

Figure 16-1. The Printer can draw basic shapes like the NXT logo on a sheet of paper.

When drawing, the Printer can move the pen in only two possible directions, as shown in **Figure 16-2**: horizontally (line *a*) or vertically (line *b*). When drawing a tilted line, the Printer moves the pen both horizontally and vertically at the same time (line *c*). Further, when drawing vertically, the Printer actually moves the paper vertically, not the pen (that is, the paper moves vertically across the tip of the pen).

Components of the Printer

Now that you understand how the Printer can draw a line with a pen, let's look at its components and how they work together. **Figure 16-3** highlights several important sections of the machine. We'll discuss the function of each section in turn.

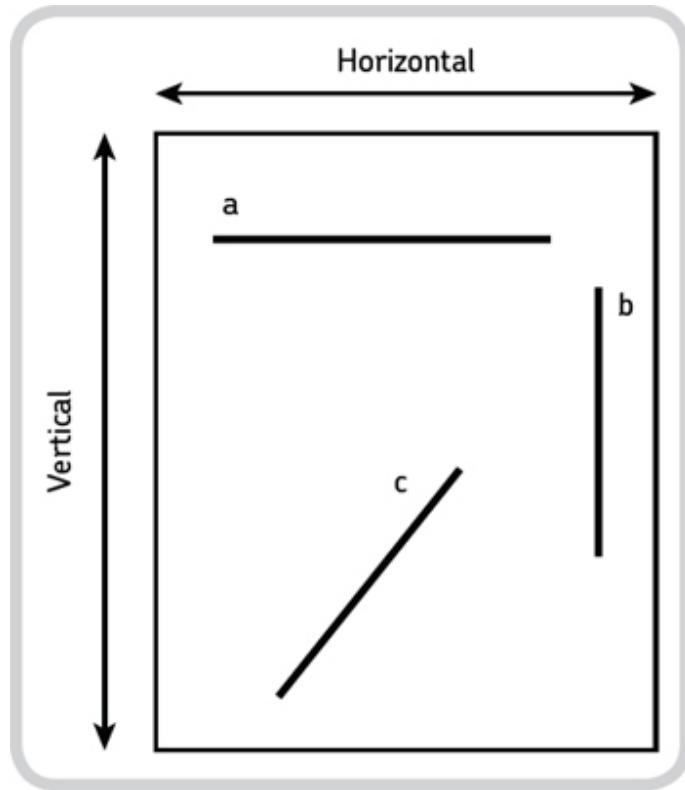


Figure 16-2. To draw a line, the Printer can move a pen horizontally (line a), vertically (line b), or in both directions (line c).

The Printer consists of two main components, or *modules*. The first is the *base*, which forms the main structure of the robot. The base holds the NXT and contains the *vertical motor*, which moves the paper vertically with the *vertical wheels*, drawing a vertical line if the motor moves when the pen touches the paper.

The base carries the second main component, the *horizontal module*, which moves over two racks that are part of the base. By using the *horizontal motor* to rotate the *horizontal wheel*, the complete module moves. If this motor moves when the pen touches the paper, the pen draws a horizontal line. The horizontal module also carries the *pen motor*, which raises and lowers the pen.

Non-LEGO Requirements for the Printer

You can build the Printer with mostly the pieces from the LEGO MINDSTORMS NXT 2.0 set, but you'll also need the following non-LEGO items. (You'll probably have everything you need around your home.)

- **Paper.** The Printer will work with both US letter paper (8.5 inches by 11 inches) and standard A4 paper (21 cm by 29.7 cm). If you live in North America, you'll likely use US letter paper. If not, you'll probably be using A4 paper. Measure your paper with a ruler to make sure you know what kind you're using because paper size is important when building the Printer.

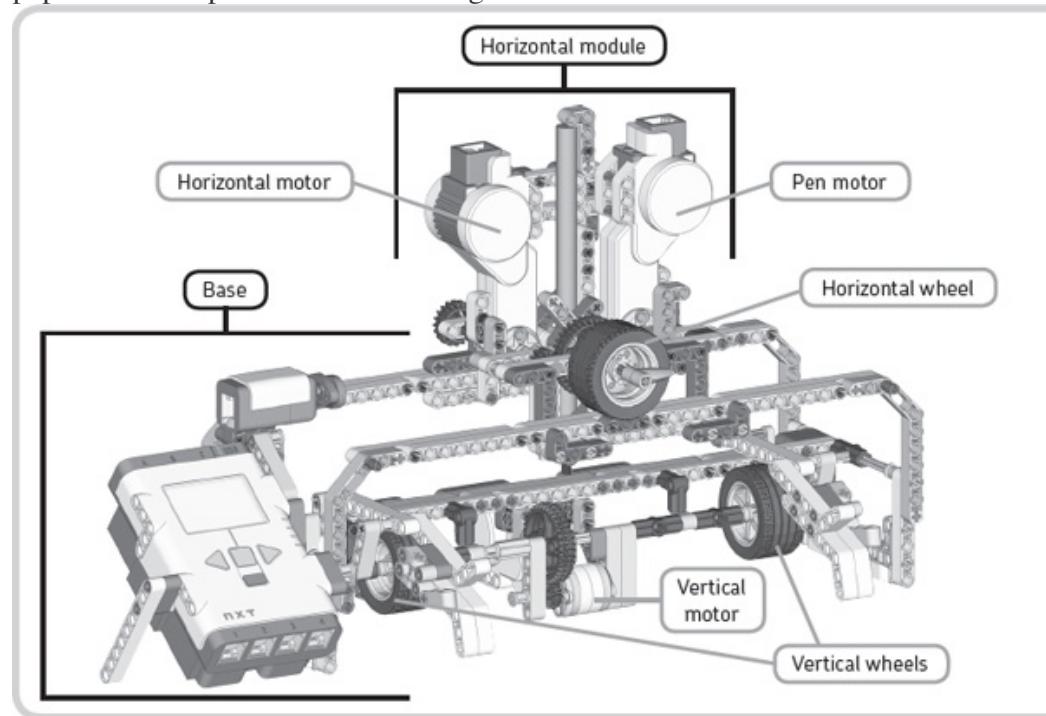


Figure 16-3. The Printer consists of several modules, each with its own function.

- **A pen.** You can use many different kinds of writing tools with the Printer. For best results, use a marker, pen, or pencil that doesn't require a lot of pressure to write with, such as a Sharpie fine-tip marker.
- **Tape.** Find some tape about 1.5 cm (0.6 inches) in width, such as Scotch Magic

tape (0.5 inches in width).

Building the Printer

Build the Printer using the instructions on the following pages. Throughout the instructions, you'll find comments about ways to customize your Printer. Read the notes carefully, or your robot may not work as expected. Before you begin building, select the required pieces, as shown in [Figure 16-4](#).

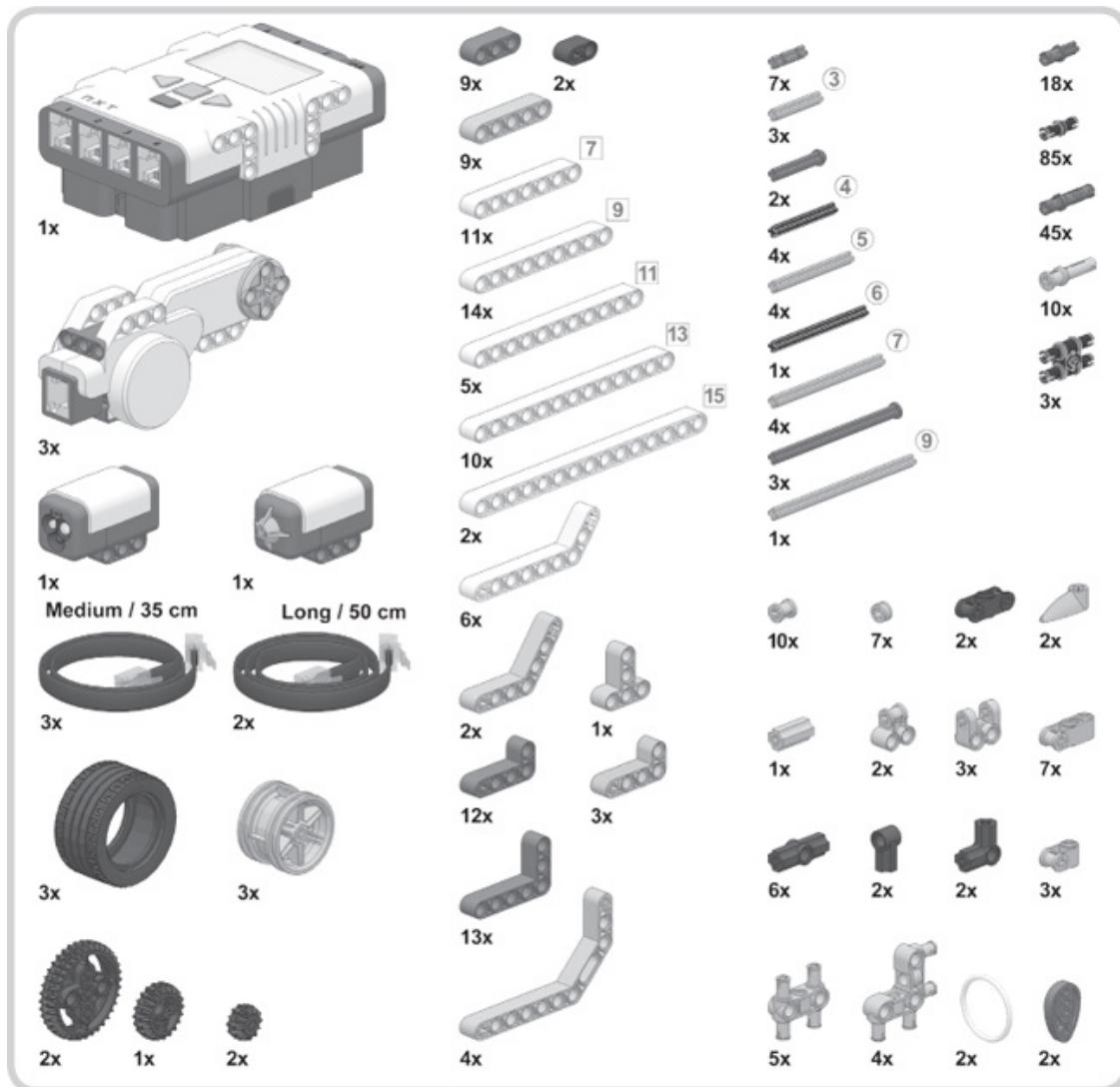
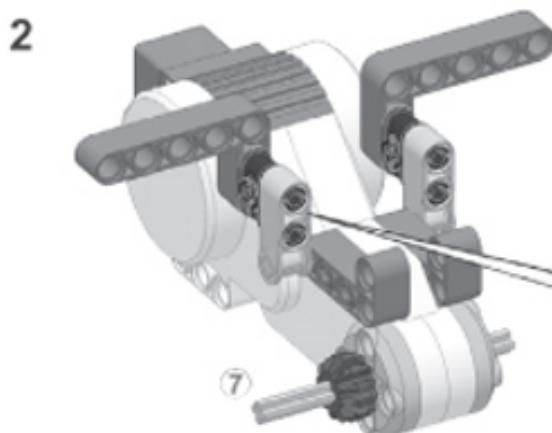
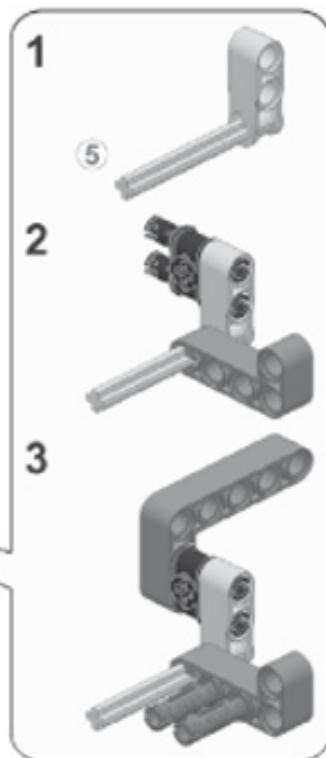
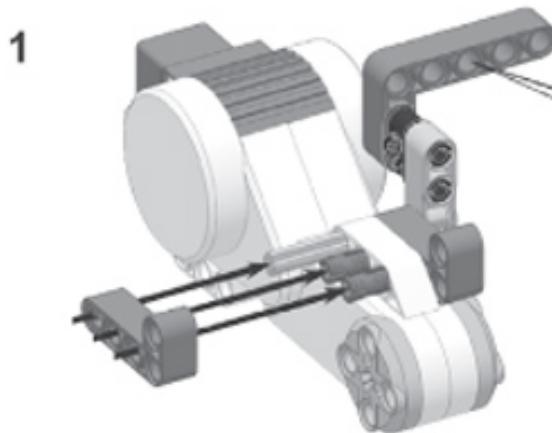
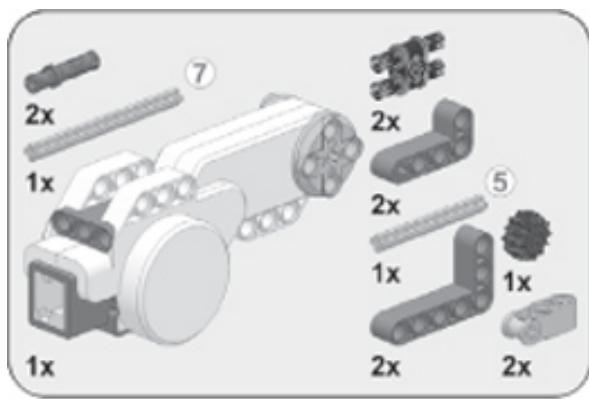
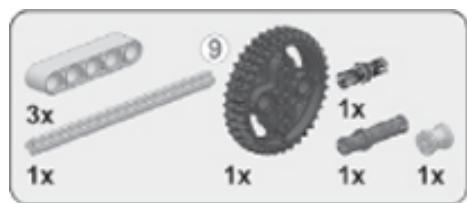
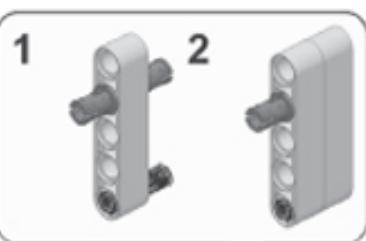
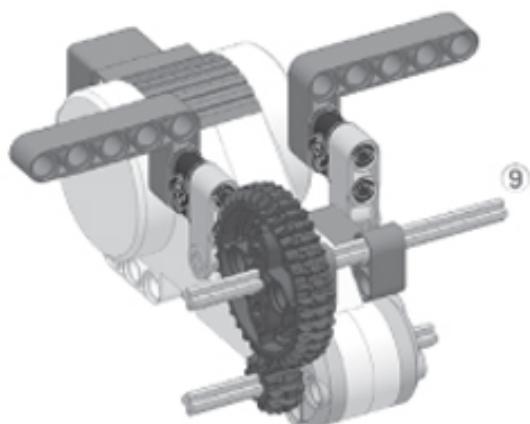


