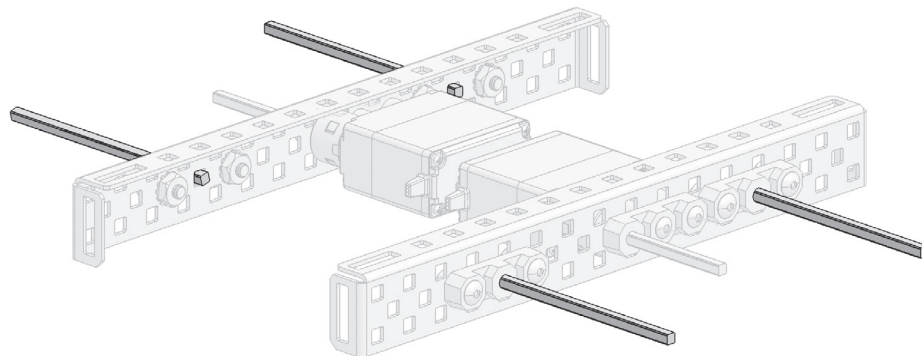
Insert a 3" square bar through the center hole of each unoccupied bearing flat, as shown. Don't push them all the way through. Push the end of the bar about $\frac{1}{8}$ " through the rail.



Parts needed in this step:



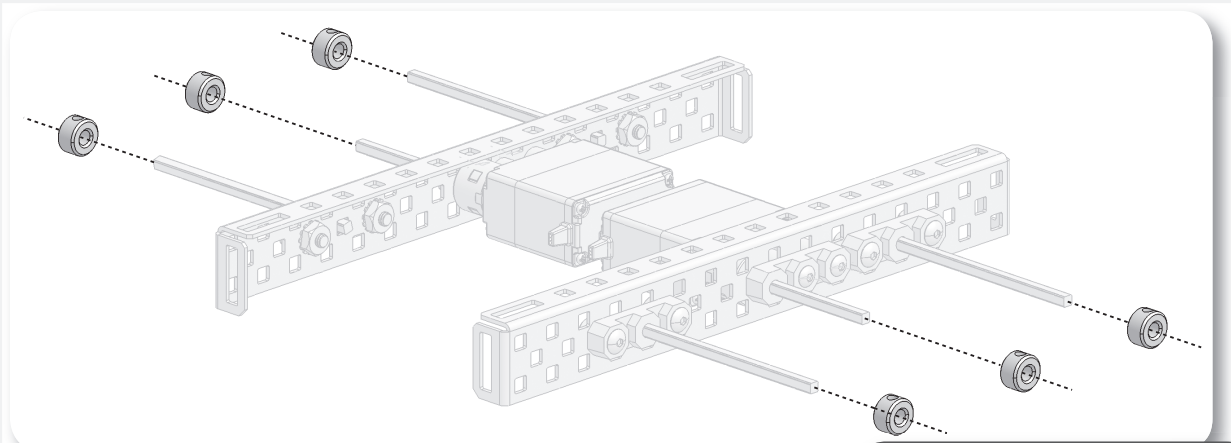
3"
x 4



squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

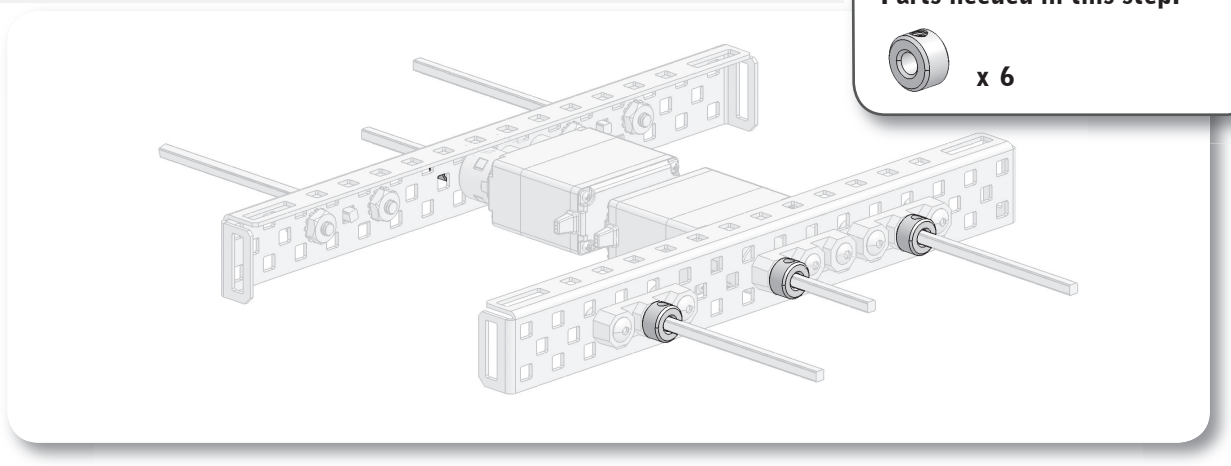
Slide metal collars (with threaded screws) onto each of the 2" and 3" square bars, mounting them flush with the surface of the bearing flat against which they will sit. Be sure the square bars don't get pushed too far in while you put the collars on, or you will not have enough bar sticking out to mount the wheels later.



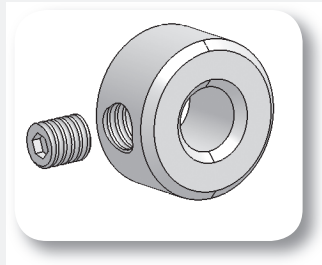
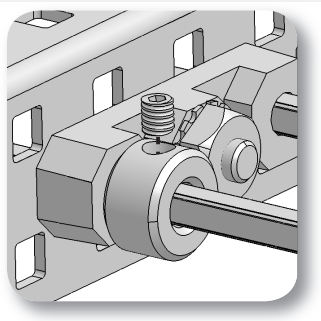
Parts needed in this step:



x 6



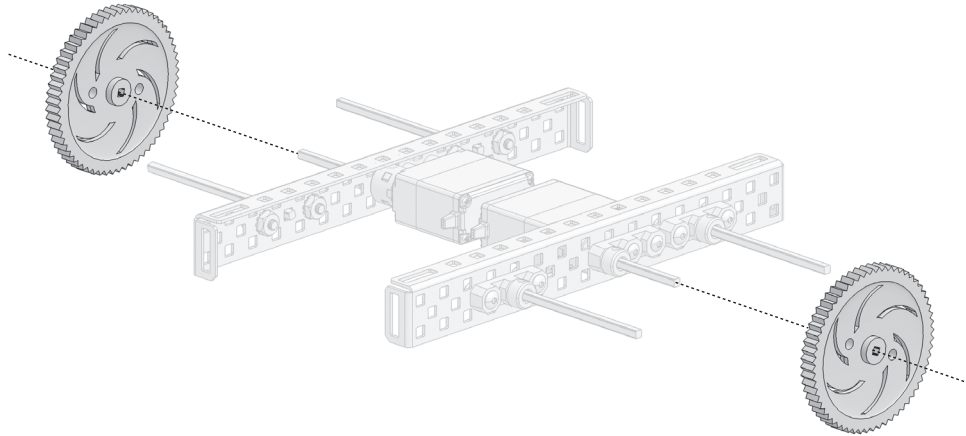
Once the collars and bars are in position, tighten the threaded screws with the smaller 5/64" hex L wrench to keep the collars from sliding out of place.



squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

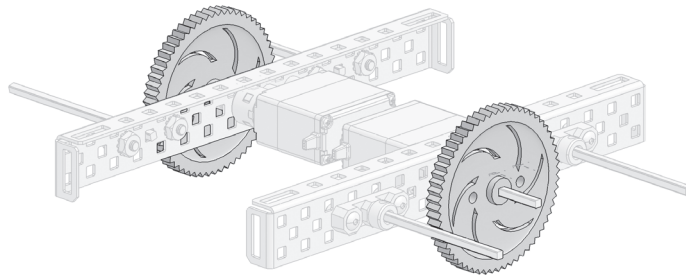
Slide a 60-tooth gear onto the drive axle of each motor, pushing it flush against the collar that you added in the previous step.



Parts needed in this step:



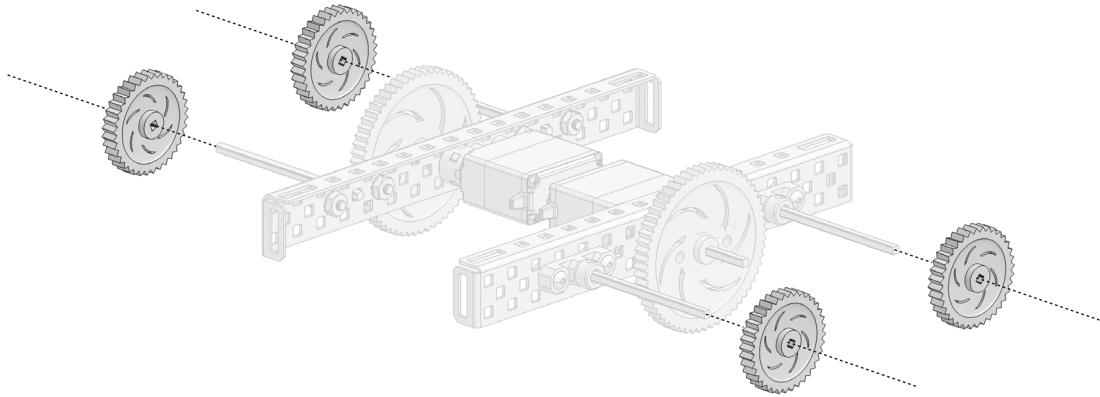
60-tooth
x 2



squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

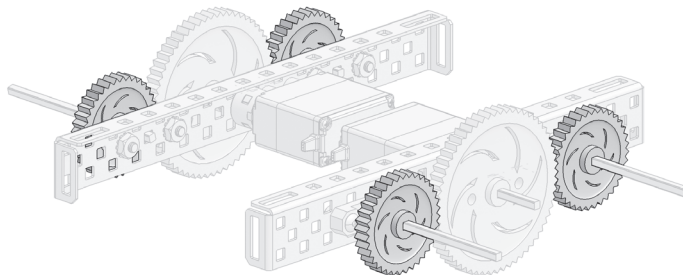
Slide a 36-tooth gear onto each of the remaining square bars, pushing them flush against the collars.



Parts needed in this step:



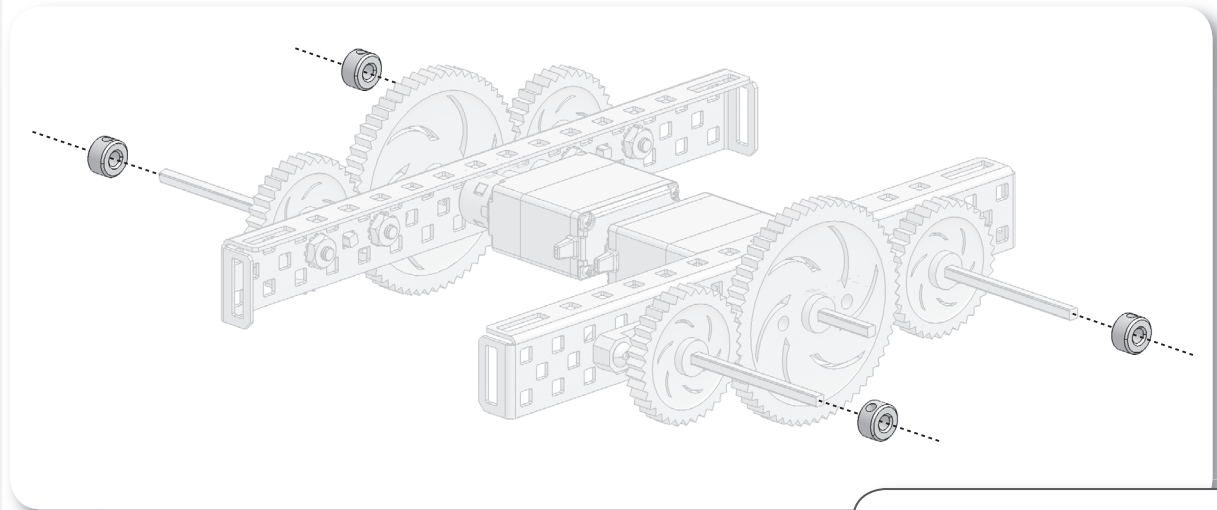
36-tooth
x 4



squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

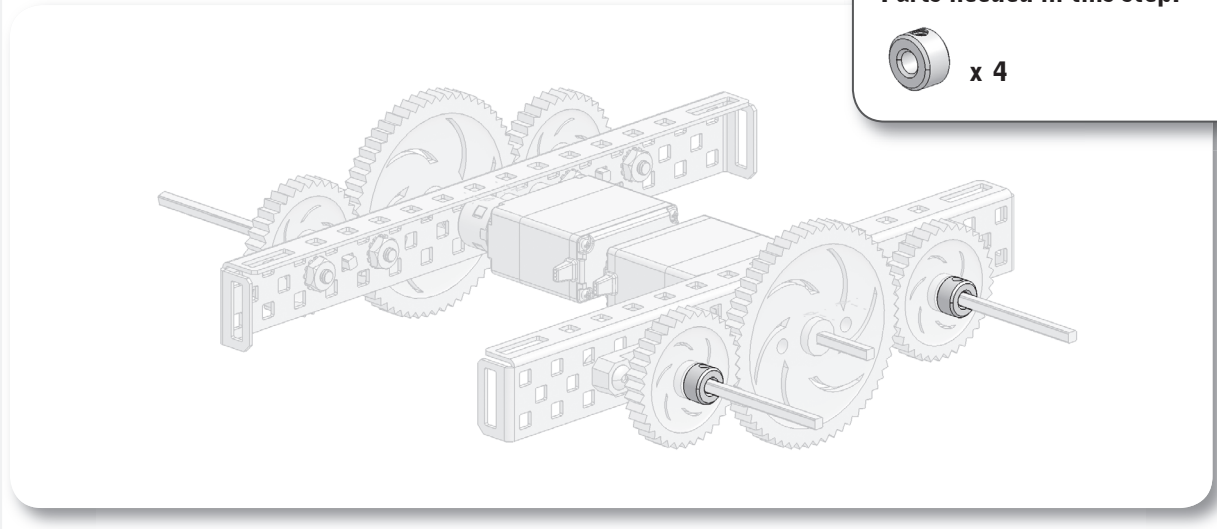
Add another collar to the end of each 3" square bar, again pushing them flush against the face of the gear before tightening the screws.



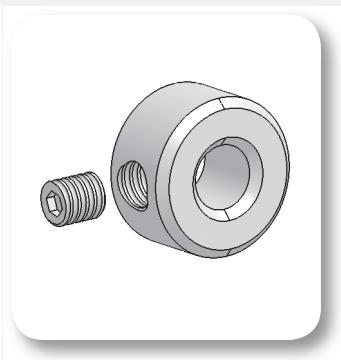
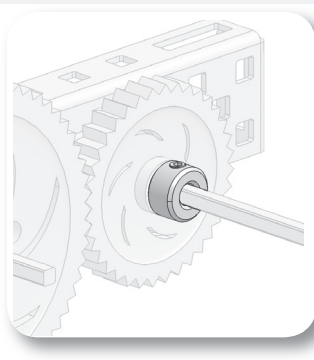
Parts needed in this step:



x 4



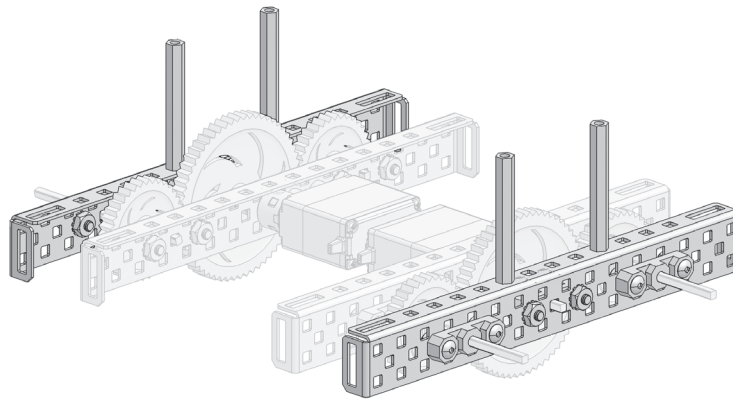
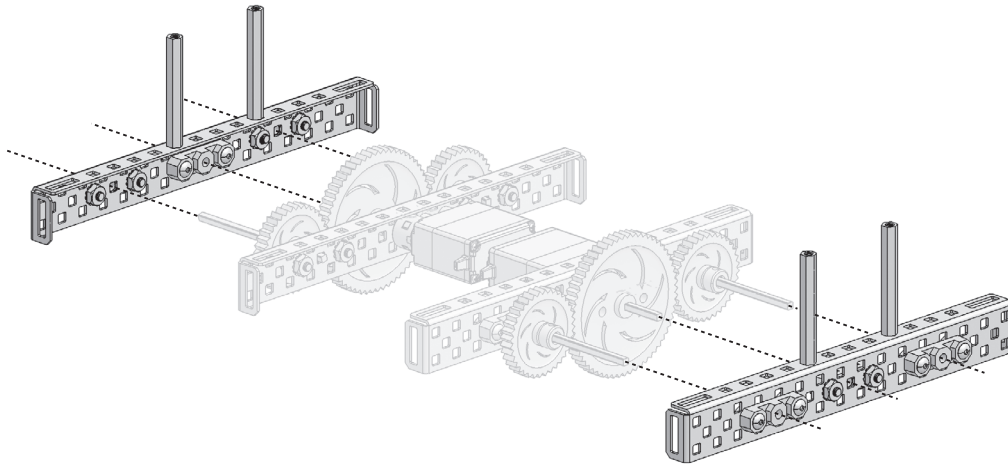
Tighten the threaded screws with a $35/64$ " hex L wrench.



squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

Install the pre-assembled outer chassis rails onto the current assembly. All three of the square bars sticking out of the inner rail should go neatly through bearing flats on the outer rail.

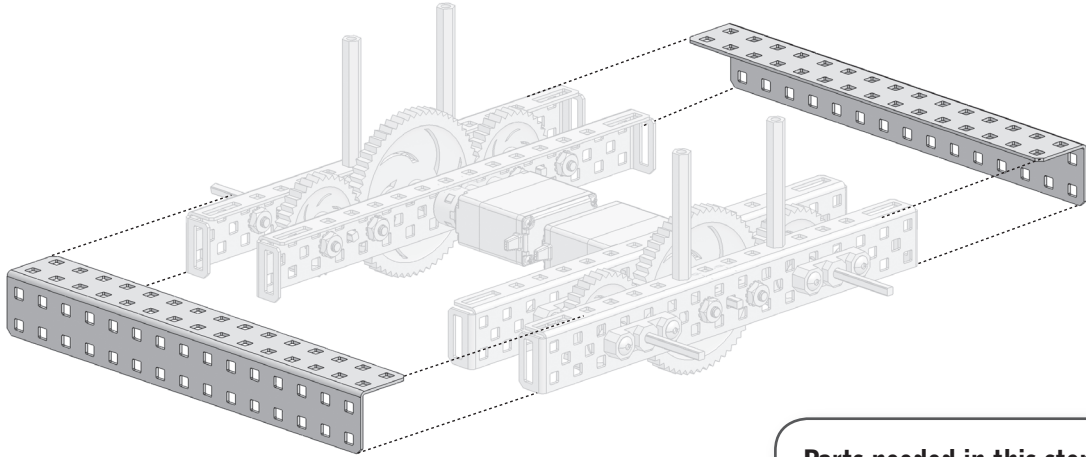


Note: If you find that your gears are sliding on the axles, you can insert the 0.182" and 0.318" plastic spacers included in the kit to block them into place.

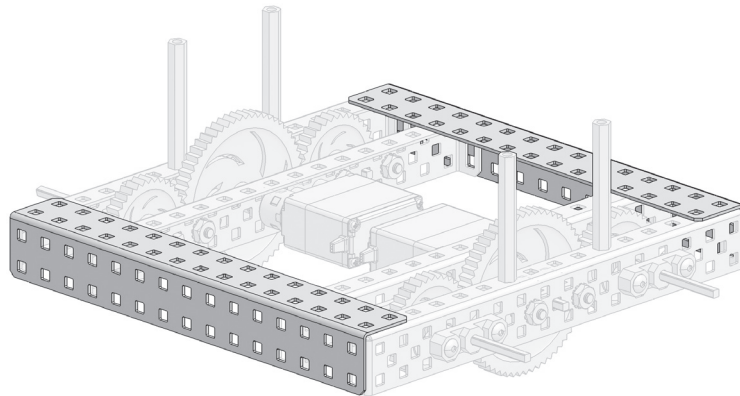
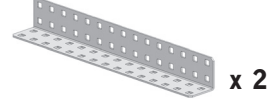
squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

Place chassis bumpers on the front and rear of the chassis rails, as shown.



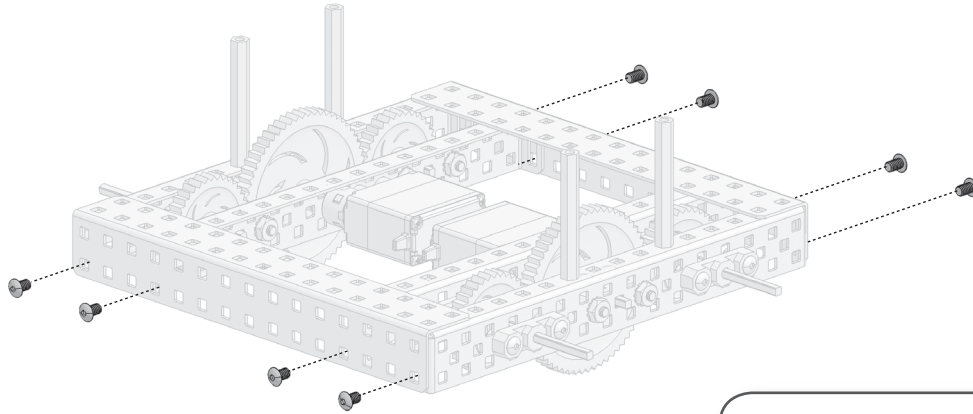
Parts needed in this step:



squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

Secure the vertical faces of the chassis bumpers to the end of the chassis rails using four $\frac{1}{4}$ " 8-32 screws and keps nuts in the front, and four in the back.