Figure 16-4. A BOM for the Printer

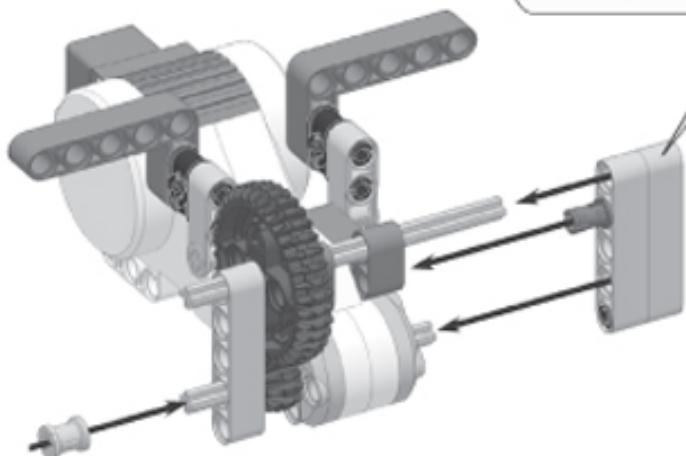


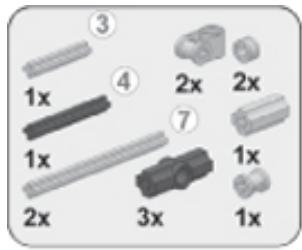


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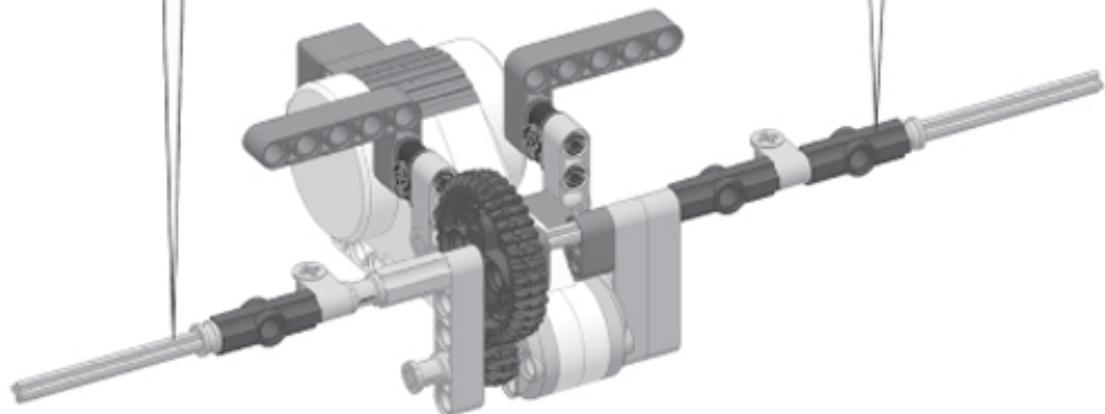
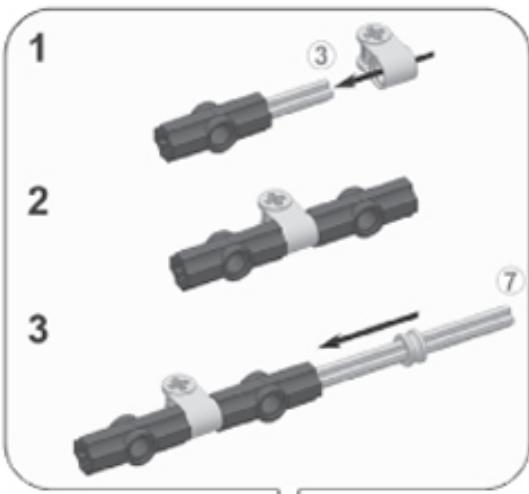
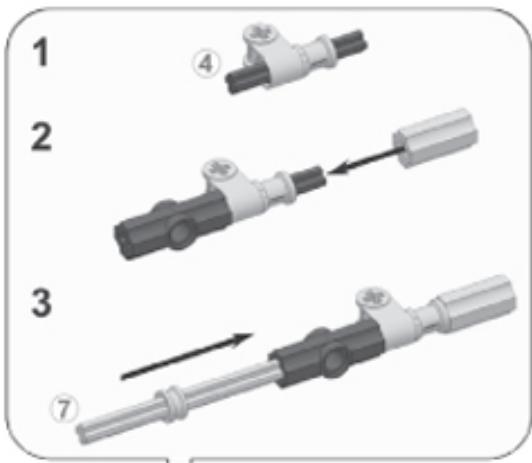


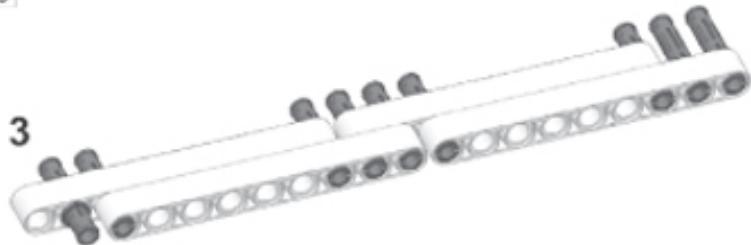
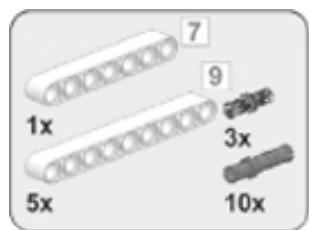
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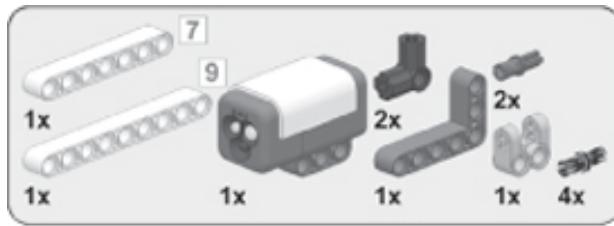




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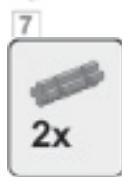
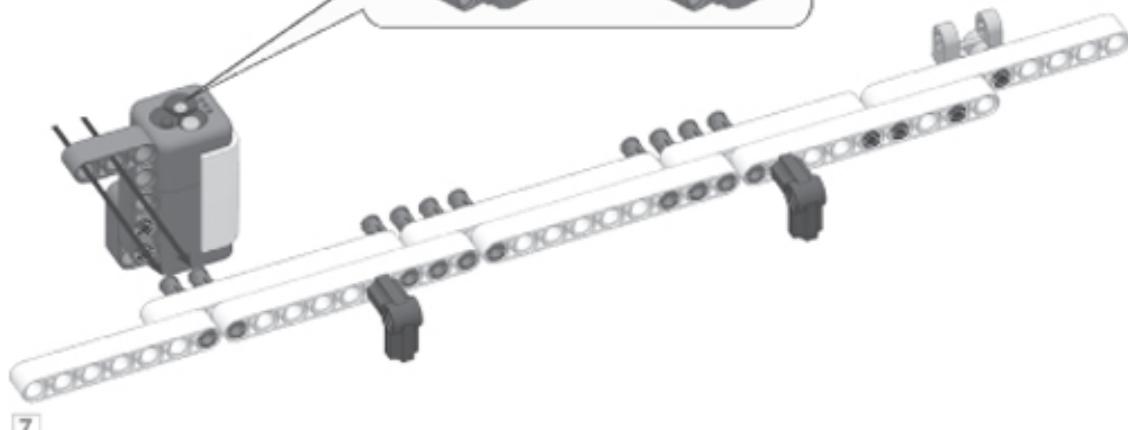
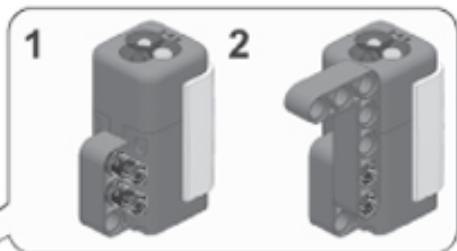




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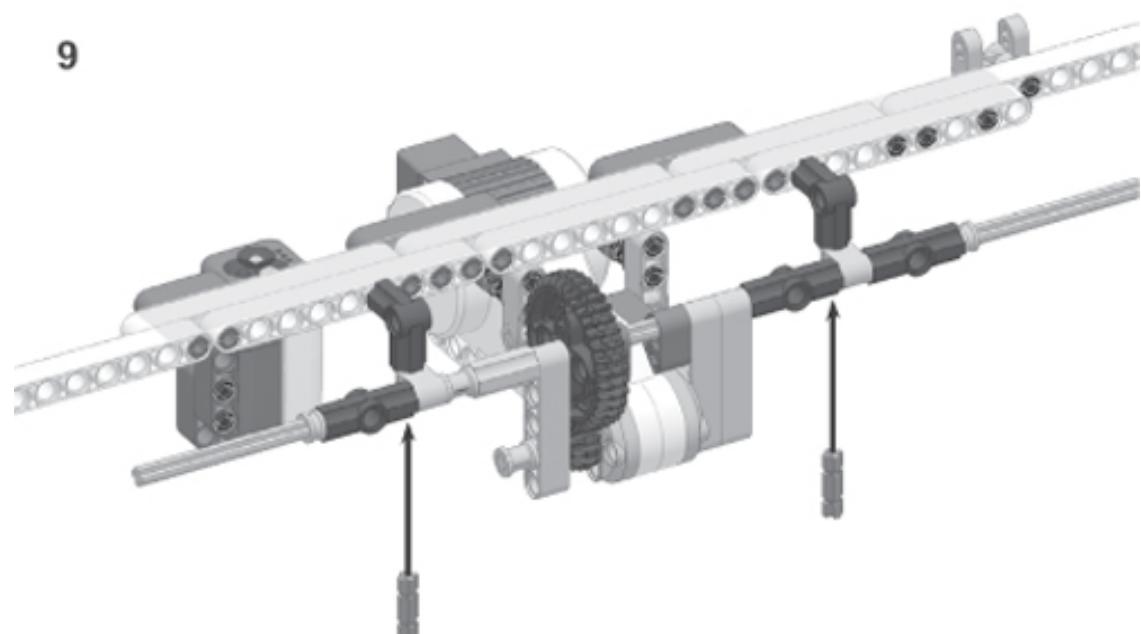
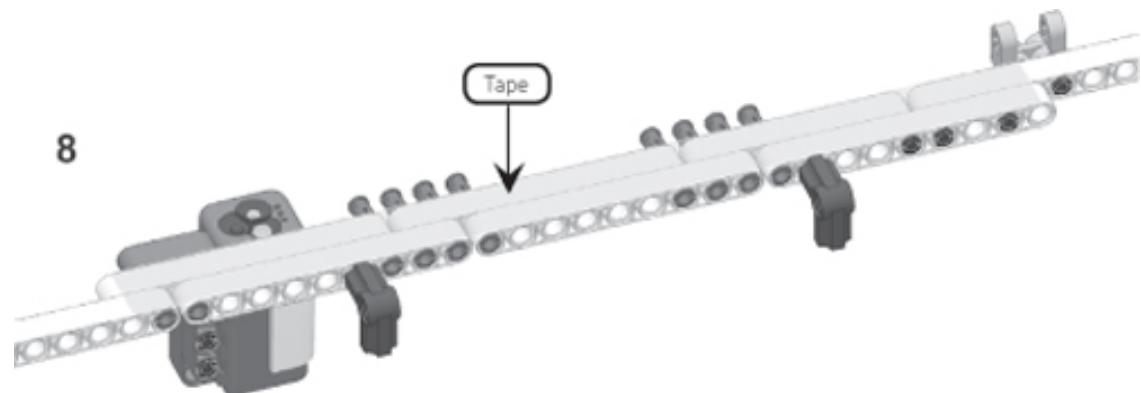


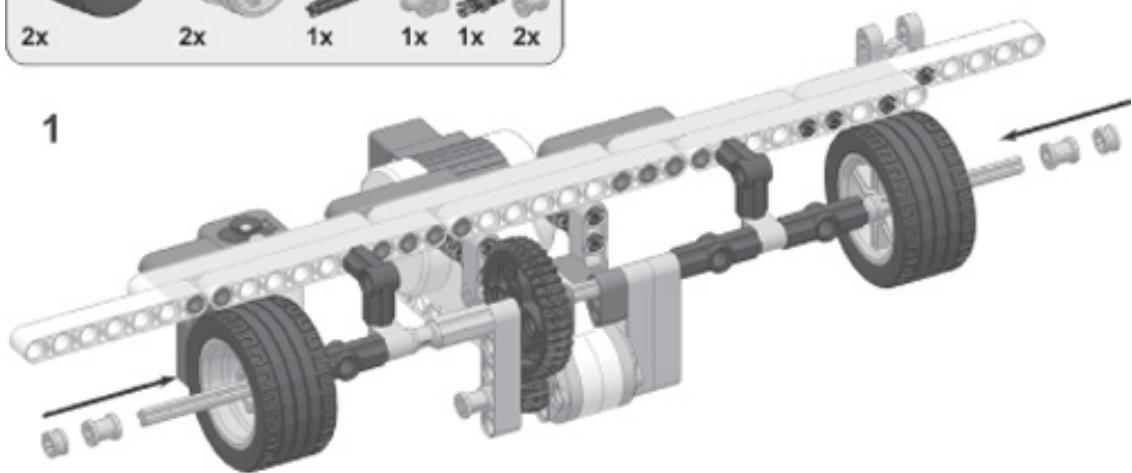
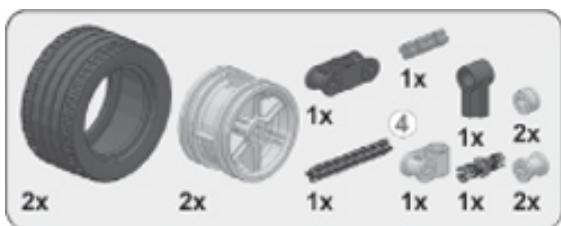
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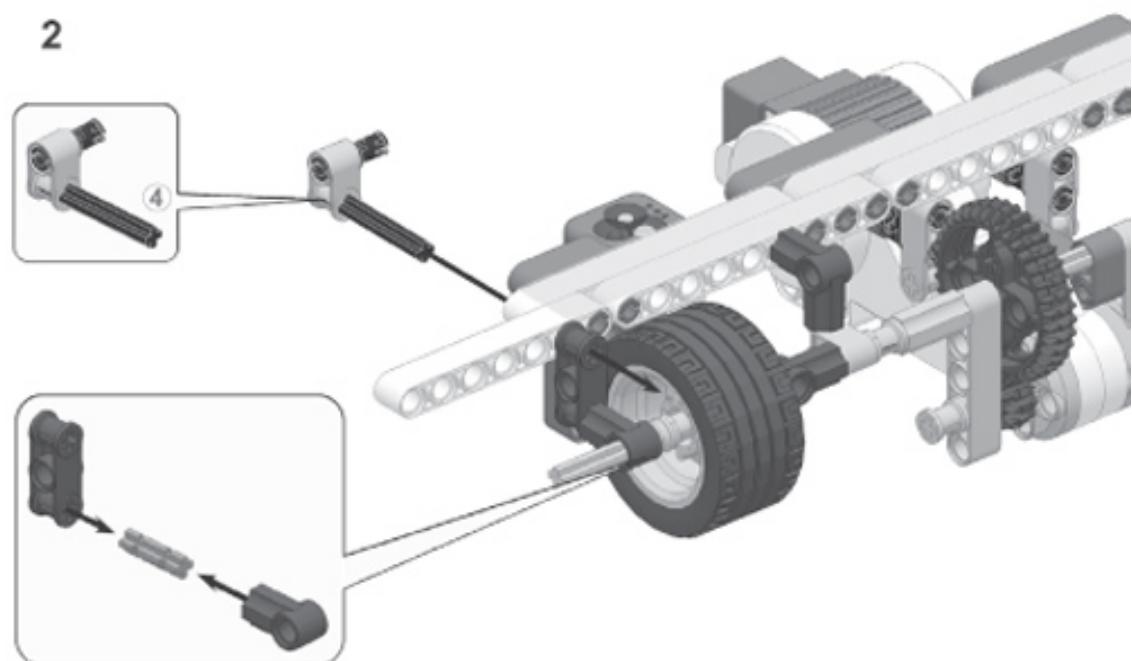
When there isn't any paper in the Printer, the pen may accidentally write on the structure you're currently building. To prevent this from happening, add a strip of tape as shown in step 8. The tape should be approximately 22 cm (8.5 inches) long and 1.3 to 1.5 cm (0.5 to 0.6 inches) wide. Make sure to place the tape precisely, leaving no dents in it or air

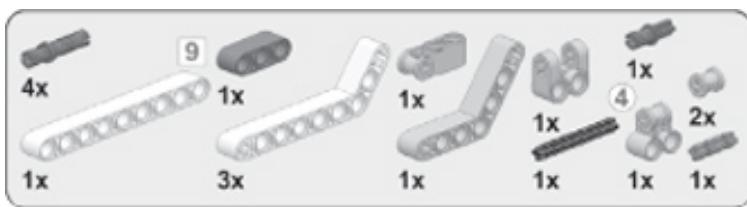
bubbles under it.