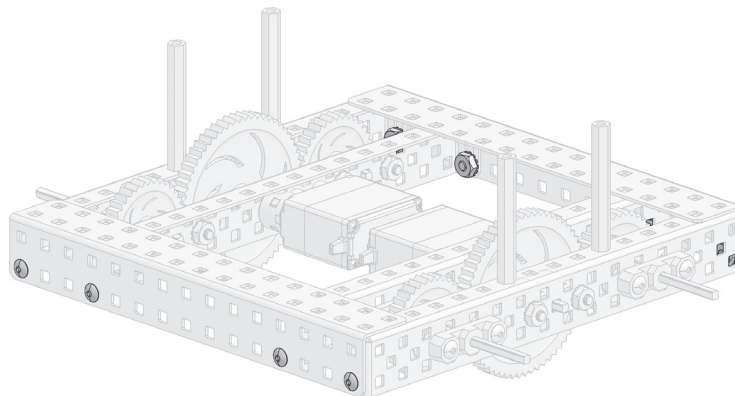
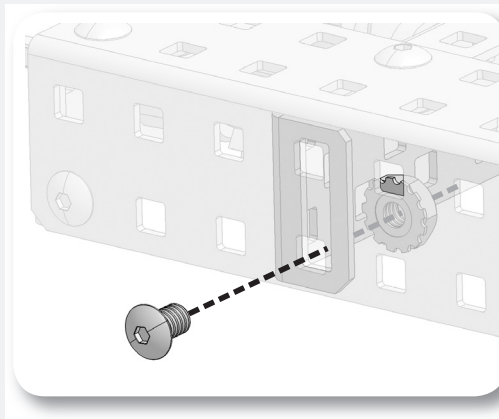
Parts needed in this step:



$\frac{1}{4}$ "
x 8



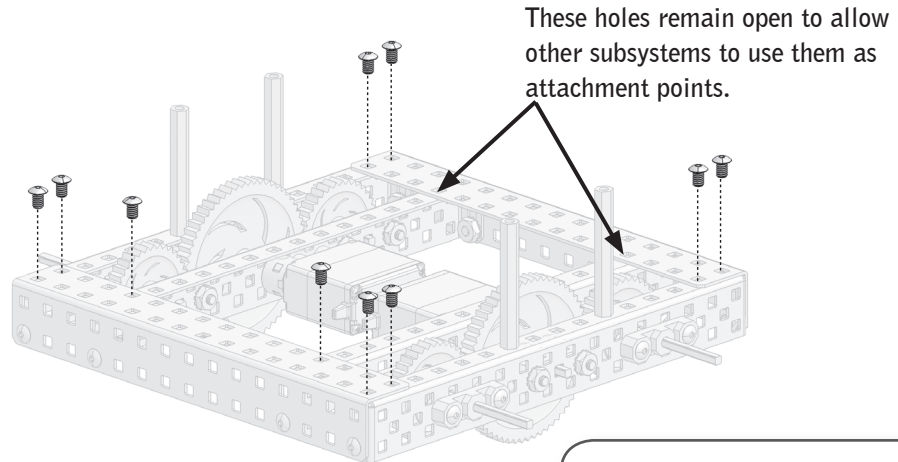
x 8




squarebot chassis parts and assembly, continued

4 Chassis Subassembly, continued

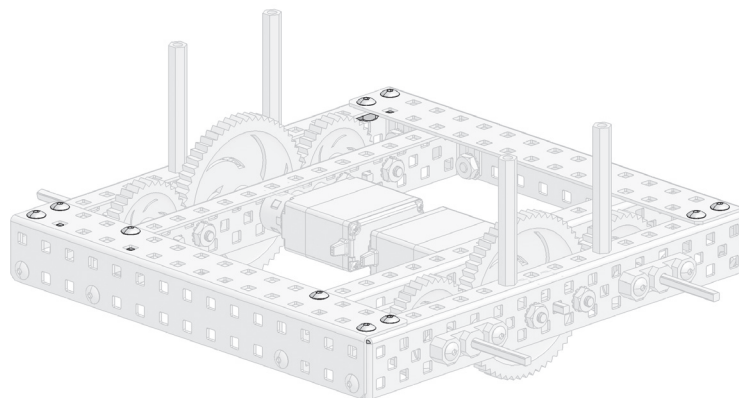
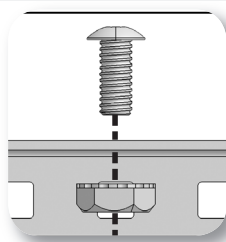
Secure the horizontal faces of the chassis bumpers to the top of the chassis rails using $\frac{1}{4}$ " 8-32 screws and keps nuts, six in the front and four in the back.



Parts needed in this step:

 $\frac{1}{4}$ "
x 10

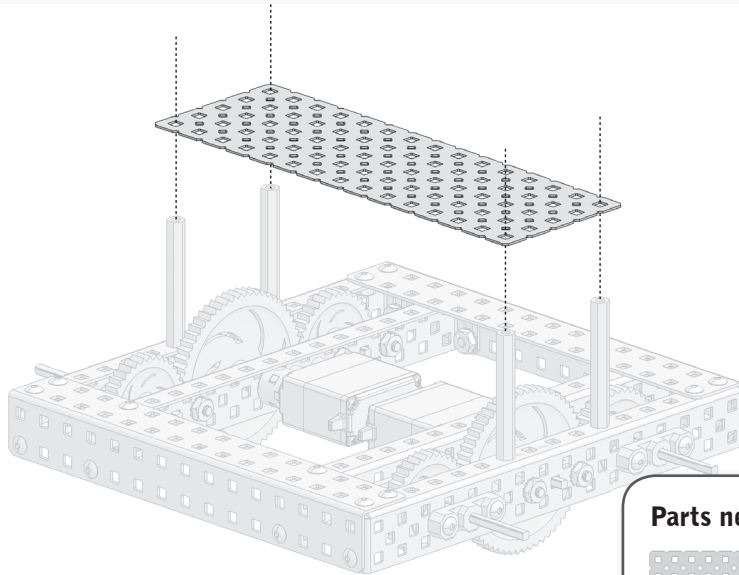
 x 10



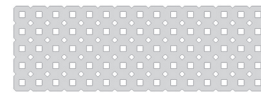
squarebot chassis parts and assembly, continued

4 Deck Subassembly

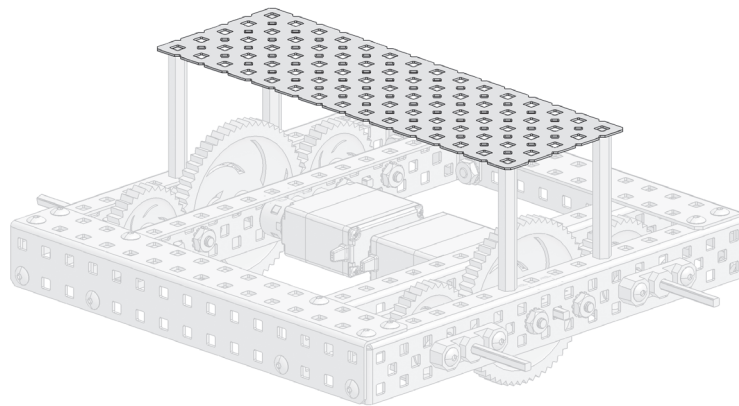
Place the large flat panel on the 2" partially threaded beams, aligning each corner of the panel with one of the threaded beams.



Parts needed in this step:



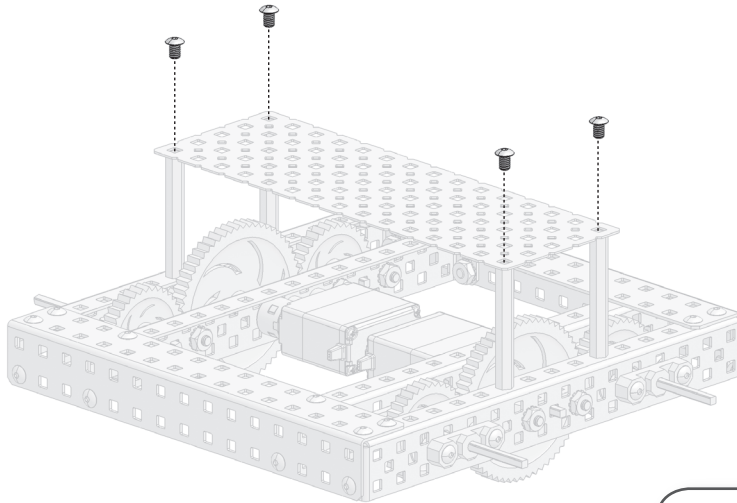
x 1



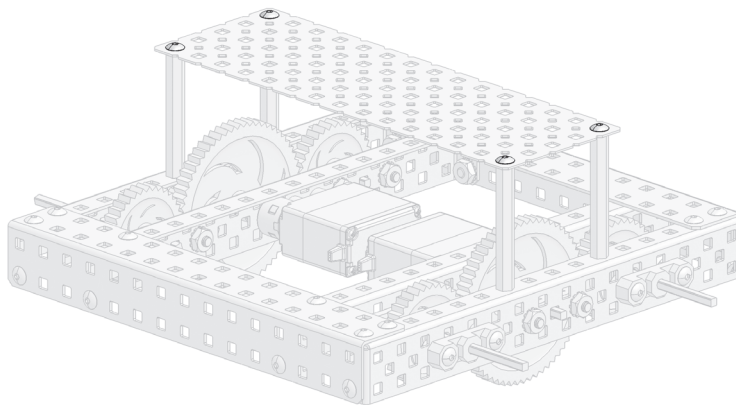
squarebot chassis parts and assembly, continued

4 Deck Subassembly

Secure the panel to the threaded beams with four ¼" 8-32 screws, as shown.