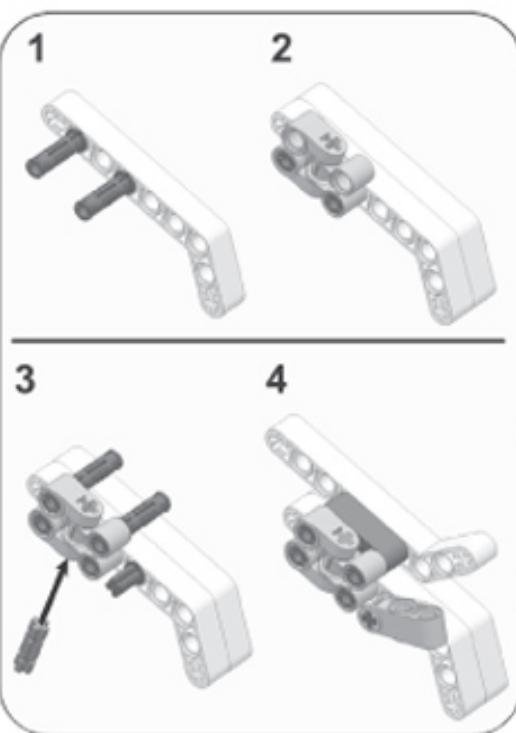
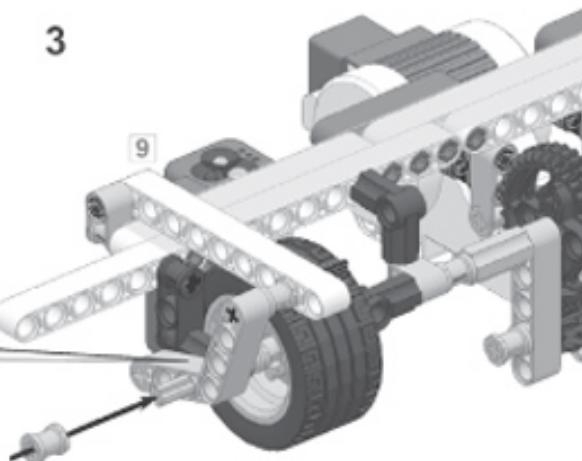


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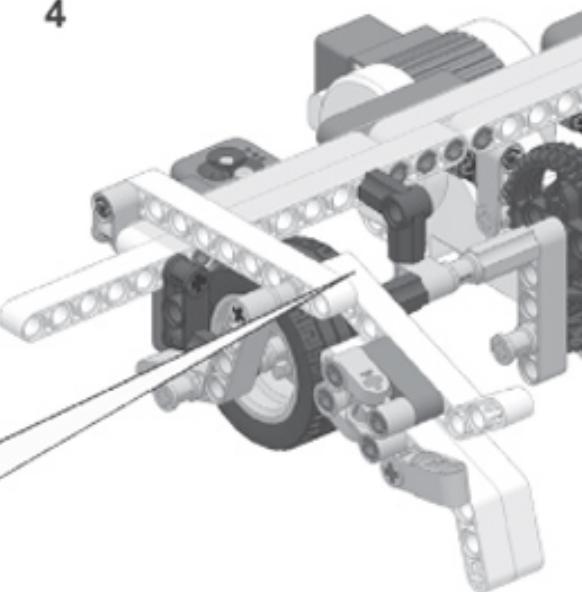


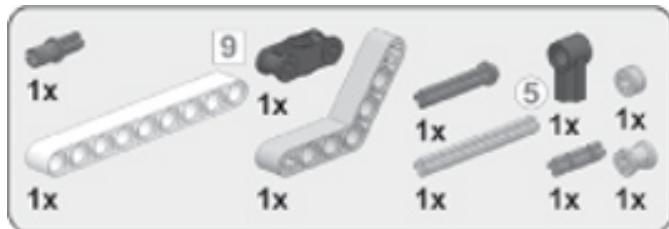


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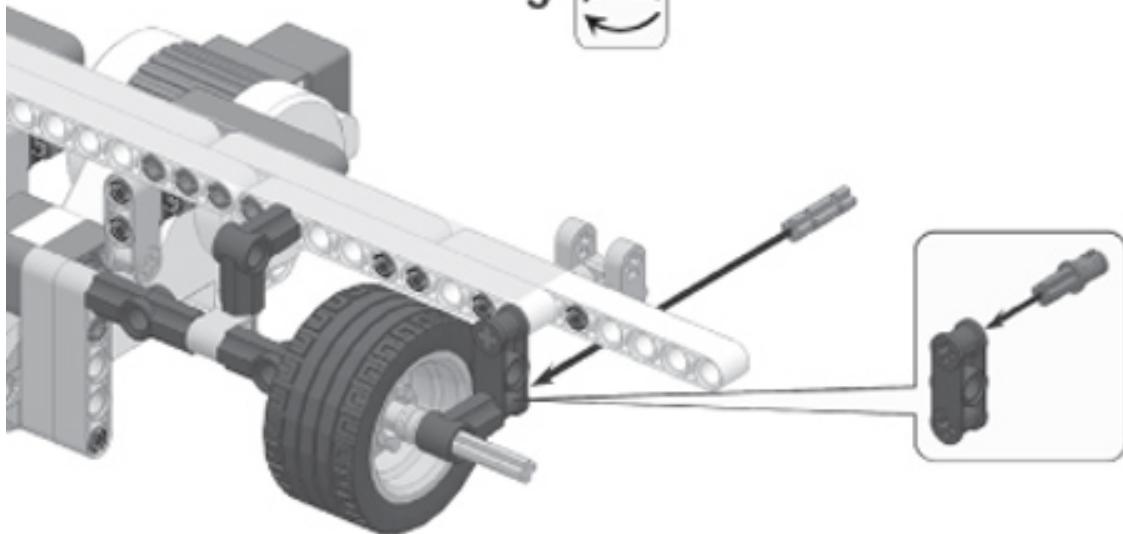


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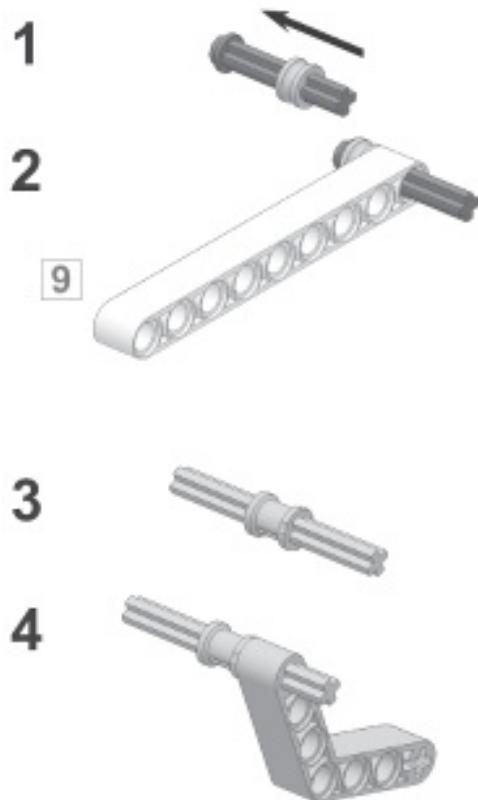


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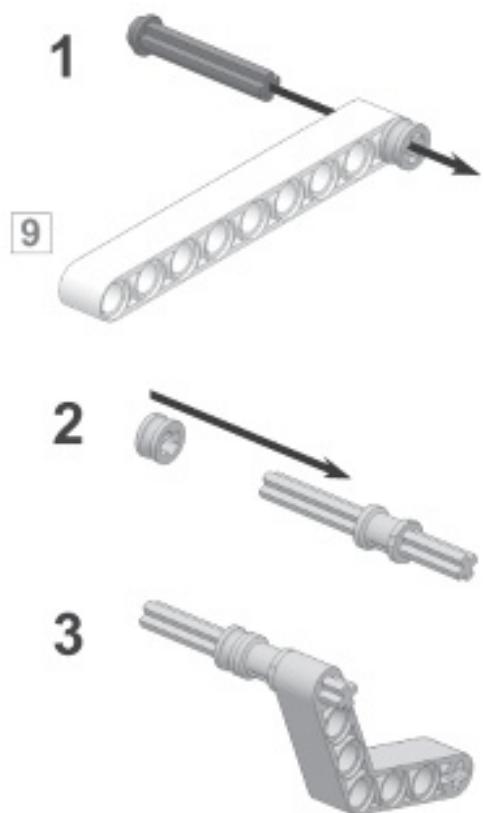


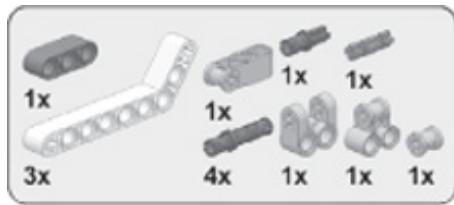
The following pieces comprise the part of the frame that will hold the paper in the Printer. Adjust your printer to the paper type you'll be using: US letter paper or A4 paper. If you use US letter paper, follow the steps to the left, and then proceed to the next page. If you use A4 paper, follow the steps to the right, and then proceed to the next page.

US letter paper:

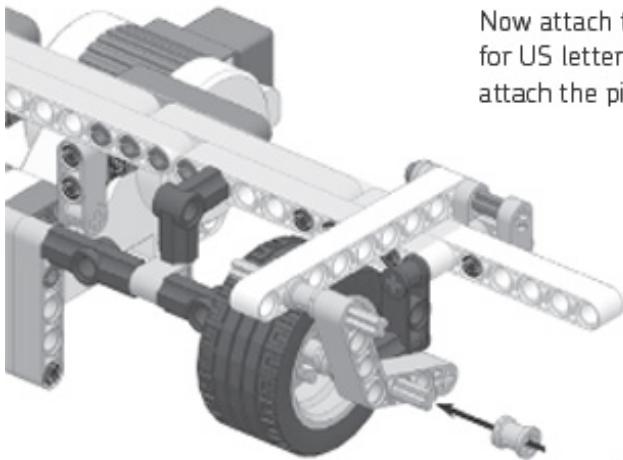


A4 paper:

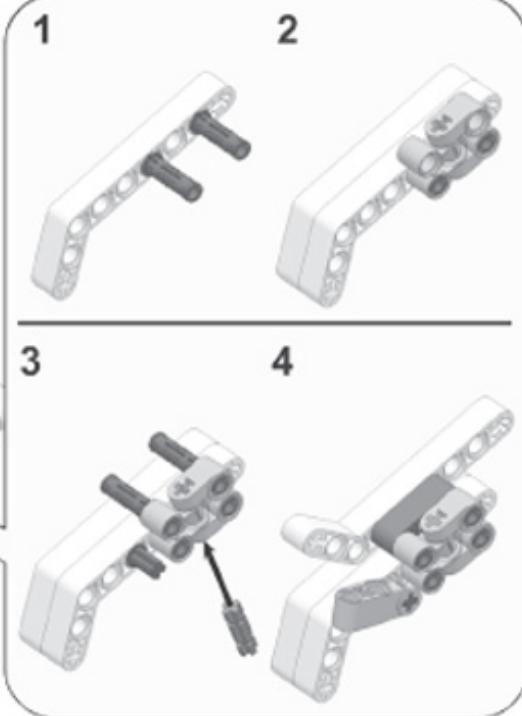
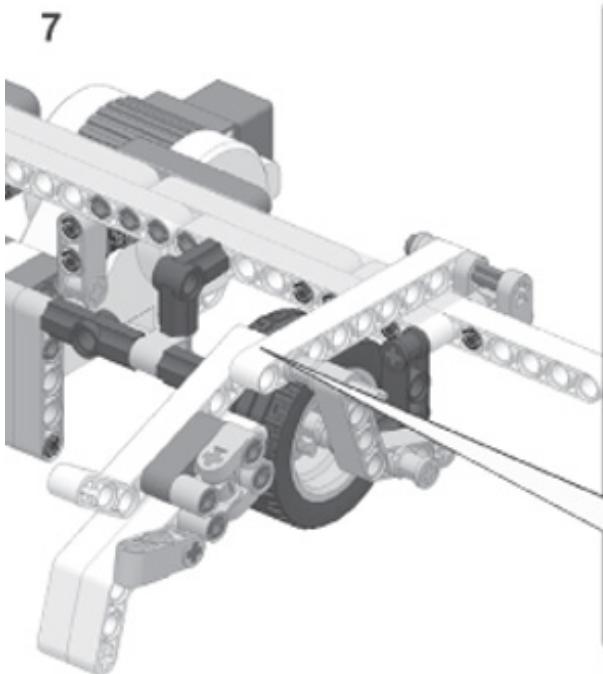


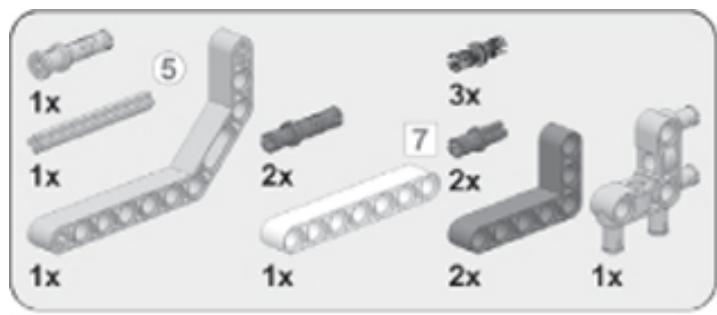


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Now attach the pieces you've just built. Only the pieces for US letter paper are shown here, but you would attach the pieces for A4 paper in the same way.

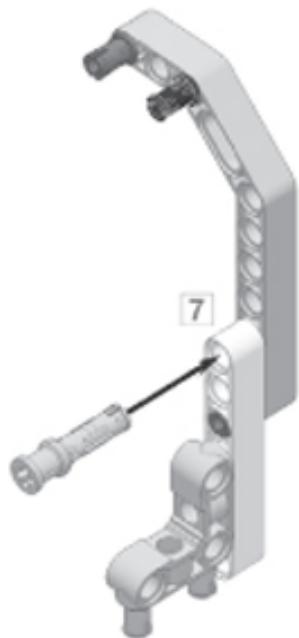




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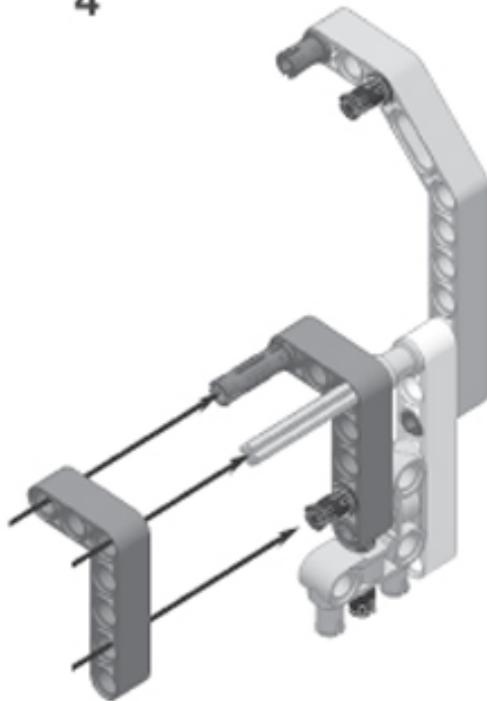
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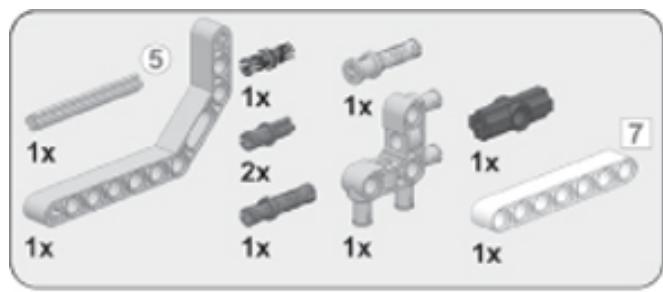


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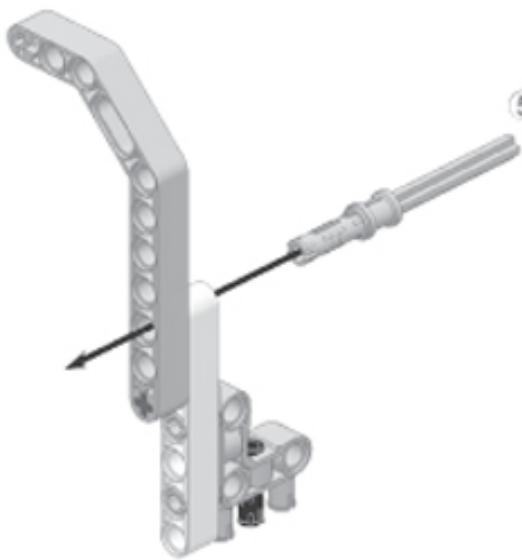
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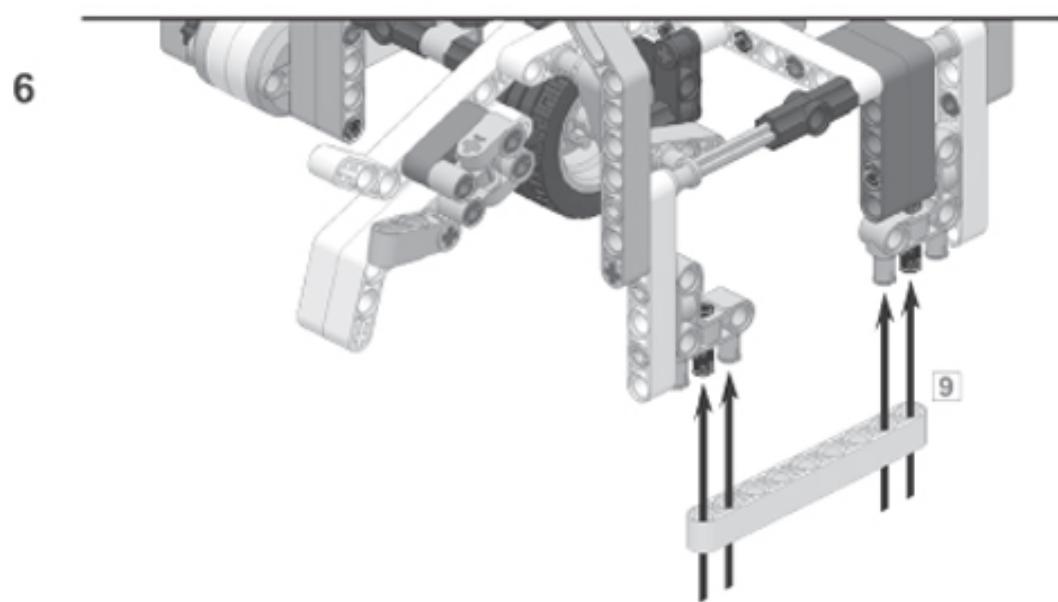
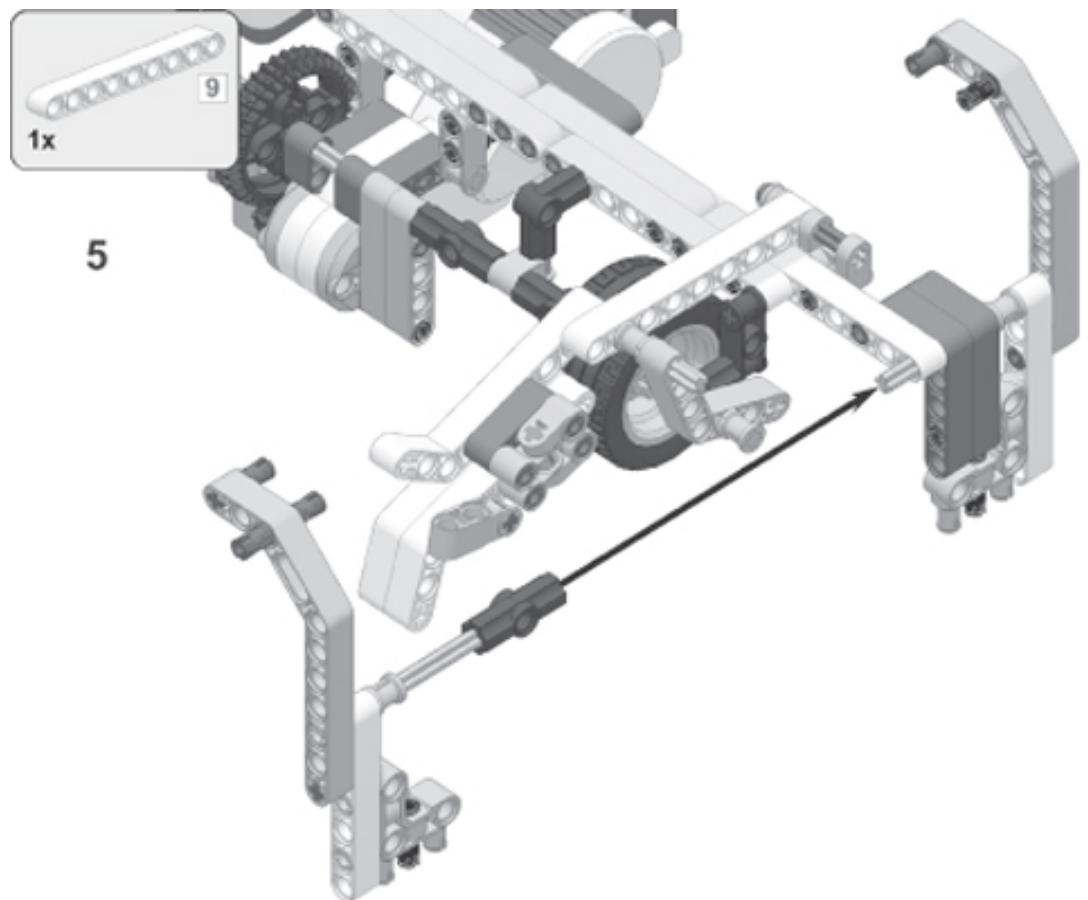


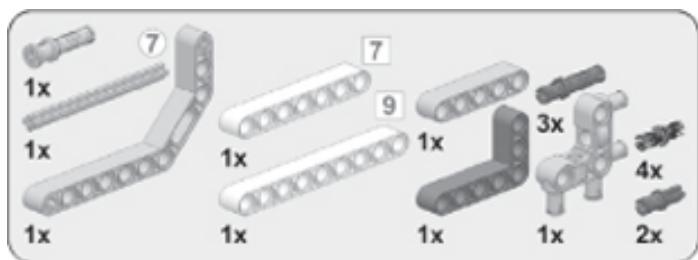
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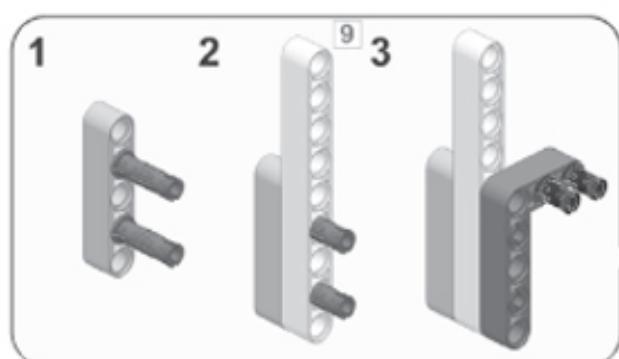
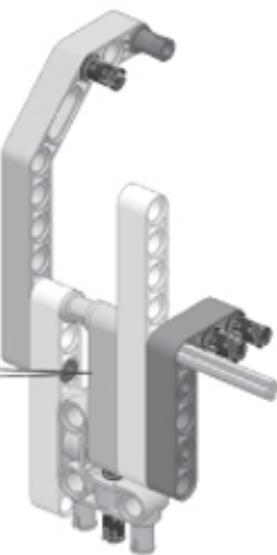
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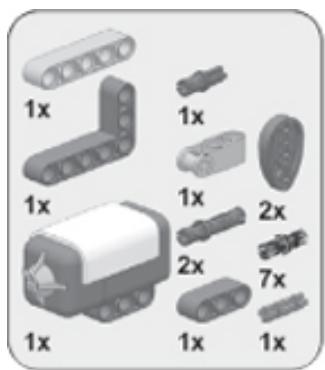


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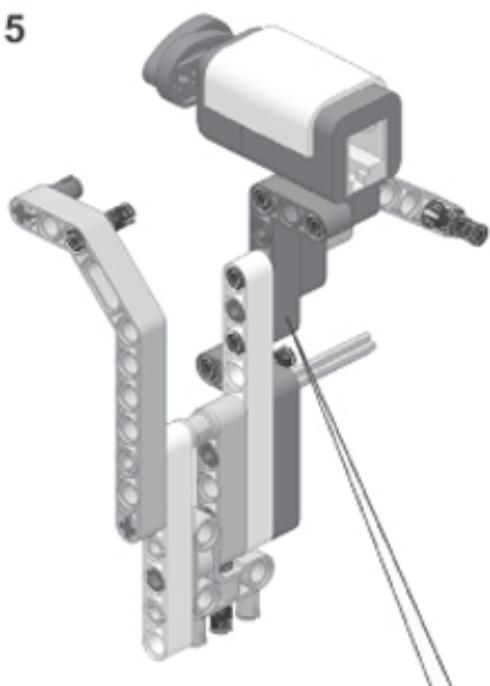


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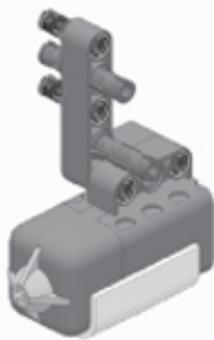
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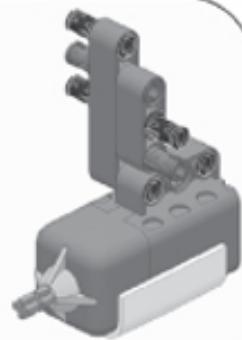
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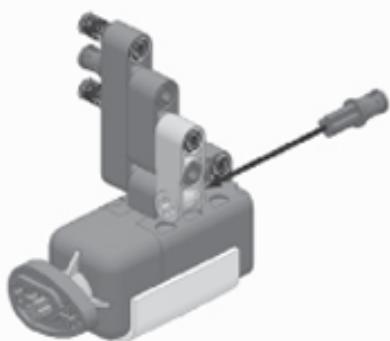
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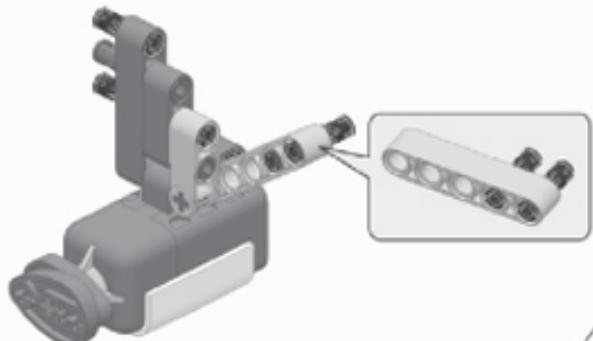
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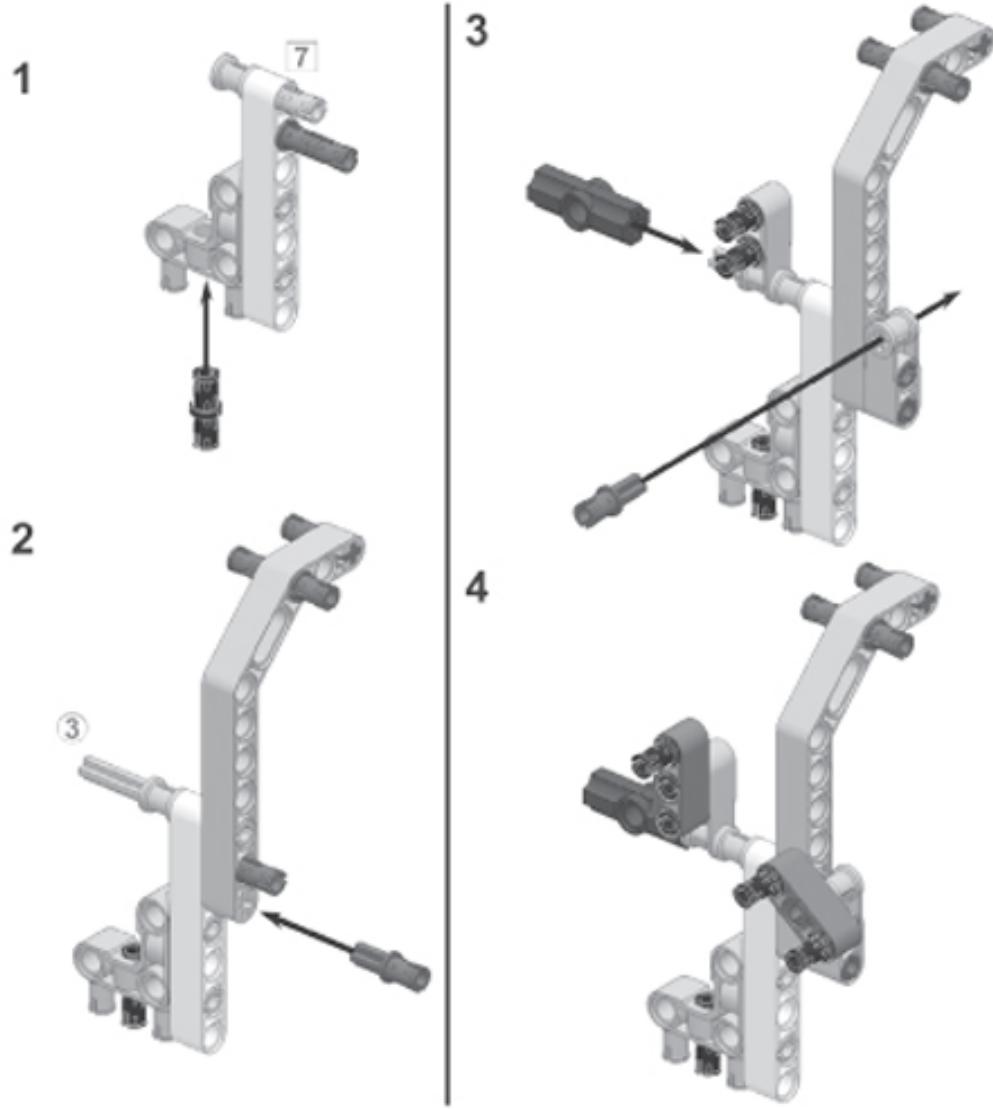
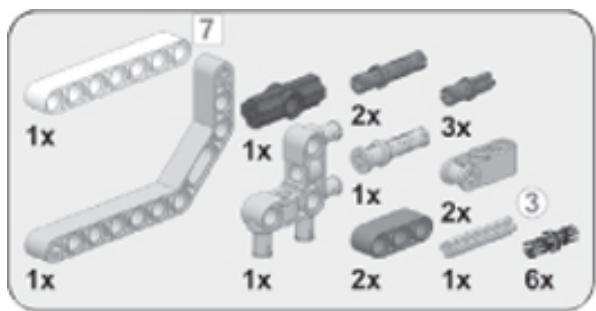


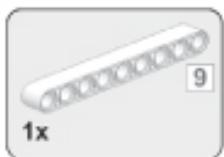
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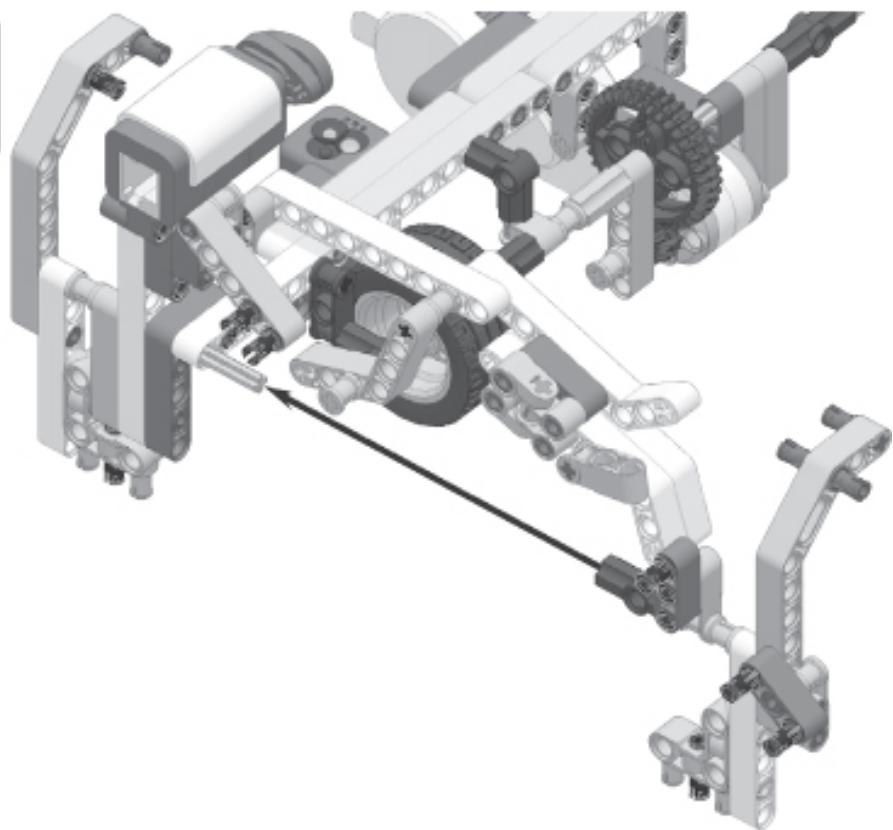
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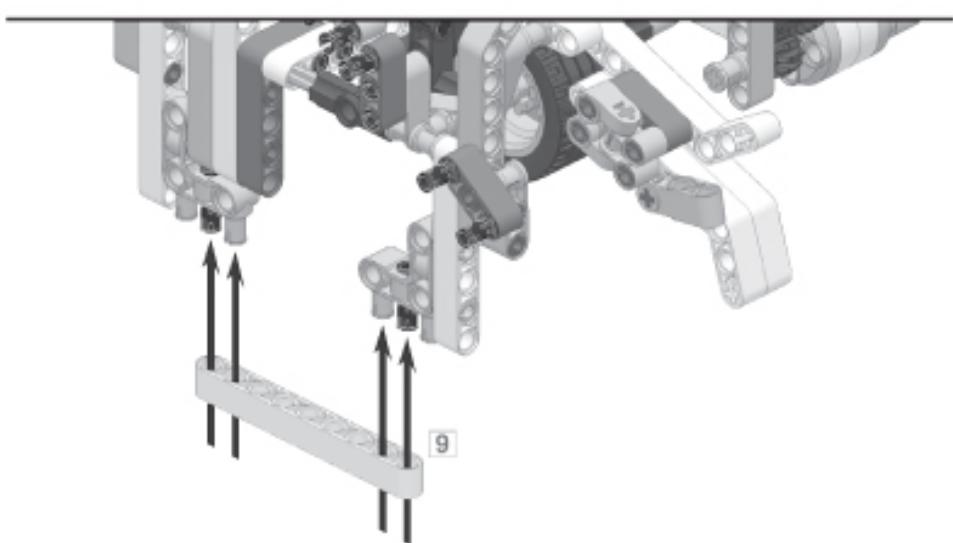