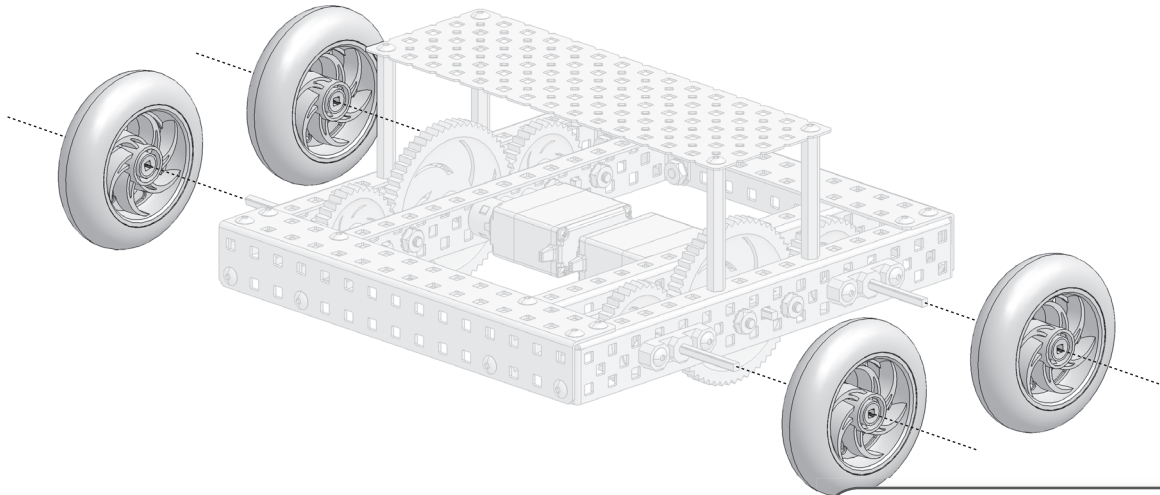
Parts needed in this step:



squarebot chassis parts and assembly, continued

4 Deck Subassembly

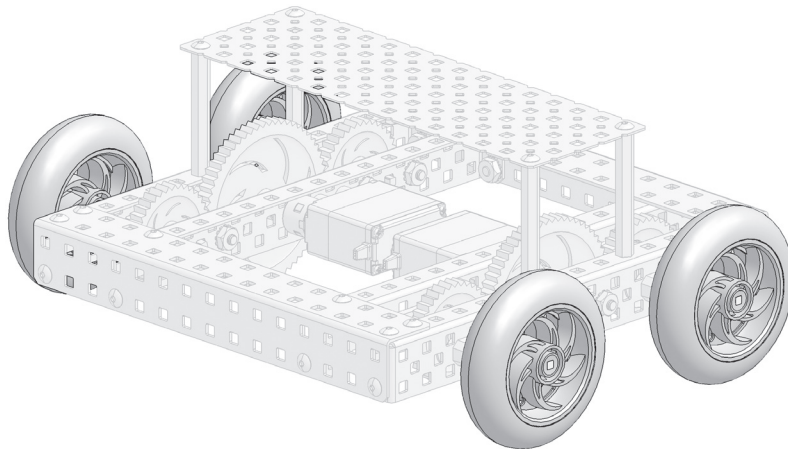
Install the small green tires (2.75" Removable Tire and 1.895" Hub) on the 3" square beams, as shown.



Parts needed in this step:



x 2



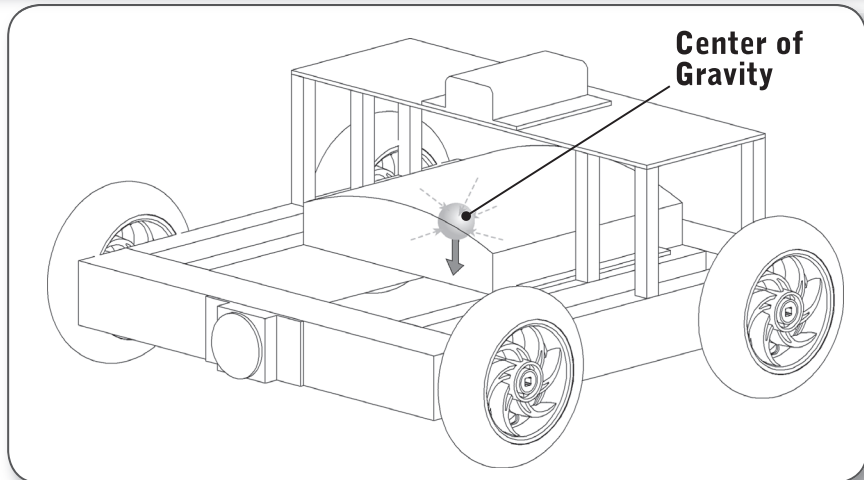
Your Squarebot chassis is complete!

concepts to understand

Stability: Center of Gravity Considerations

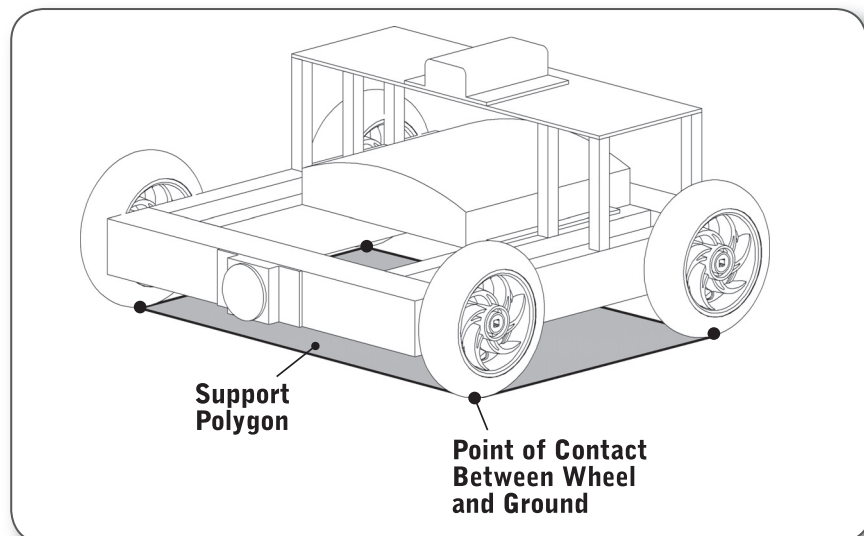
Center of Gravity

You can think of the robot's center of gravity as the "average position" of all the weight on the robot. Because it is an average of both weight and position, heavier objects count more than lighter ones in determining where the center of gravity is, and pieces that are farther out count more than pieces that are near the middle.



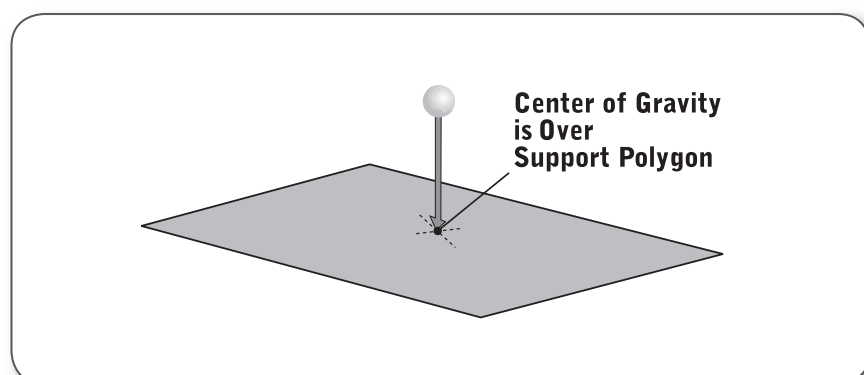
Support Polygon

The support polygon is the imaginary polygon formed by connecting the points where your robot touches the ground (usually the wheels). It varies by design, but there is always one support polygon in any stable configuration.



Stability

The rule for making a robot stable is very simple: the robot will be most stable when the center of gravity is centered over the polygon. Your robot will encounter much more complex situations than just standing still, however, and you need to take these into account when making your design.

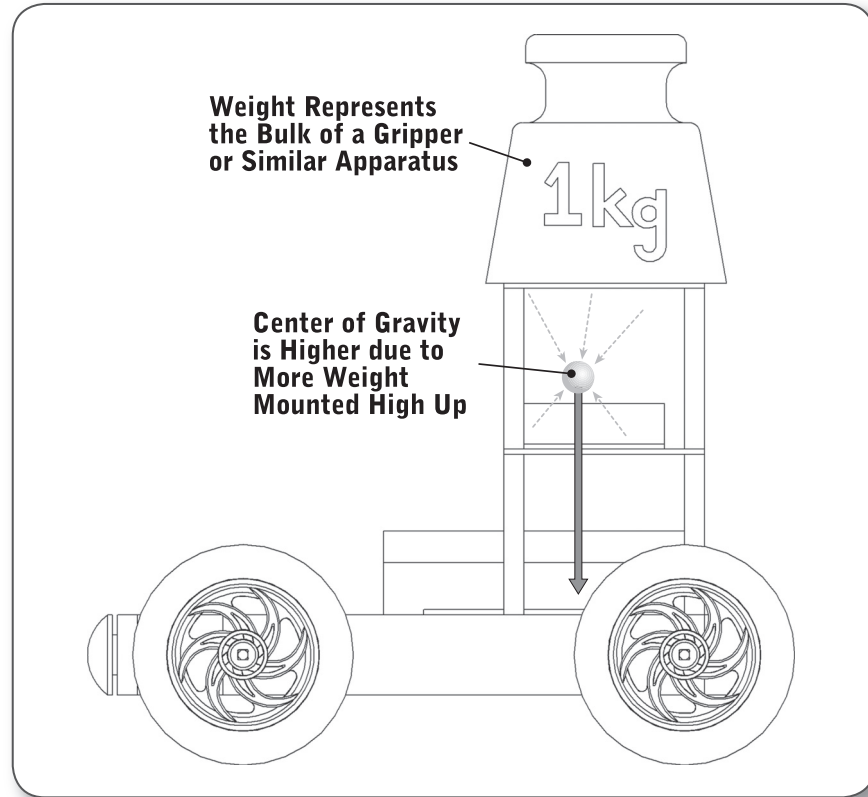


concepts to understand, continued

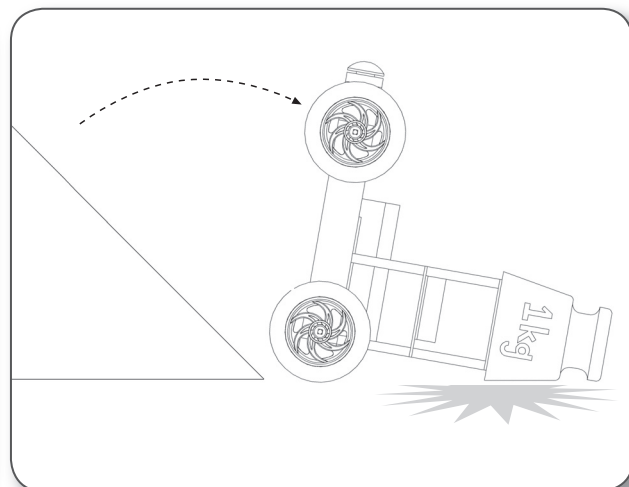
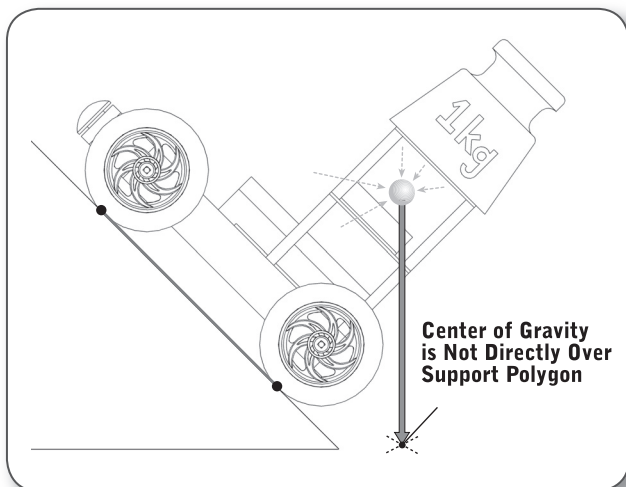
Stability: Center of Gravity Considerations, continued

EXAMPLE 1: Towerbot

This robot was built very tall so that it would be able to reach a hanging goal for a challenge. However, along the way, it had to first climb a ramp.