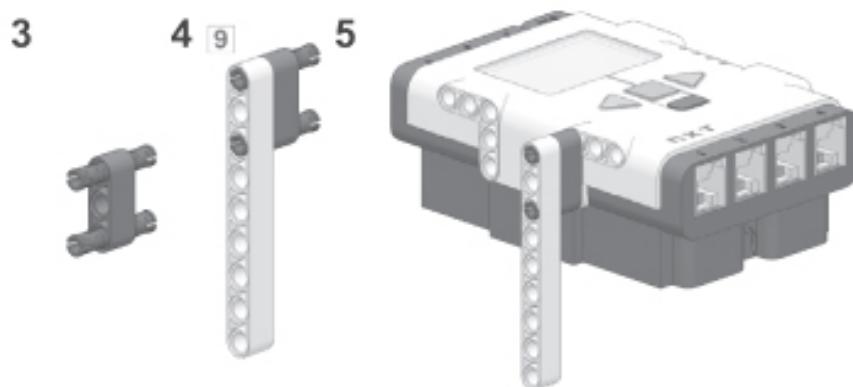
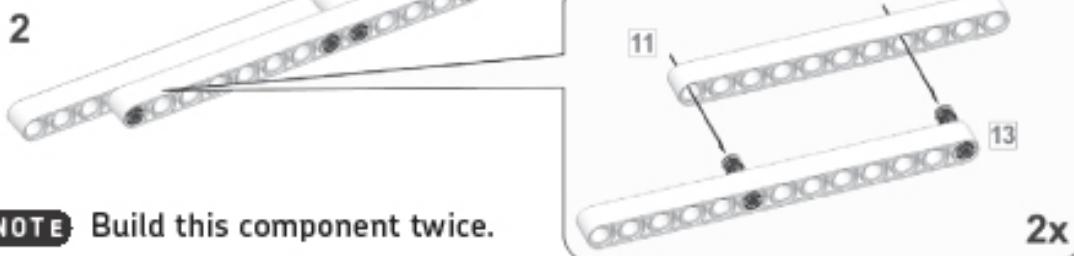
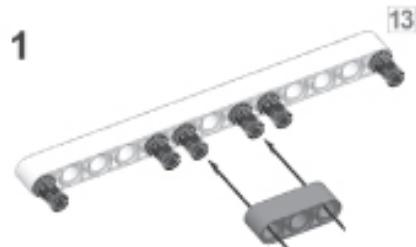
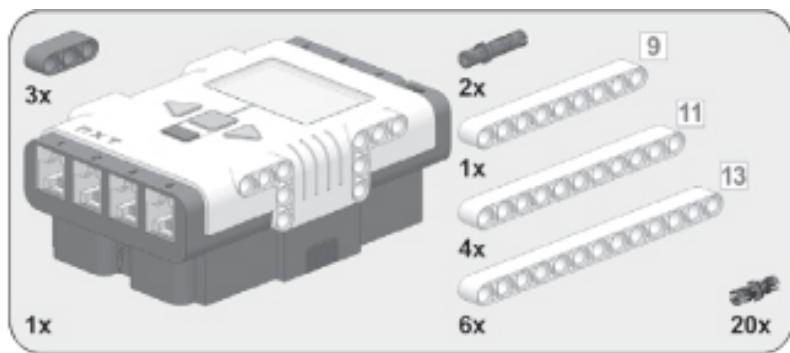


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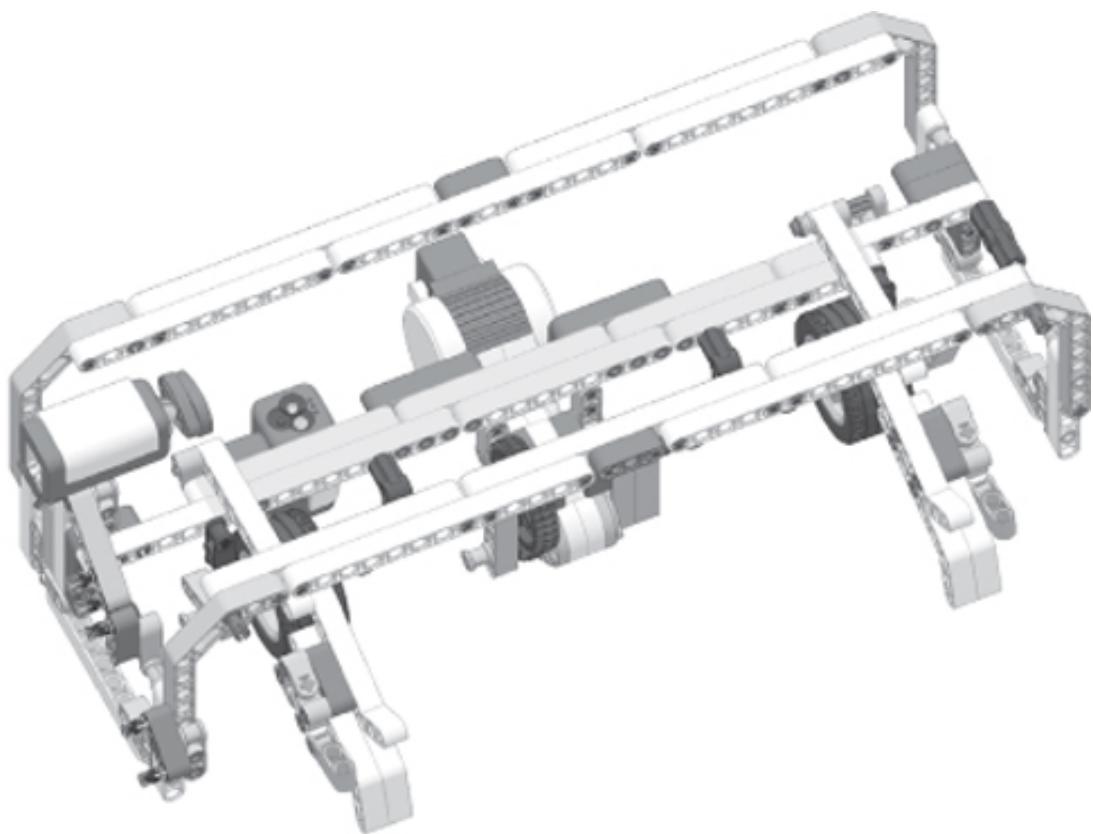


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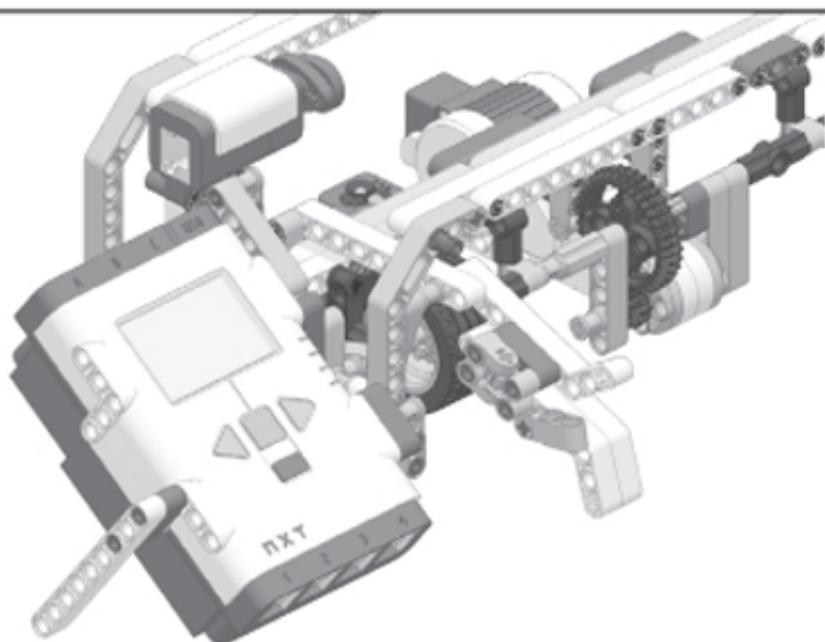


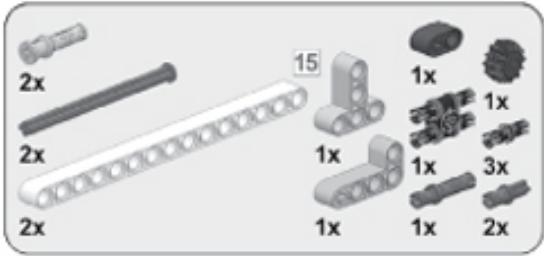


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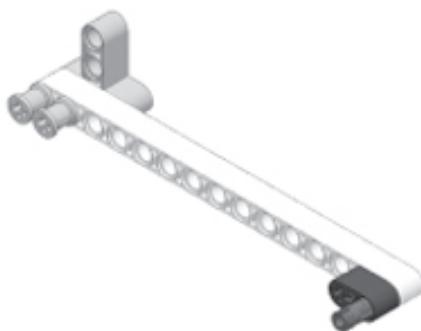




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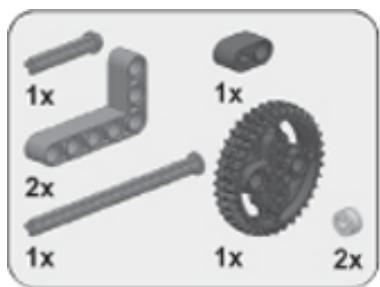


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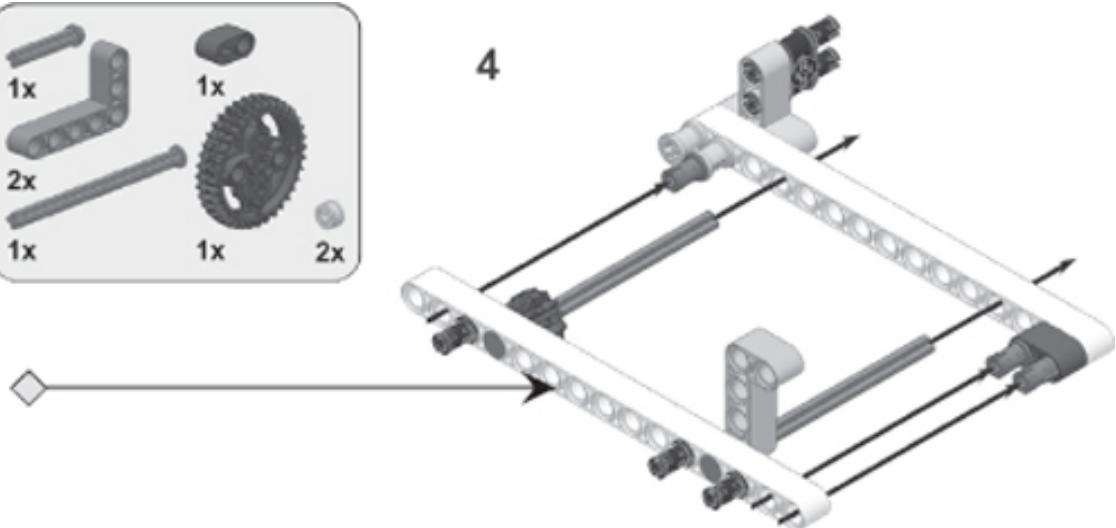


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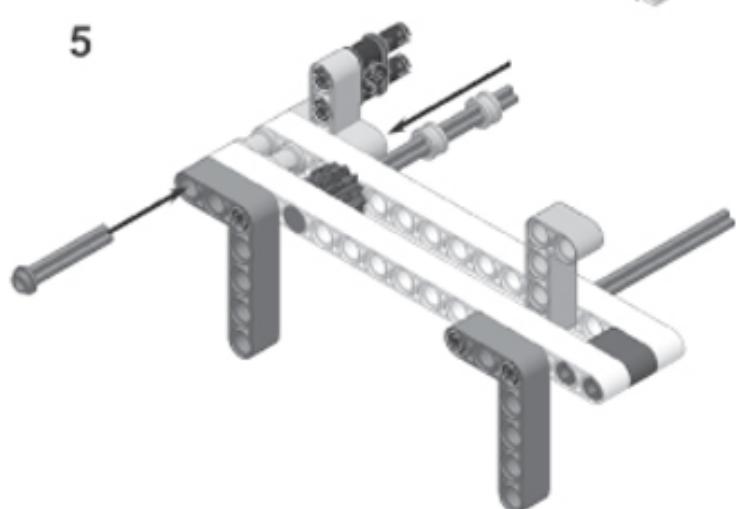




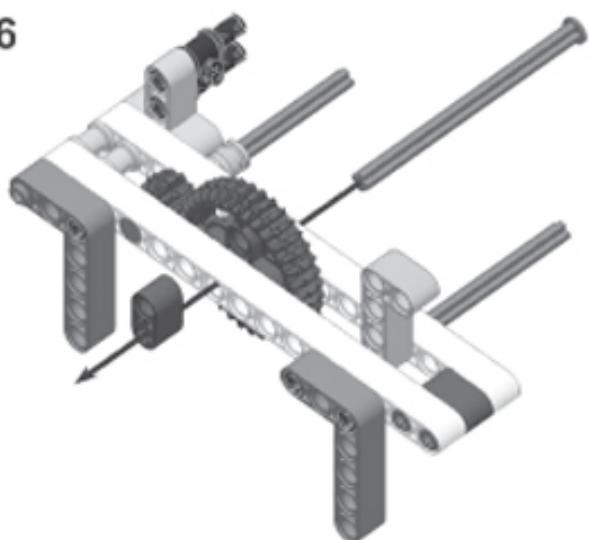
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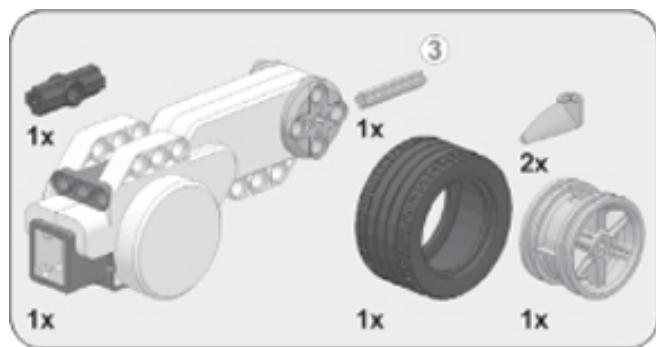


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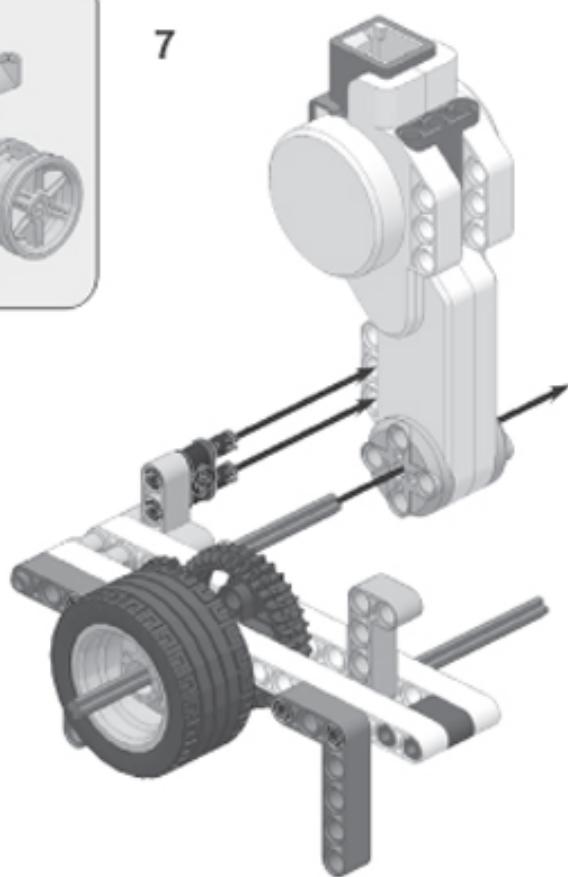


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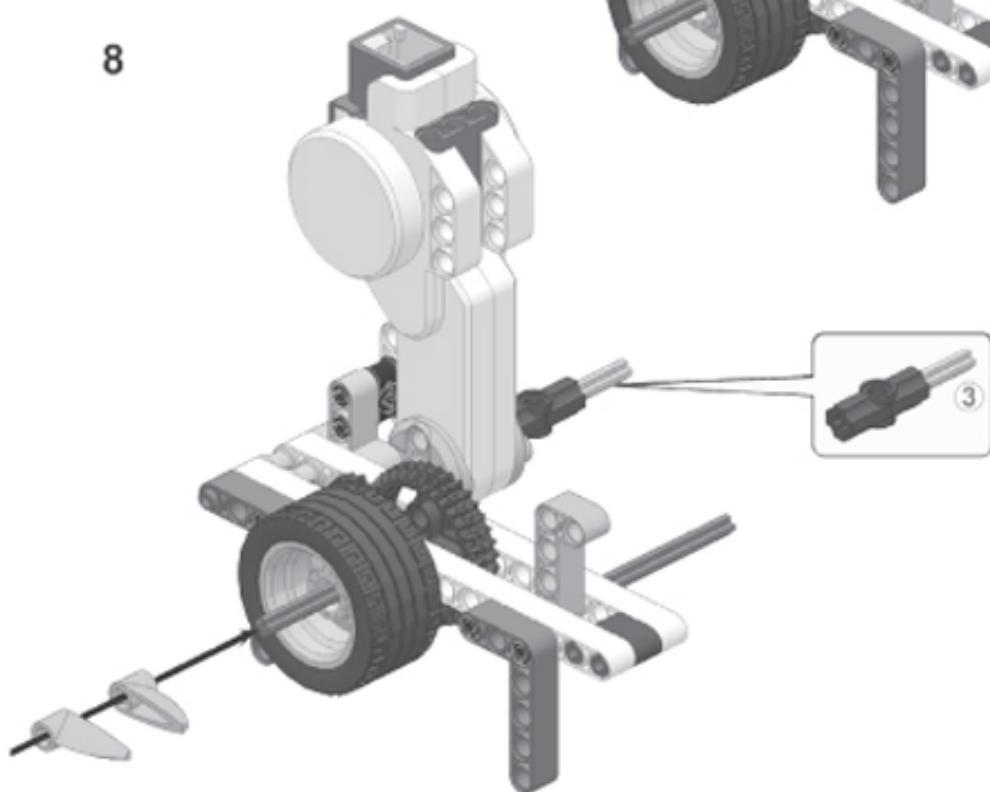


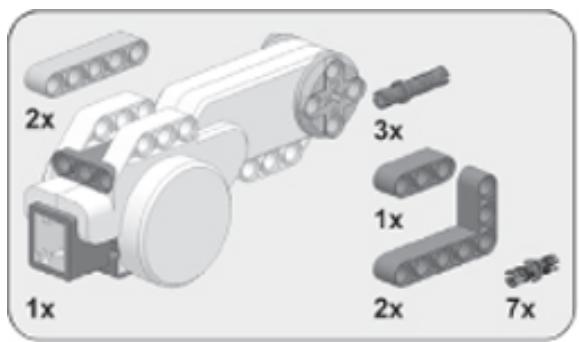


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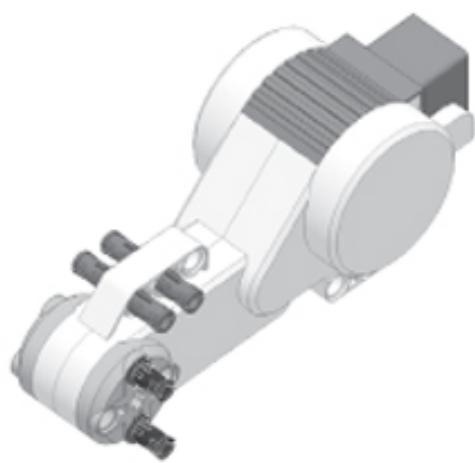


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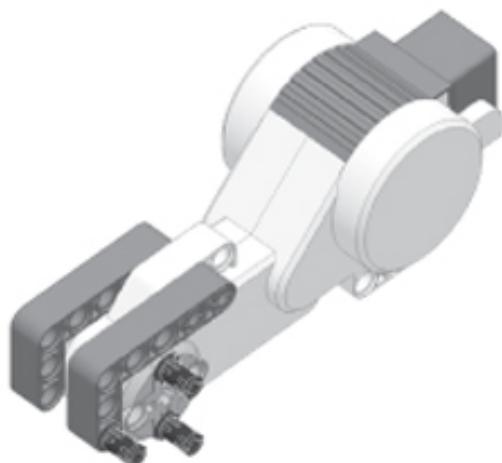
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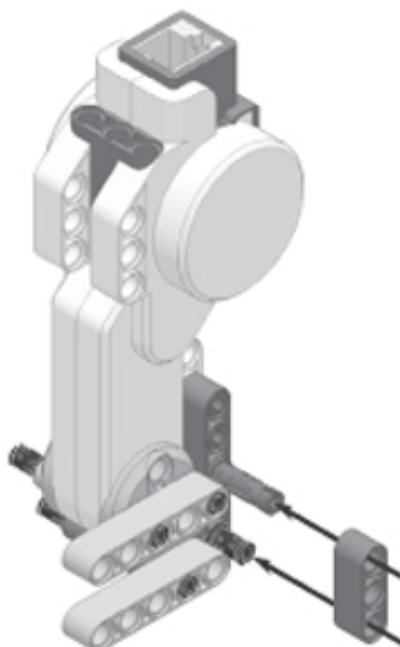
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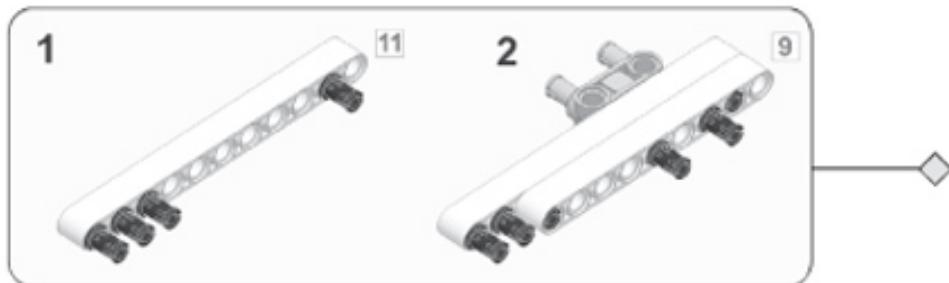
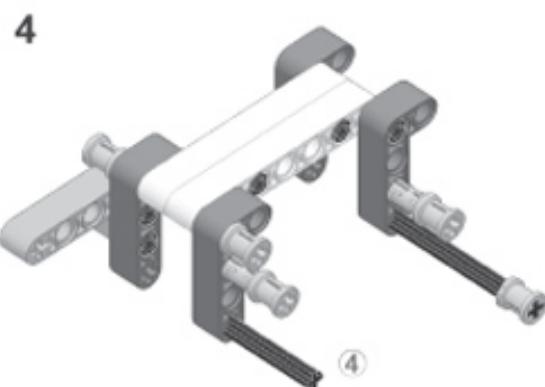
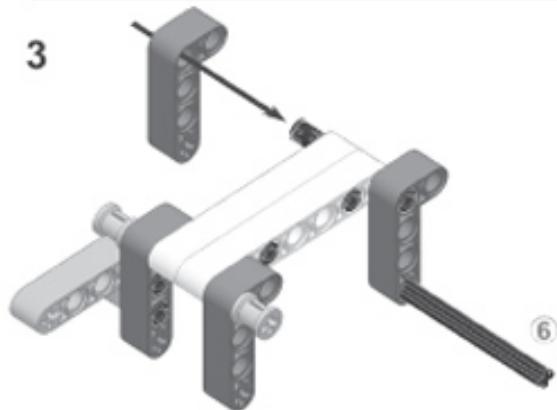
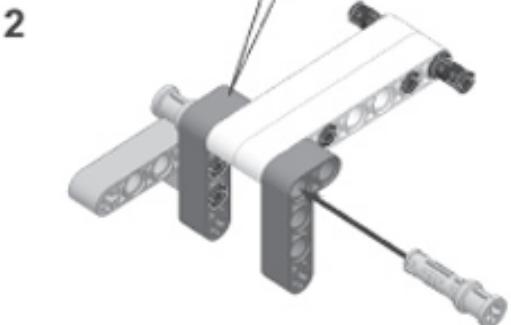
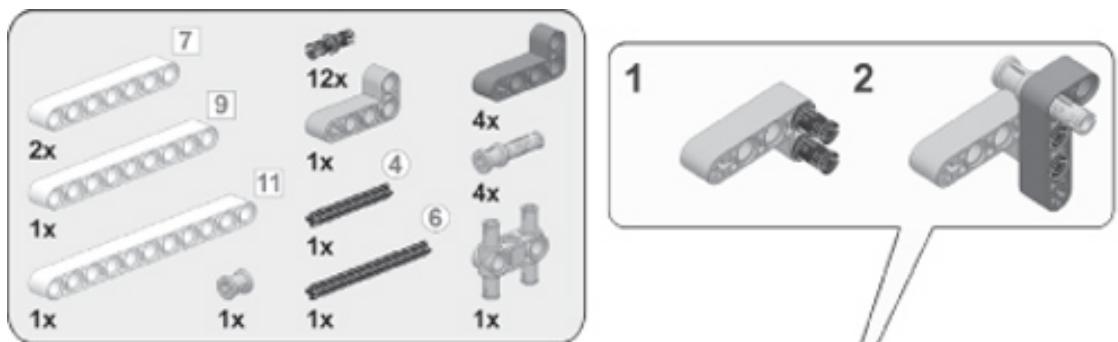


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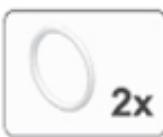
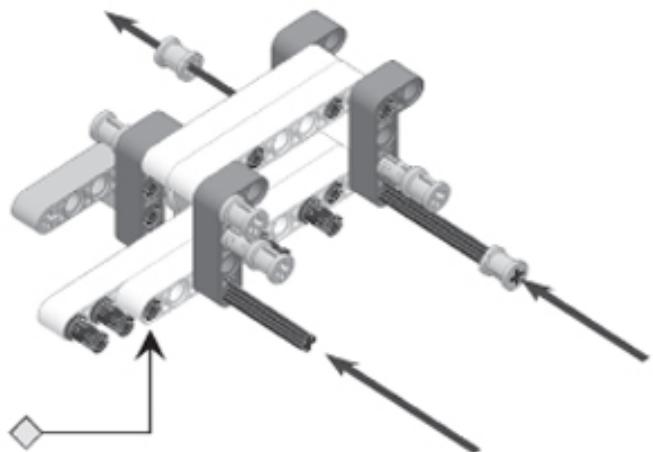
4







5



6



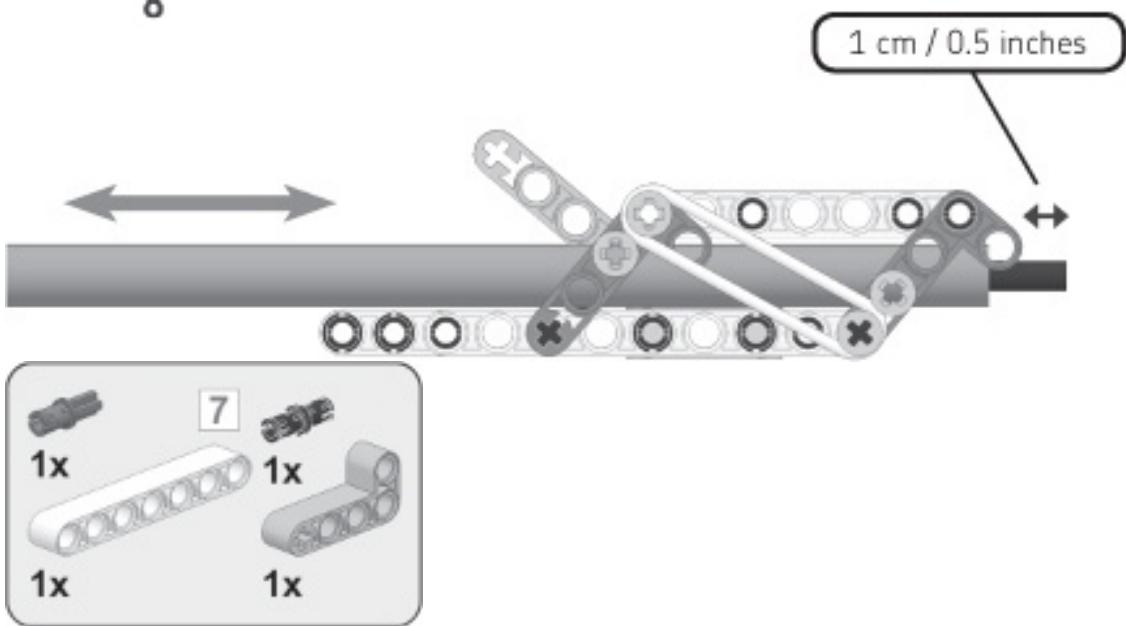
Now insert the pen that you've chosen into the pen holder that you just built. To do so, press the orange handle (see gray arrow), slide the pen in, and press the bushed friction pegs so that they press against the pen (see black arrows).

7



Next, adjust the position of the pen so that its tip sticks out of the holder by 1 cm (approximately 0.5 inches).

8



Finally, you'll add a structure that ensures that the pen doesn't slip out of its holder. Choose one of the three options shown here, or modify one of them to work with your pen. When you add this structure, make sure your pen tip still sticks out by approximately 1 cm (0.5 inches), as shown in step 8.