Notice that the robot's center of gravity is no longer over the support polygon. This robot would fall over as soon as it started up the ramp.

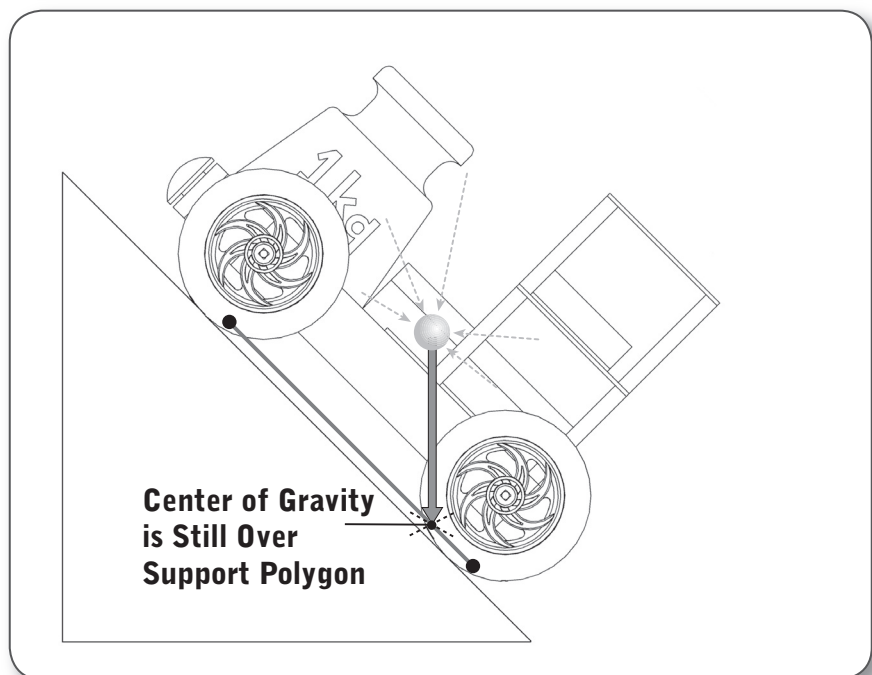
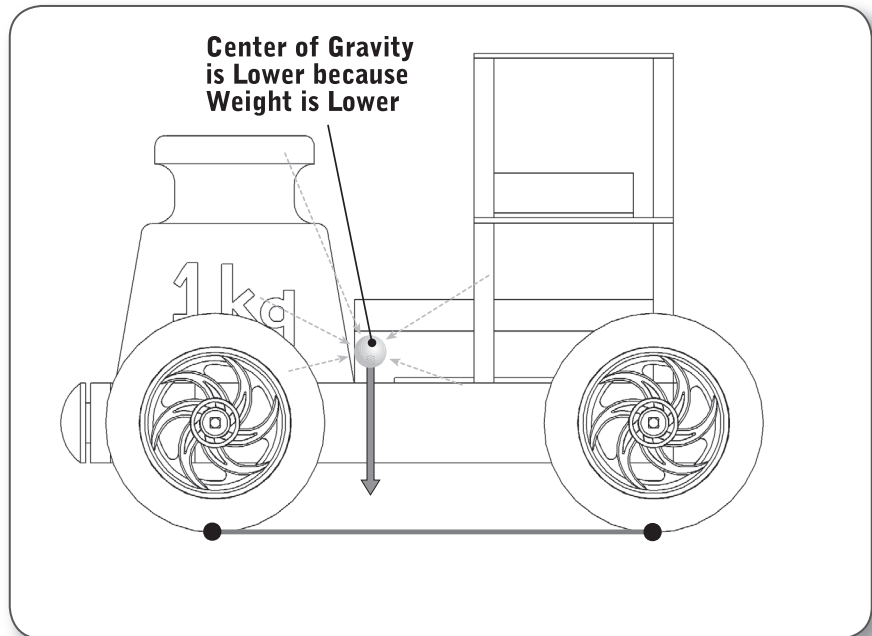


concepts to understand, continued

Stability: Center of Gravity Considerations, continued

EXAMPLE 1: Towerbot, continued

To fix this problem, you must lower the robot's center of gravity so that it does not move as far when the robot is on an incline. In general, it is always advantageous to have your robot's center of gravity as close to the ground as possible!



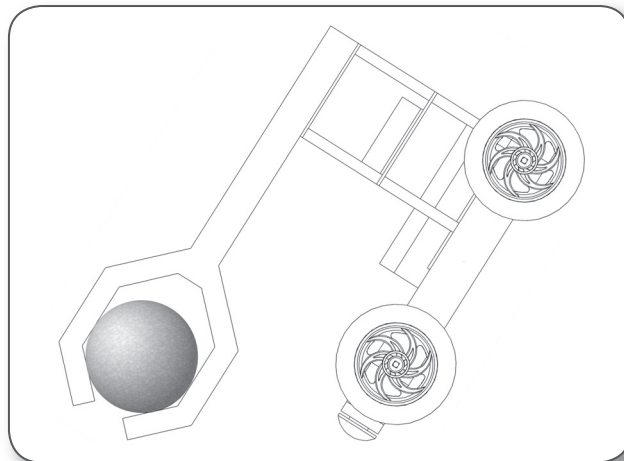
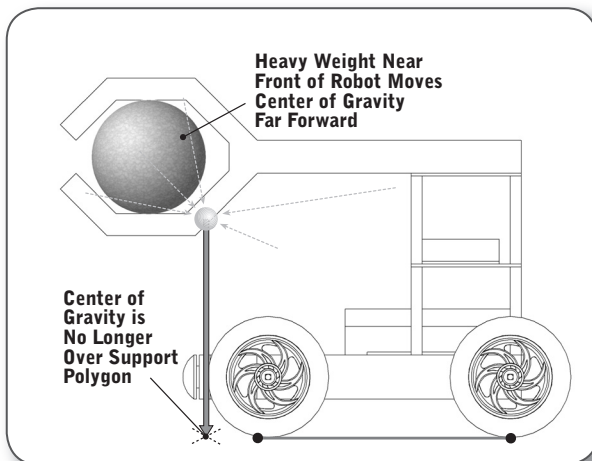
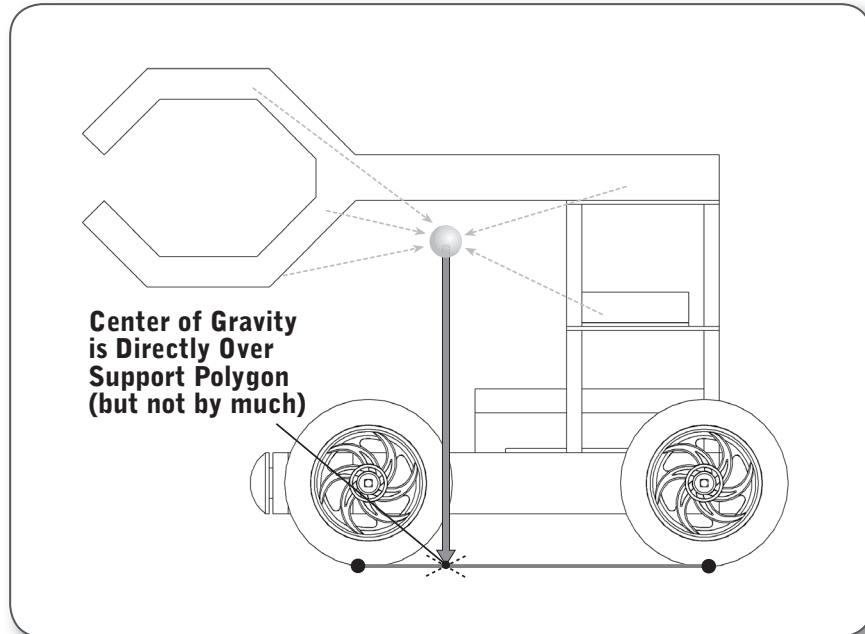
concepts to understand, continued

Stability: Center of Gravity Considerations, continued

EXAMPLE 2: Grabberbot

This robot is designed to pick up a heavy object using the gripper claw on the front, and transport the object to another location.

When the robot picks up the object, it effectively adds it to the robot's structure. The combined robot-ball structure now has the new center of gravity (shown below), which is outside the support polygon. The robot tips over as a consequence.



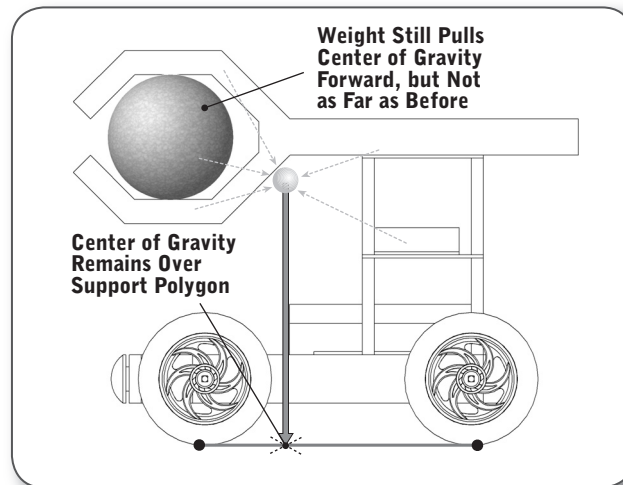
concepts to understand, continued

Stability: Center of Gravity Considerations, continued

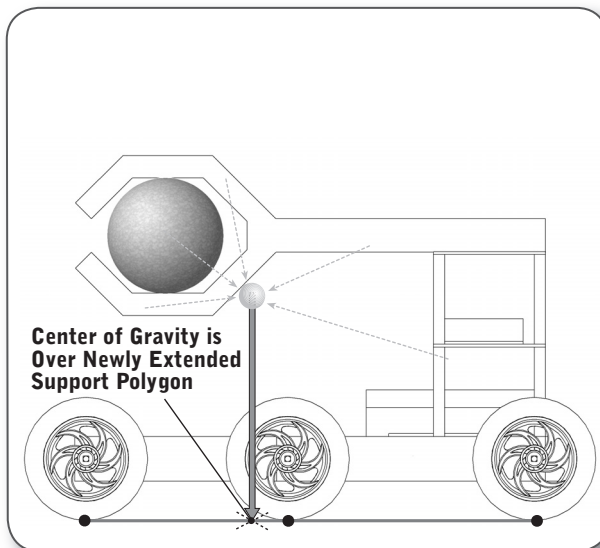
EXAMPLE 2: Grabberbot, continued

There are many solutions to this problem. Depending on the specifics of the challenge, some or all of these modifications could work:

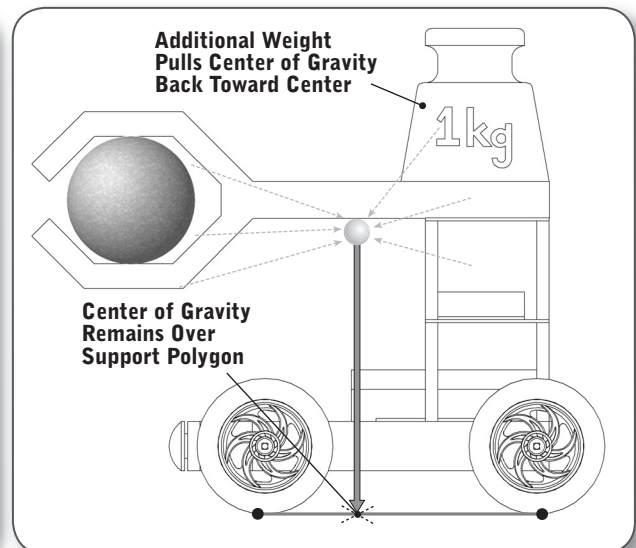
Moving the center of gravity back by moving the gripper farther back on the robot



Extending the support polygon by adding more wheels farther out



Moving the center of gravity back by adding counterweights on the back of the robot



concepts to understand, continued

Sturdiness

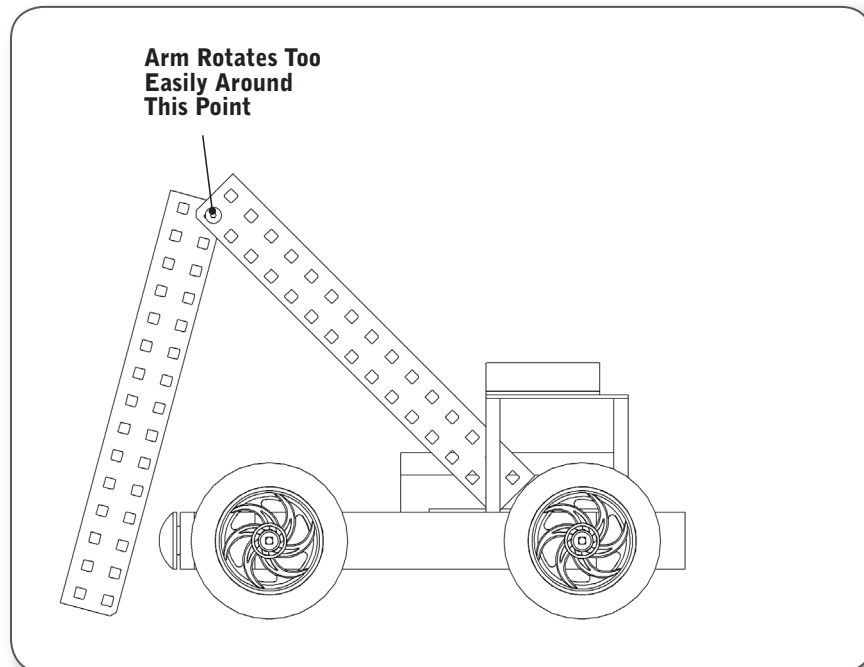
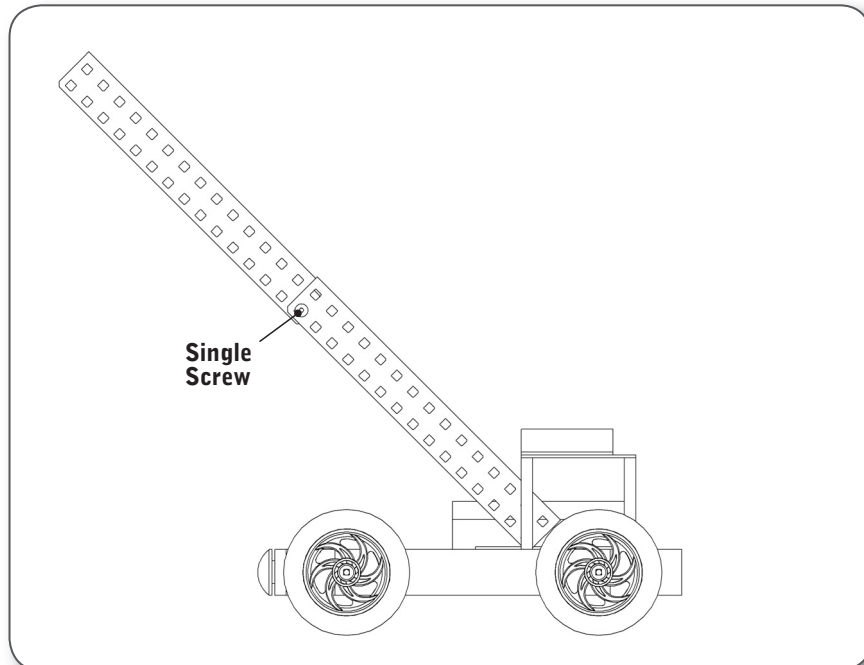
Fasteners

There are over a hundred screws in your starter kit. Use them! The most common problems with robots that fall apart or lose pieces easily is not that individual parts come apart or bend, but rather that groups of parts are not joined securely enough, and separate from each other or move around.

EXAMPLE 1:

Arm Extension

A robot needs to be able to reach a goal that is high off the ground. The goal is so high that a single long piece will not reach it. Two pieces must be joined together to reach the desired height.



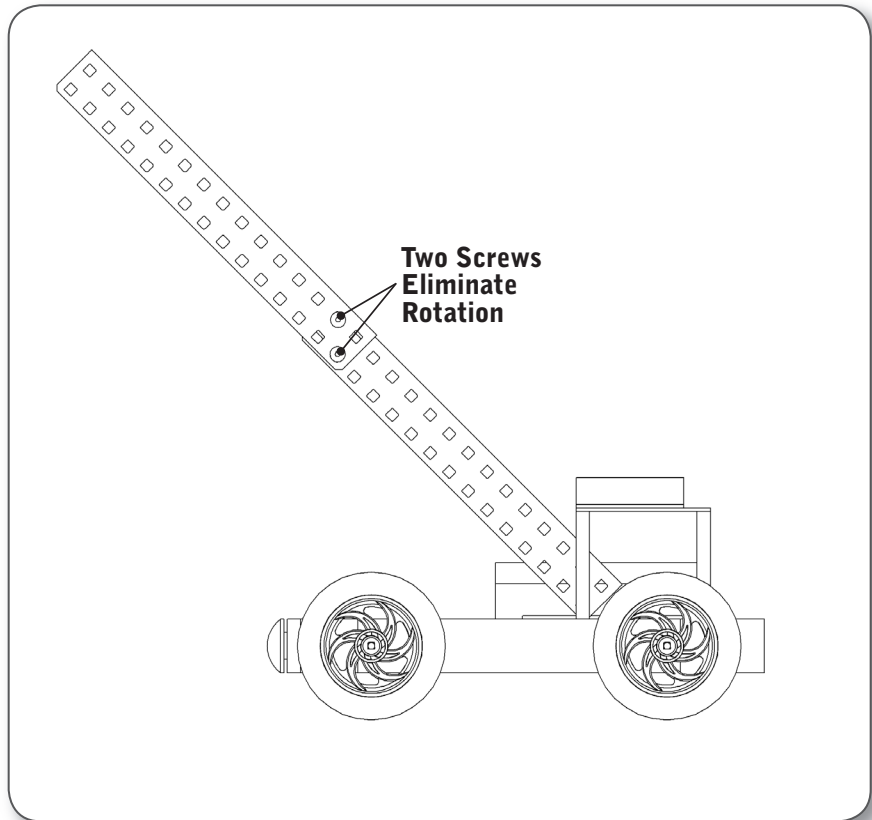
concepts to understand, continued

Sturdiness, continued

EXAMPLE 1, continued: Arm Extension, continued

This attachment uses a single screw to join the two bars. As you can see, it has a problem when weight is applied to it: the extension bar rotates around the screw. Also, if this screw were to come loose or fall out for any reason, the entire arm would come crashing down.

By using two screws, this design removes the possibility of rotation around either one of them. Additionally, the design is much more resilient, and can maintain its shape to a limited extent even if one of the two screws were to come loose or fall out.



concepts to understand, continued

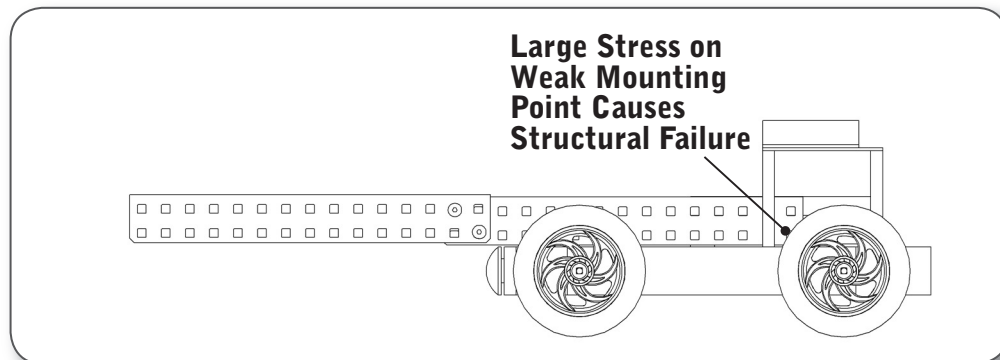
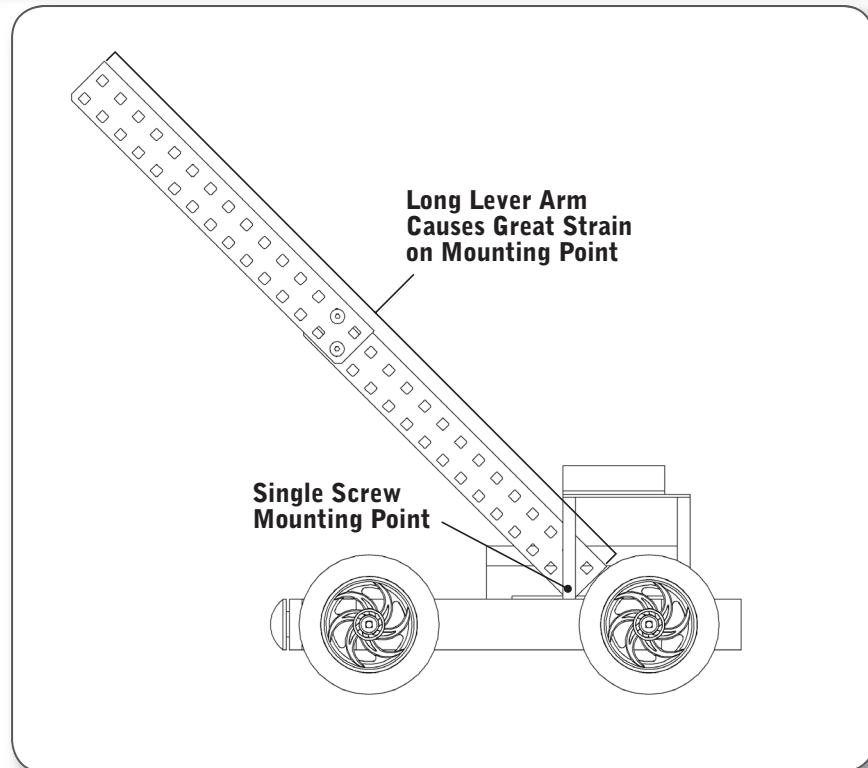
Sturdiness, continued

EXAMPLE 2:

Bracing

The extended bars are now attached firmly to each other, and the long arm is mounted on your robot. However, the long arm is liable to generate huge stresses at its mounting point because it is so long, especially when the force is applied near the end.