Shorter pen



Average pen



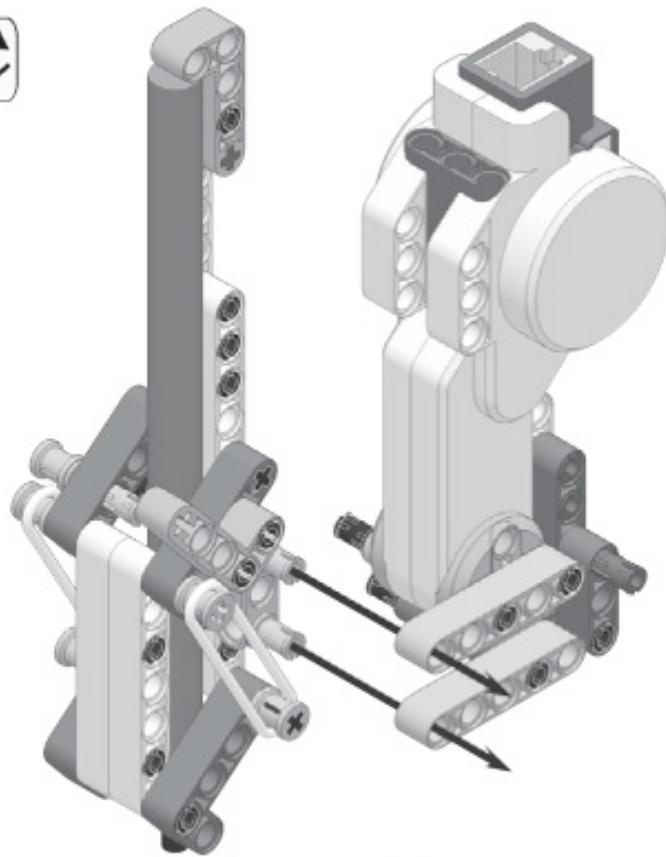
Longer pen



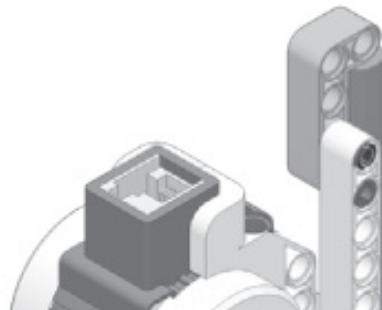
9

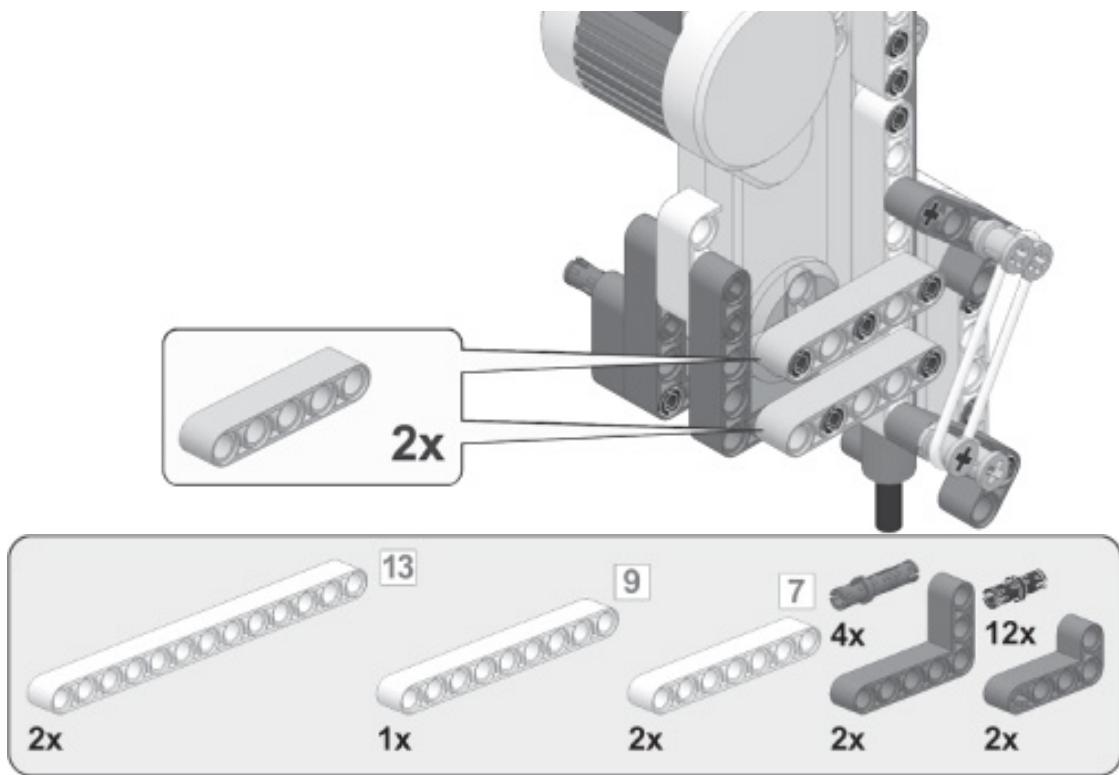


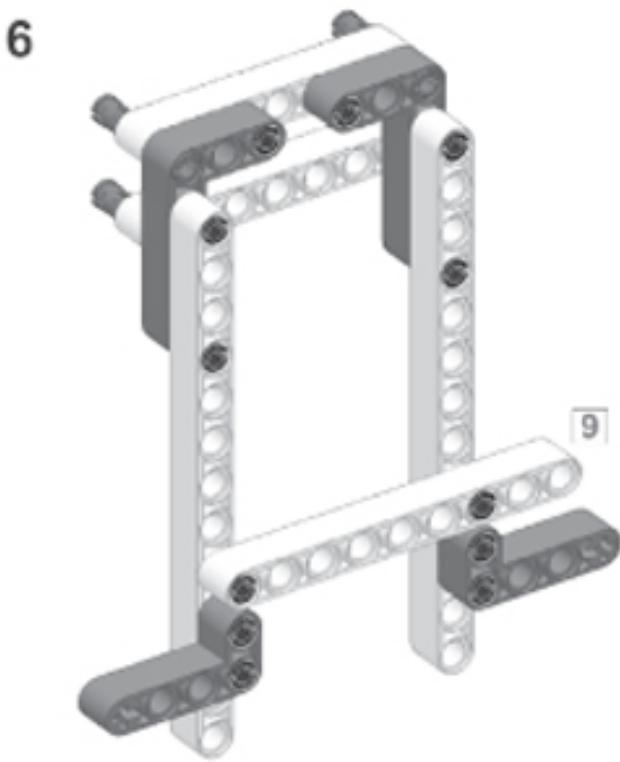
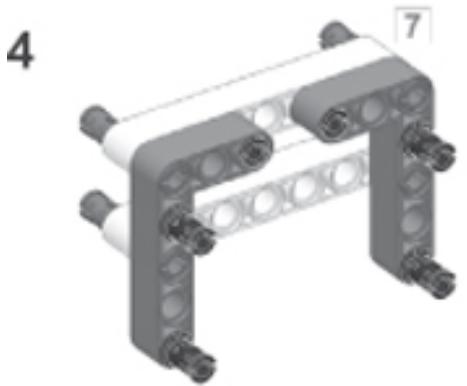
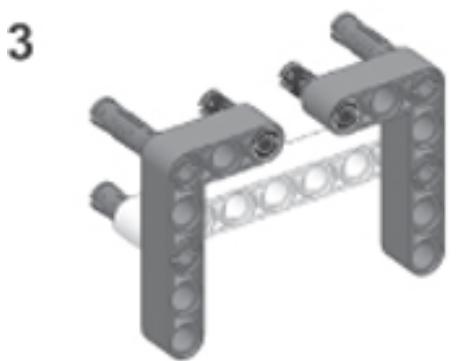
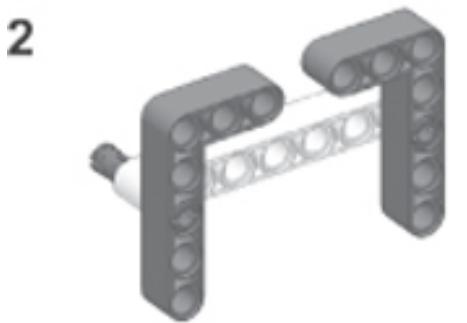
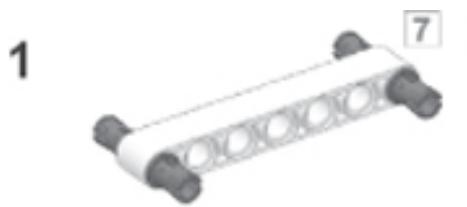
5 

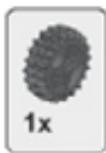


6 



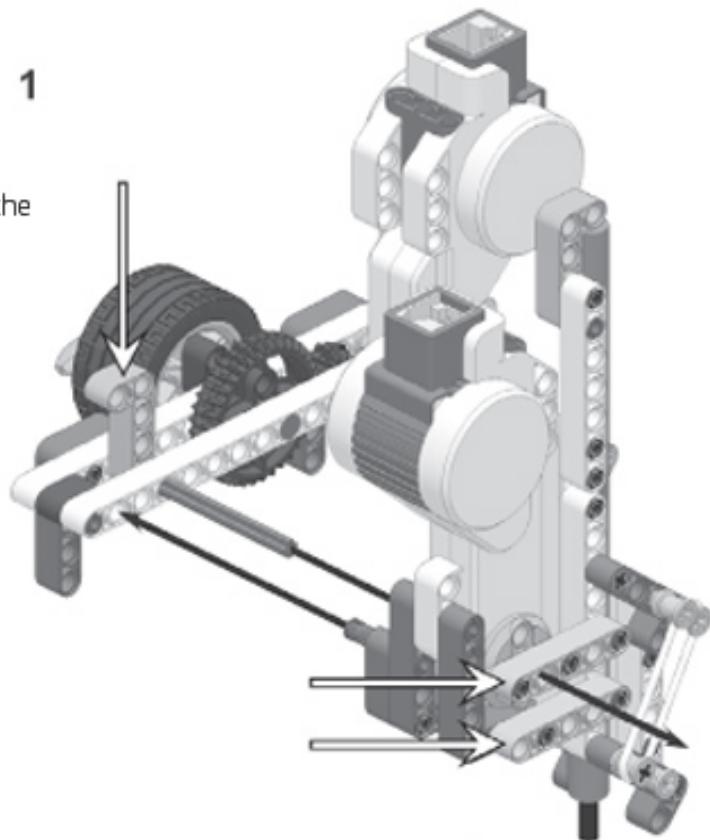




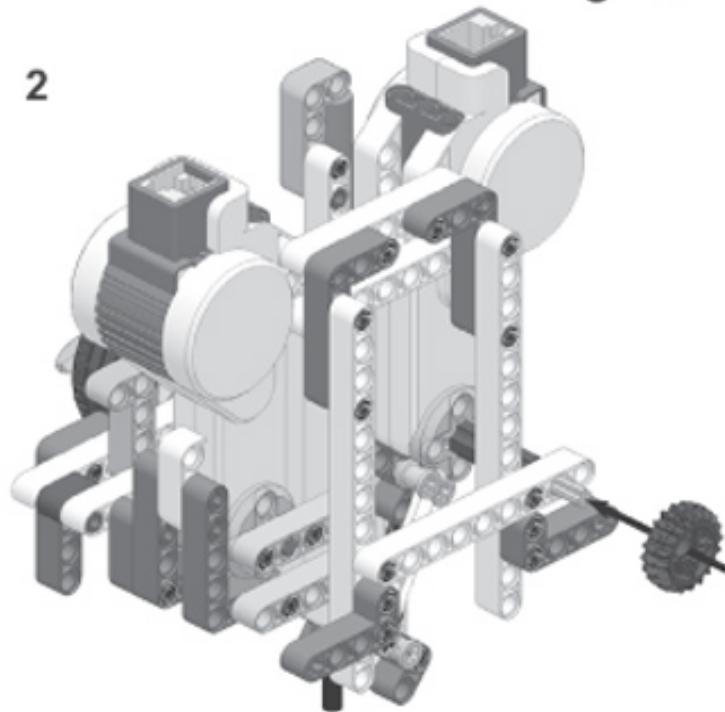


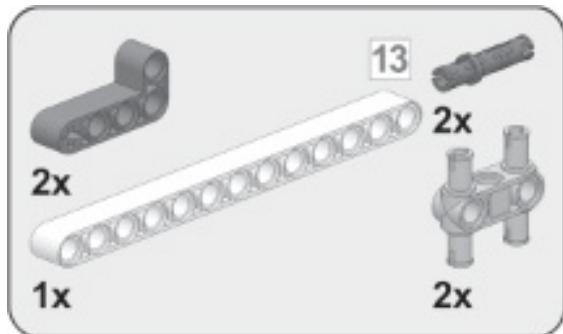
1

Carefully note the positions of the pieces indicated with the white arrows before connecting the motor modules as shown.



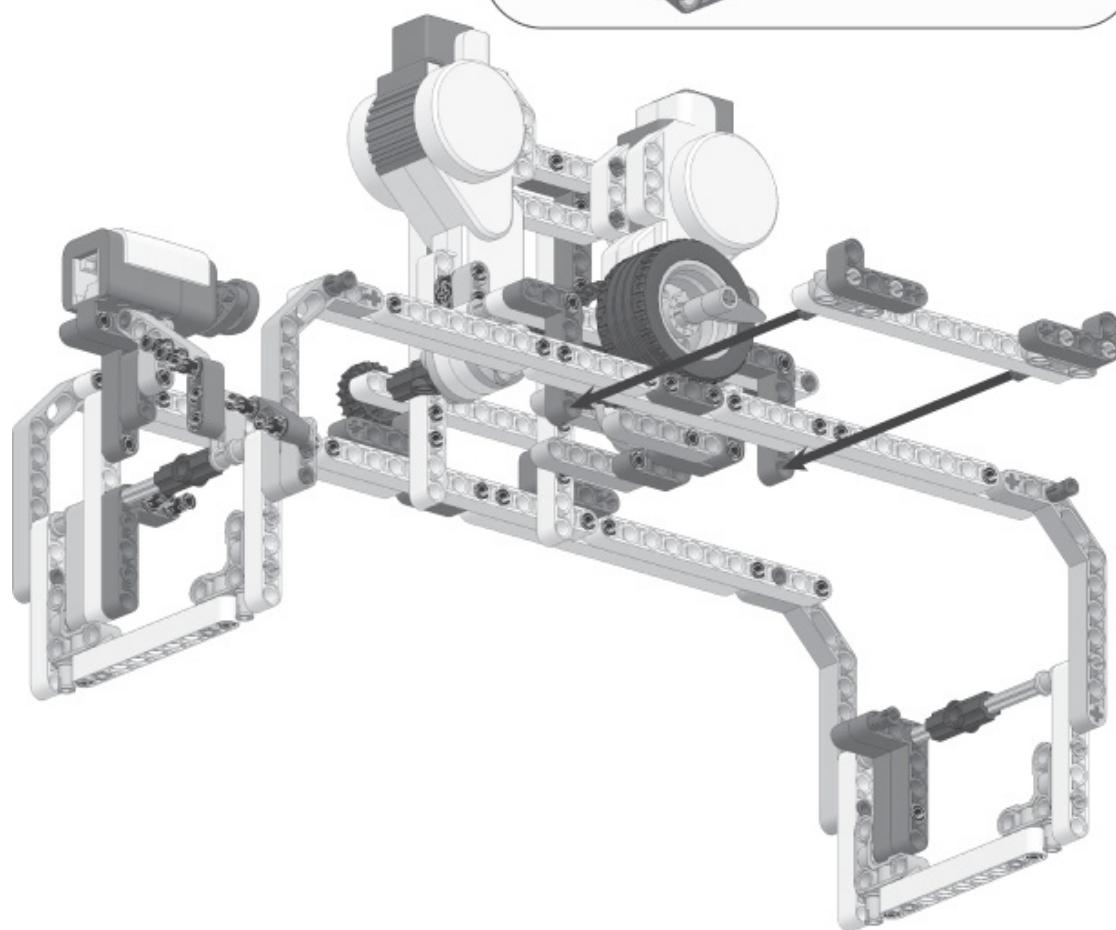
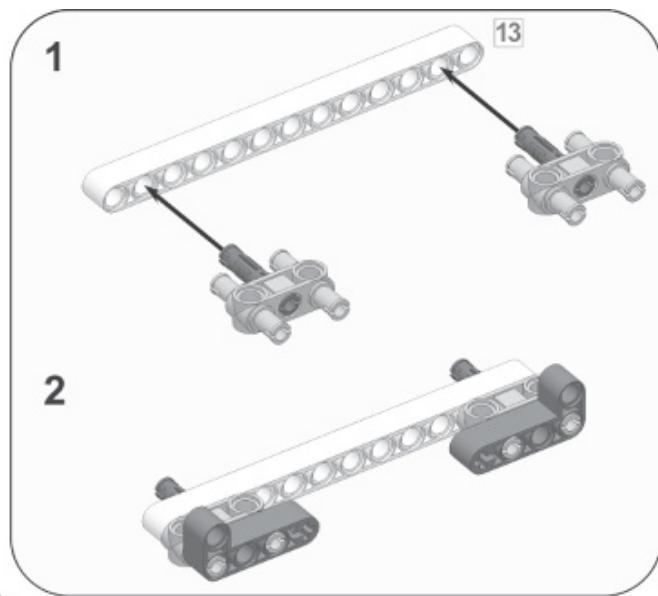
2

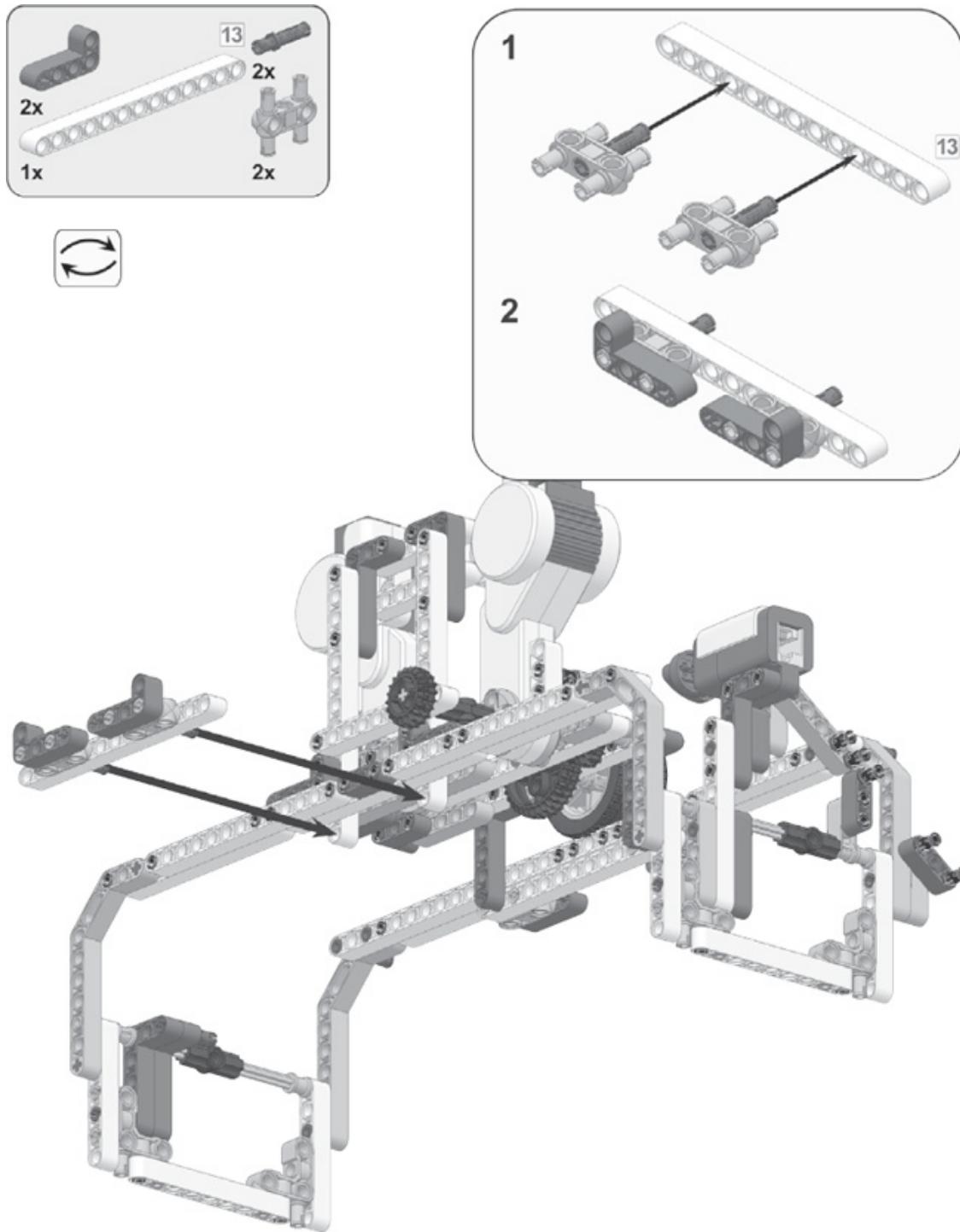




You have now completed the base and the horizontal modules. Position the horizontal module on top of the base. The two brackets that you'll build on this page and the next will connect these two sections.

When you follow these steps, rest the base on the edge of a table so that you can easily look at the robot's underside, as shown here. Some pieces have been hidden here to make these steps easier to follow, but you shouldn't need to remove any pieces.





Connecting the Cables

Once you've assembled the Printer, it's time to connect the cables. Begin by connecting the touch sensor to input port 1 and the color sensor to input port 3 on the NXT using **medium cables**. Before you connect the cable to the color sensor, bend its end as shown in [Figure 16-5](#), or your printer will lean on this cable and become unstable. Next, connect

both cables as shown in [Figure 16-6](#).



Figure 16-5. Bend the cable as shown so that when you release it, the cable remains bent.



Figure 16-6. Plug the bent end into the color sensor as shown, and then plug the other end into input port 3. Next, connect the cable from the touch sensor to input port 1.

Connect the motors to the NXT as shown in [Figure 16-7](#). Use a **medium cable** to connect the vertical motor to output port A, and then use the **longest cables** to connect the horizontal motor to port B and the pen motor to port C.