In order to keep the arm from falling back down, you will need to brace it. You could use a second screw to hold it, like you did with the arm itself, but because the arm has so much mechanical advantage from its length (it is effectively a lever), that screw would actually be in danger of deforming or breaking. A better solution would be to give the structure support at a point closer to the end, thus reducing the mechanical advantage that the arm has relative to the supports.



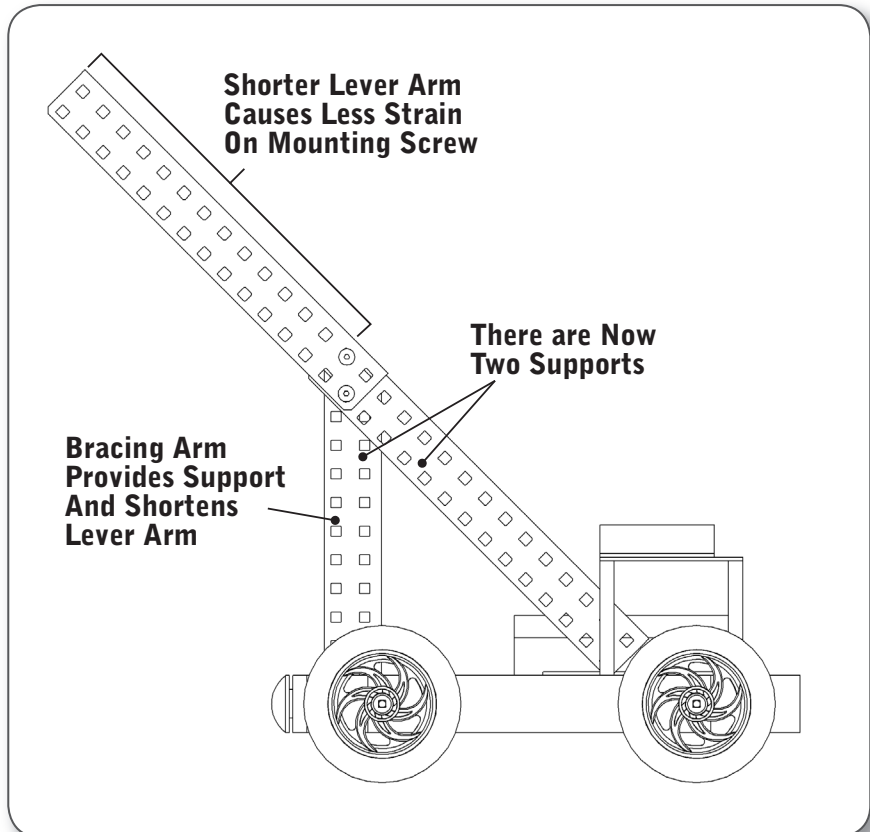
concepts to understand, continued

Sturdiness, continued

EXAMPLE 2:

Bracing the Bars, continued

The arm is now more stable and better able to withstand stresses placed on it from both its own weight, and any external forces acting on it. It has both decreased the mechanical advantage from the long lever arm, and spread the load over two supports instead of just one.



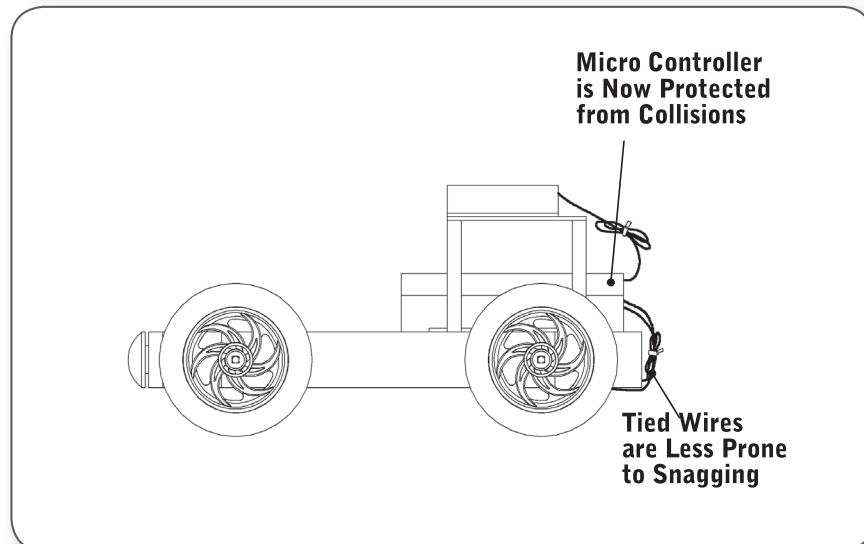
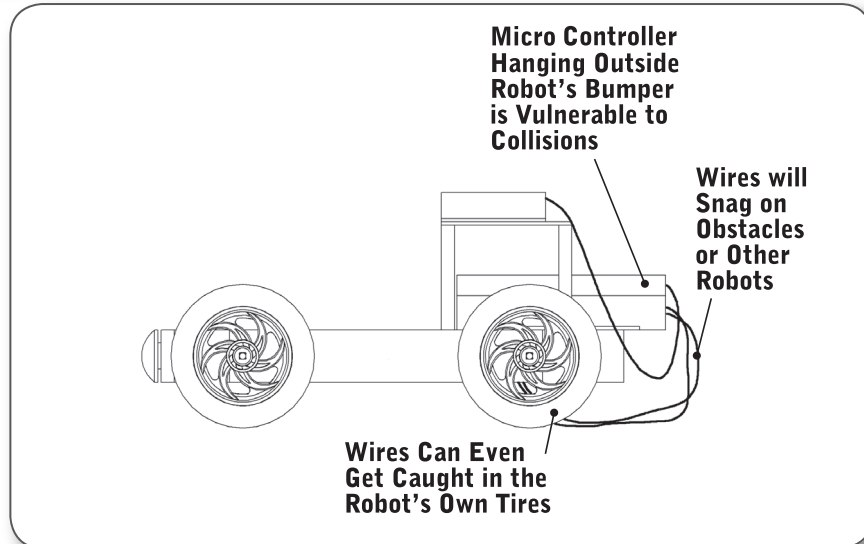
concepts to understand, continued

Exposure and Vulnerability

There are certain parts of a robot that are more fragile than others. Always plan the structural design to protect these parts from unwanted physical contact if possible.

The design in the example at the right is asking for trouble. The Vex Micro Controller is a sensitive piece of electronic equipment, and it can be a poor design decision to put it somewhere like this where it could be damaged by a simple physical impact. In particular, this design leaves the back of the Vex Micro Controller exposed in such a way that a passing robot or a careless driver could smash the entire rear connector panel, potentially damaging the radio control and power connections. Also, the wires are a mess. This is dangerous, because if one of those wires were to snag on another robot (or even on the robot's own wheels!), the connector would be forcibly removed from its port. Not only would this disable the robot on the field, but it could cause permanent damage to the cable or the ports on the Vex Micro Controller.

Adjusting the position of the controller so that it is not likely to get hit by anything, and cleaning up the wires (the kit comes with wire ties) reduce the chance of damage to the sensitive electronic components on the robot. As a bonus, it looks a lot cleaner as well.



subsystem interactions

How does the Structure Subsystem interact with...

...the Motion Subsystem?

- The motion and structure subsystems are tightly integrated in many robots designs, including the Squarebot. The motion subsystem can't be constructed without certain structural components (like the chassis rails) to provide support and positional reference. By the same token, the structure subsystem must be designed largely to accommodate the motion components.
- On Squarebot, the structure and motion subsystems are so interconnected that you cannot build them separately. Hence, they are constructed together in the Squarebot chassis assembly instructions.

...the Power Subsystem?

- The structure subsystem generally provides a safe, protected place to secure the battery.
- On the Squarebot, the structure subsystem provides a mounting platform for the battery holder, on the upper deck of the chassis (see Power Subsystem building instructions).

...the Sensor Subsystem?

- The structure subsystem provides a mounting and stabilization platform for sensors on the robot. Often, sensors need to be held in a specific position to function properly, and the structural subsystem must be designed to accommodate these needs.
- On the Squarebot, the structure subsystem provides a mounting spot for the bumper switch sensors, where they can detect collisions from the front and rear.

...the Control Subsystem?

- The structure subsystem will generally provide a place to store the RF Receiver module on the robot. In some cases, you will need to construct a piece to hold the antenna wire in a safe place, or to hold it up above the robot to extend its signal range.
- On Squarebot, the structure subsystem provides an elevated deck for the RF receiver module and antenna holder to be mounted for enhanced reception.

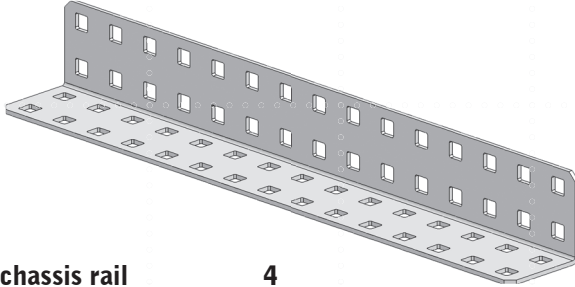
... the Logic Subsystem?

- The structure subsystem holds the Micro Controller in place. Since the Micro Controller is a very delicate and important part of the robot, the structure subsystem will also need to provide physical protection for the Micro Controller by keeping it in a secure spot.
- The structure subsystem does not plug into the Micro Controller in any way; however, the structure subsystem does need to provide accommodation and protection for the wires that run between the Micro Controller and other pieces.
- On the Squarebot, the structure subsystem provides a mounting platform for the Micro Controller module, and a place to tie wires down.

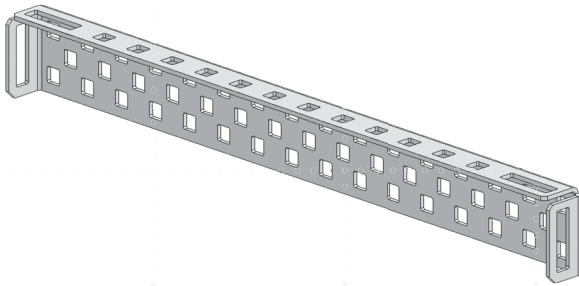
structure subsystem inventory

component qty

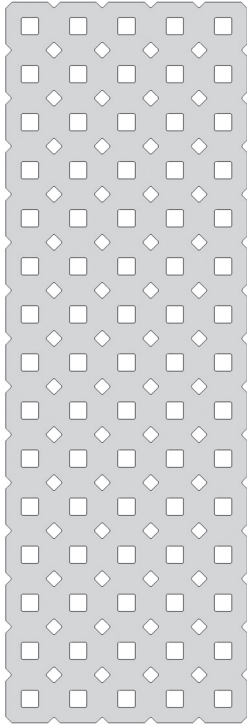
chassis bumper 2



chassis rail 4

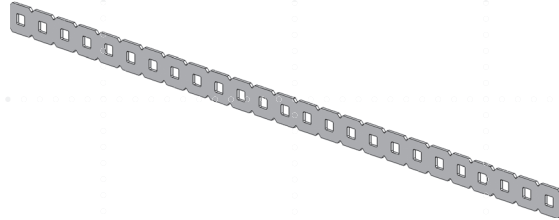


panel 2

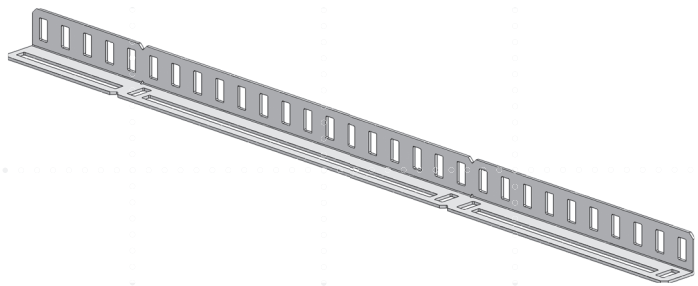


component qty

long bar 4



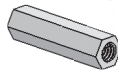
long angle bar 4



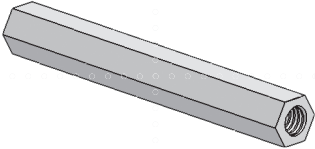

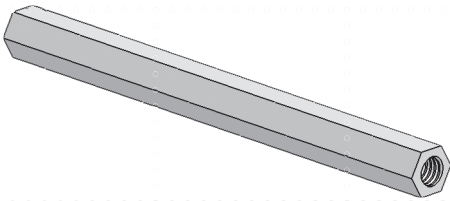

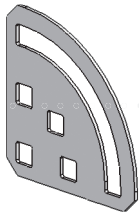

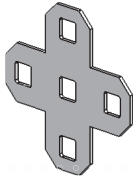

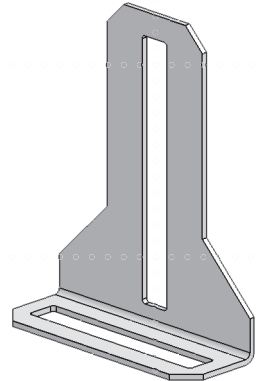




fully threaded beams (1/2") 10



fully threaded beams (1") 8



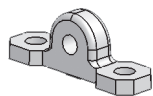
structure subsystem inventory, continued

component	qty	component	qty
partially threaded beams (2")	4	washer, steel	30
			
partially threaded beams (3")	4	washer, delrin	10
			
pivot	2	keps nut (1/4")	65
			
plus gusset	2	lock nut (1/4")	14
			
gusset	2	screw 8-32 x 1/4"	70
			
		screw 8-32 x 3/8"	28
			
		screw 8-32 x 1/2"	28
			
		screw 8-32 x 3/4"	14
			

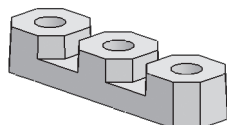
structure subsystem inventory

component	qty
-----------	-----

bearing block	6
---------------	---



bearing flat	16
--------------	----



0.182" plastic spacer	20
-----------------------	----



0.318" plastic spacer	20
-----------------------	----



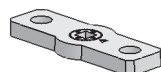
collar	16
--------	----



threaded screw for collar	16
---------------------------	----



lock plate	4
------------	---



metal and hardware kit

Metal and Hardware:

This kit contains additional structural elements that you can use to build bigger, better, stronger, and more complex robot designs. Or, since bigger isn't always better... use the pieces in this kit to make sure that you always have the most efficient part for the job. All the parts included in this kit were also included in the Starter Kit, so consult your original Inventor's Guide for building tips and examples on how to use them.

INSERT THESE PAGES
at the **back of the**
Structure Chapter in your
Vex Inventor's Guide.

screw, 8-32 x 1/4" x 70



screw, 8-32 x 3/8" x 28



screw, 8-32 x 1/2" x 28



screw, 8-32 x 3/4" x 14



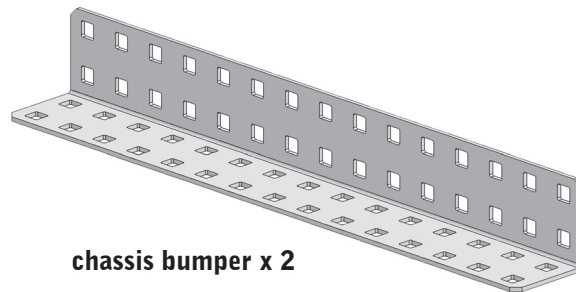
threaded screw
for collar x 16



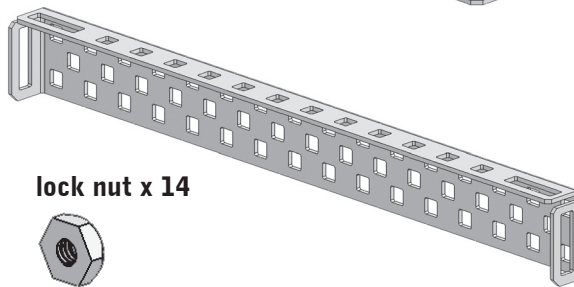
keps nut x 65



chassis rail x 4



chassis bumper x 2



lock nut x 14



collar x 16



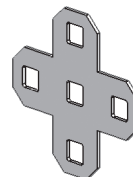
0.182" plastic
spacer x 20



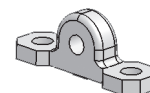
0.318" plastic
spacer x 20



plus gusset x 2



bearing block x 6



bearing flat x 16

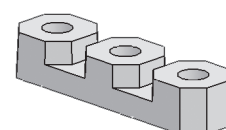
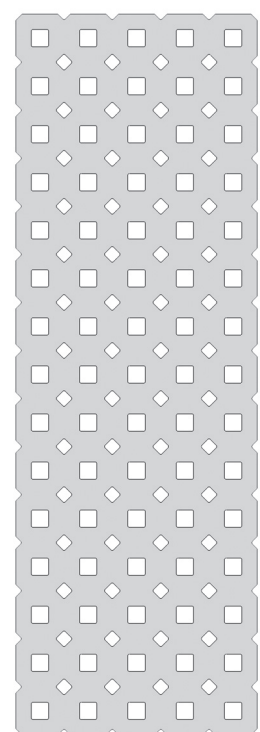


plate x 2



washer, steel x 30



washer, delrin x 10

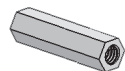


metal and hardware kit, continued

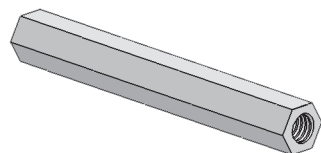
fully threaded beam (1/2") x 10



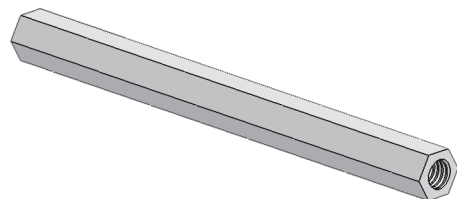
fully threaded beam (1") x 8



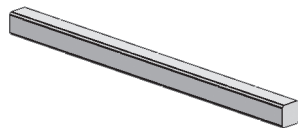
partially threaded beam (2") x 4



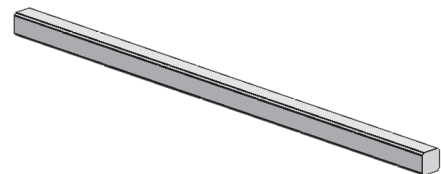
partially threaded beam (3") x 4



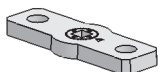
square bar (2") x 4



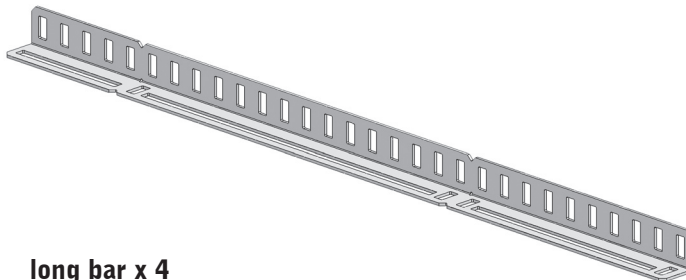
square bar (3") x 4



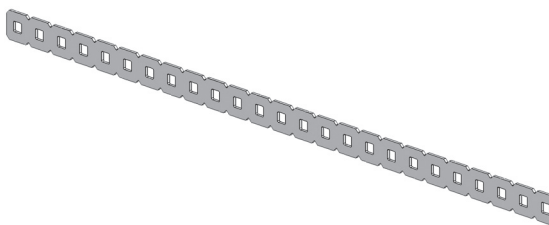
lock plate x 4



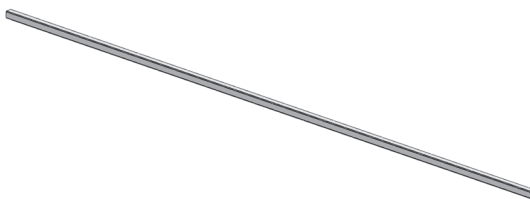
long angle bar x 4



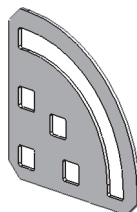
long bar x 4



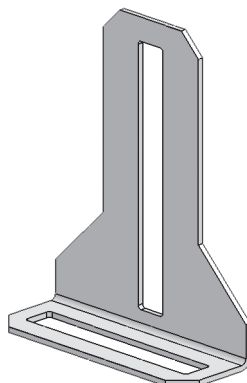
square bar (12") x 2



pivot x 2



gusset x 2



Limited 90-day Warranty

This product is warranted by Innovation One against manufacturing defects in material and workmanship under normal use for ninety (90) days from the date of purchase from authorized Innovation One dealers. For complete warranty details and exclusions, check with your dealer.

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