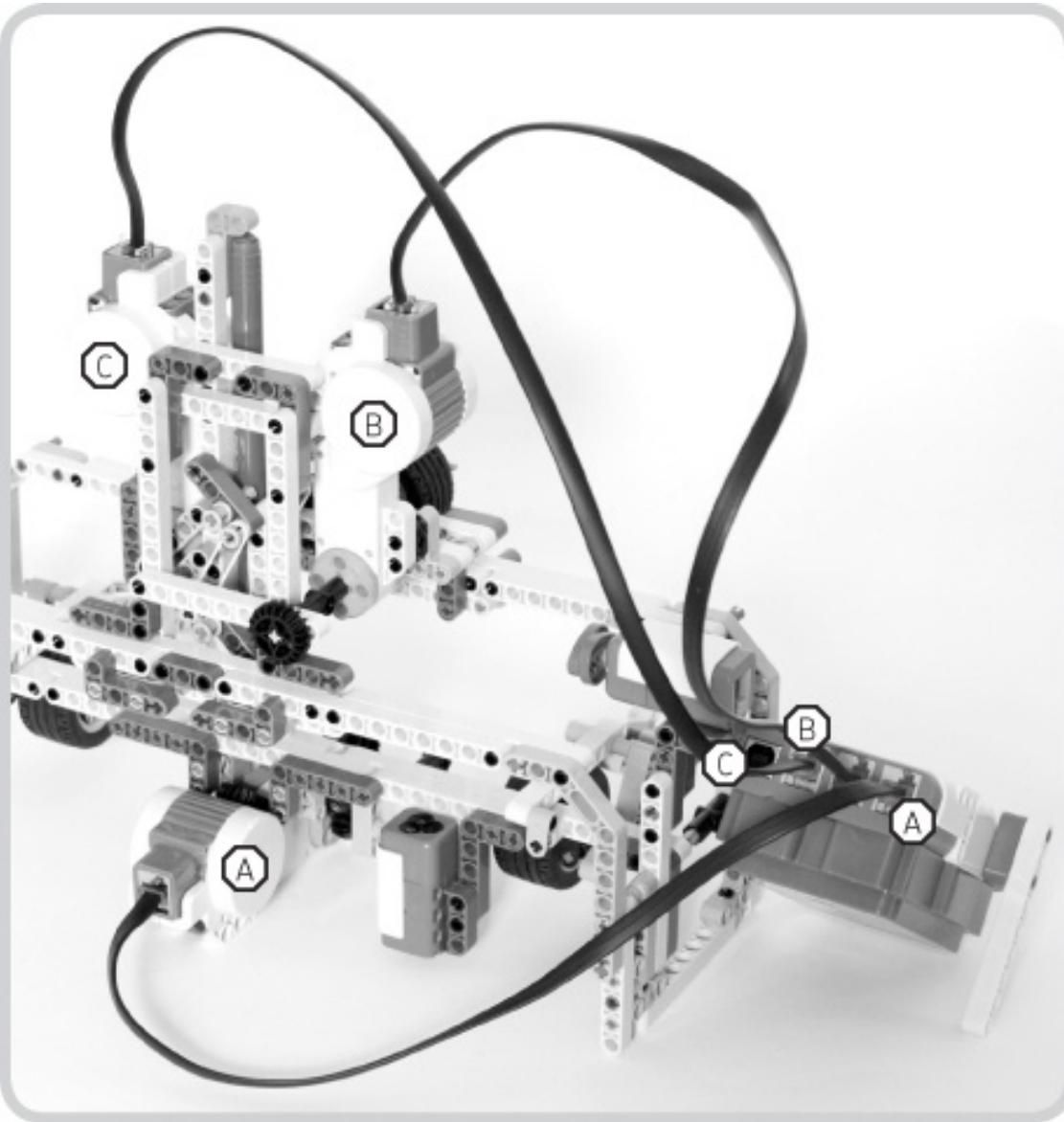


Figure 16-7. Connect all three motors to the NXT (sensor cables hidden for better visibility).

Programming the Printer

Congratulations on having built this complex machine. Next you'll program the Printer. You'll first create a series of My Blocks with basic functionality and then use them to create the complete program.

Creating the My Blocks

In [Understanding How the Printer Works](#), you learned what actions the robot must per-

form in order to draw a line. In the following sections, you'll create a My Block for each action as well as two blocks for resetting the Printer and one for ejecting the paper when the robot is finished drawing.

My Block #1: Liftpen

The first My Block, LiftPen, is a simple one. The Printer uses it to lift the pen from the paper so that it can move the pen to a different place on the paper without drawing a line as it moves. You need just one Motor block to accomplish this, but turning it into a My Block makes the action easier to perform frequently. Configure this Motor block as shown in [Figure 16-8](#) (left side), and turn it into a My Block called **LiftPen** as shown in [Figure 16-8](#) (right side). Be sure to select a few icons for this block to distinguish it from the LowerPen block you'll make next.

My Block #2: Lowerpen

The LowerPen block lowers the pen so that it touches the paper. To do this, the block first instructs motor C to lower the pen for a certain amount of time. This action firmly presses the pen against the paper, deliberately applying too much pressure. The motor then reduces the pressure by raising the pen for a moment. Configure the blocks that perform this process as shown in [Figure 16-9](#) (left side), and turn them into a My Block called **LowerPen**, selecting a few icons for the block as shown in [Figure 16-9](#) (right side).

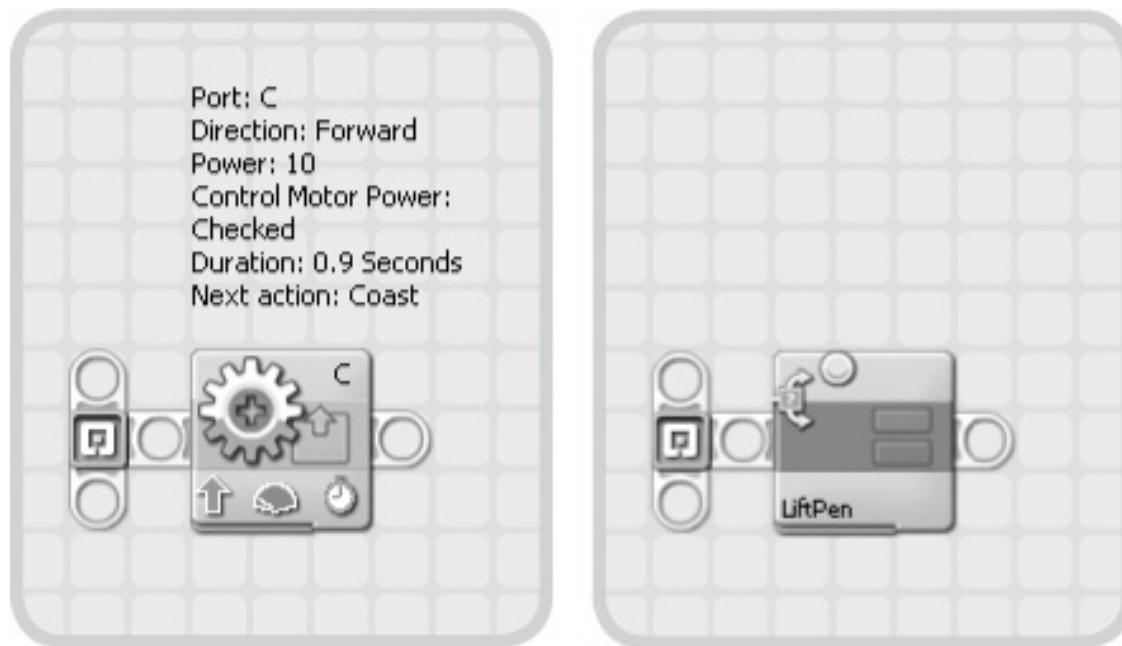


Figure 16-8. A single Motor block (left) comprises the LiftPen My Block (right).

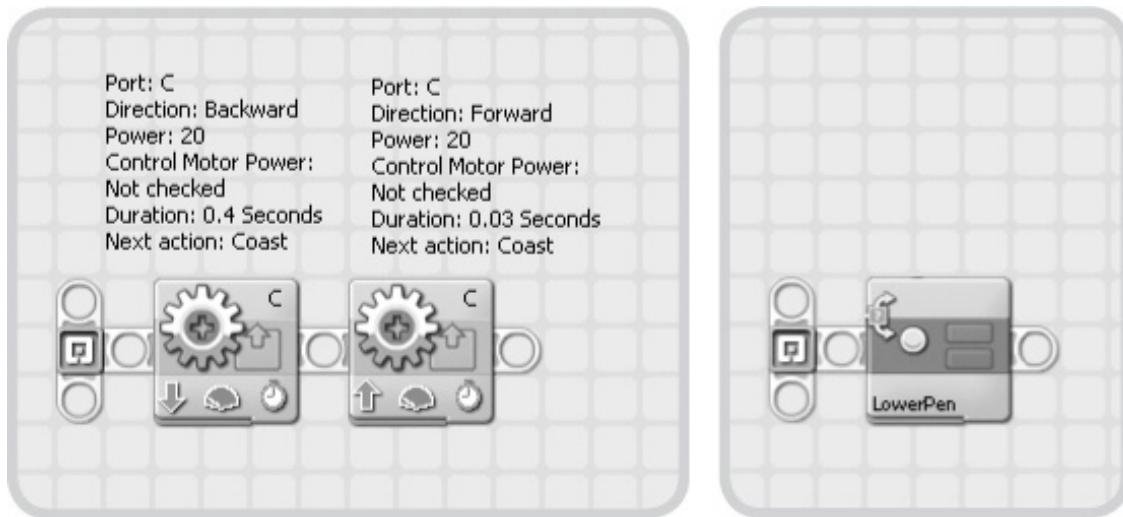


Figure 16-9. Two Motor blocks (left) comprise the LowerPen block (right).

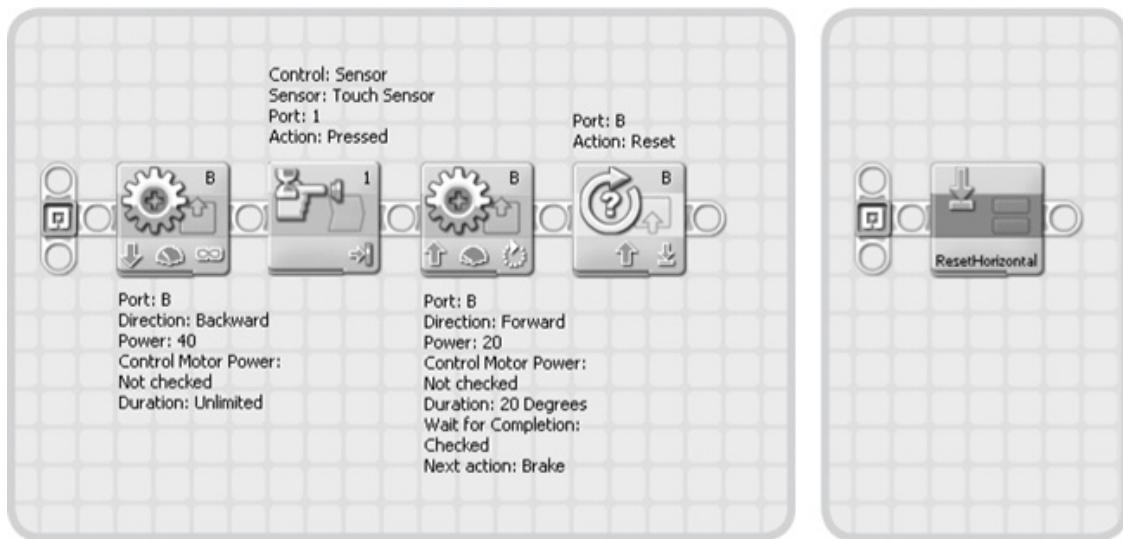


Figure 16-10. Four blocks (left) comprise the ResetHorizontal My Block (right).

My Block #3: ResetHorizontal

For accurate printing, the Printer should know where it is writing on the paper. To determine its position, the Printer always starts printing on the top left of the page and thereafter tracks its position relative to that starting point.

Now you'll make two My Blocks that position the pen at the upper-left corner of the paper. Begin by creating the **ResetHorizontal** My Block, which moves the horizontal mo-

dule with the pen all the way to the left of the page. The module stops moving left when it presses the touch sensor and then moves to the right slightly to release some pressure. The rotation sensor in the horizontal motor resets at this point so that the Printer knows the pen is in the starting horizontal position.

Configure the blocks to do this as shown on the left of [Figure 16-10](#), turn them into a My Block called **ResetHorizontal**, and select a reset icon for it as shown on the right of [Figure 16-10](#).

My Block #4: ResetVertical

The ResetVertical My Block moves the paper in the machine so that the pen is at the top of the page. When you insert a sheet of paper into the Printer's drawer, this My Block should move the paper into the machine until the color sensor detects white, at which point the machine knows that paper is present. Next, the block draws the paper further into the machine in order to release stress from the paper. Finally, the block pushes the paper back out a little so that the paper sits in the correct position. The rotation sensor in the vertical motor resets at this point so that the Printer knows that the sheet of paper is in the starting vertical position.

Configure the blocks to perform the previous action as shown on the left of [Figure 16-11](#), turn them into a My Block called **ResetVertical**, and select a reset icon for your My Block as shown on the right of [Figure 16-11](#).

My Block #5: Eject

The Eject My Block ejects the paper. It runs until the color sensor detects that the paper is no longer present, at which point the motor moves for another second to make sure that the paper is released and then stops. You place the LiftPen block inside the Eject block to make sure that the Printer won't accidentally draw a line all the way across the paper.

Configure the blocks to perform this action as shown on the left of [Figure 16-12](#), turn them into a My Block called **Eject**, and select the red stop sign for this My Block as shown on the right of [Figure 16-12](#).

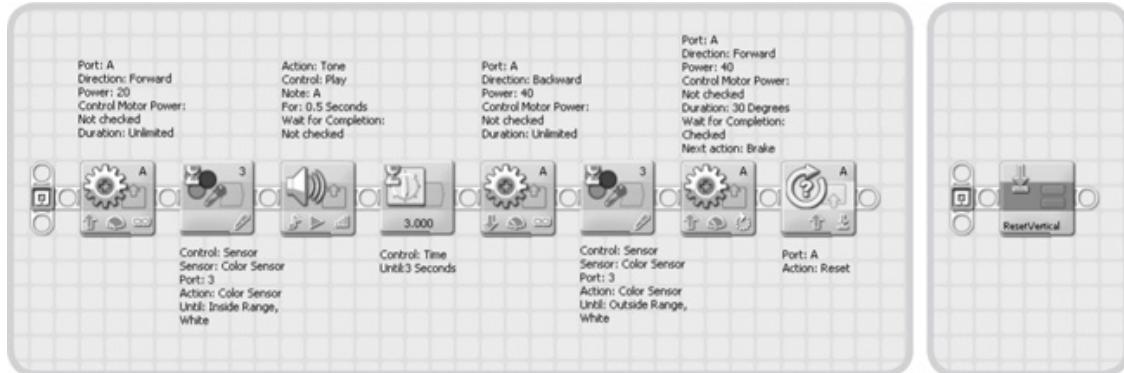


Figure 16-11. Eight blocks (left) comprise the ResetVertical My Block (right).

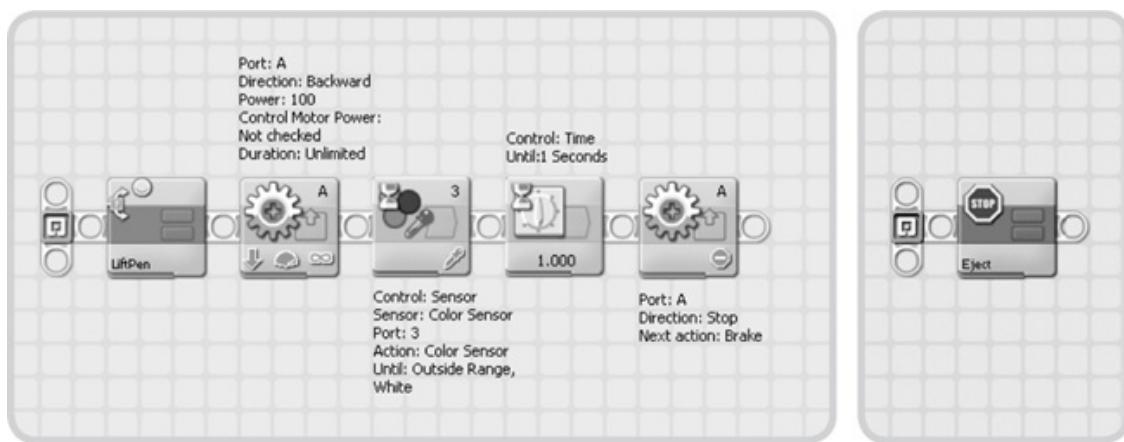


Figure 16-12. Five blocks (left) comprise the Eject My Block (right).

My Block #6: Horizontal

The last two My Blocks you'll create move the pen on the paper. You can use these blocks while the pen is lowered (a line is drawn) or raised (no line is drawn).

If the horizontal motor rotates forward a certain number of degrees, the horizontal module moves to the right. Running the motor in reverse will move the module to the left. You'll create a special My Block for this action that can accept input values (an amount of degrees), allowing you to configure the block with a configuration panel. Positive values move the module to the right, and negative ones move it to the left. Create the **Horizontal** My Block by following the steps in Figure 16-13 to Figure 16-15.

NOTE

For the Motor blocks in the Horizontal and Vertical My Blocks, you'll need to set the Dura-

tion setting to Degrees in order to configure the Wait for Completion setting.

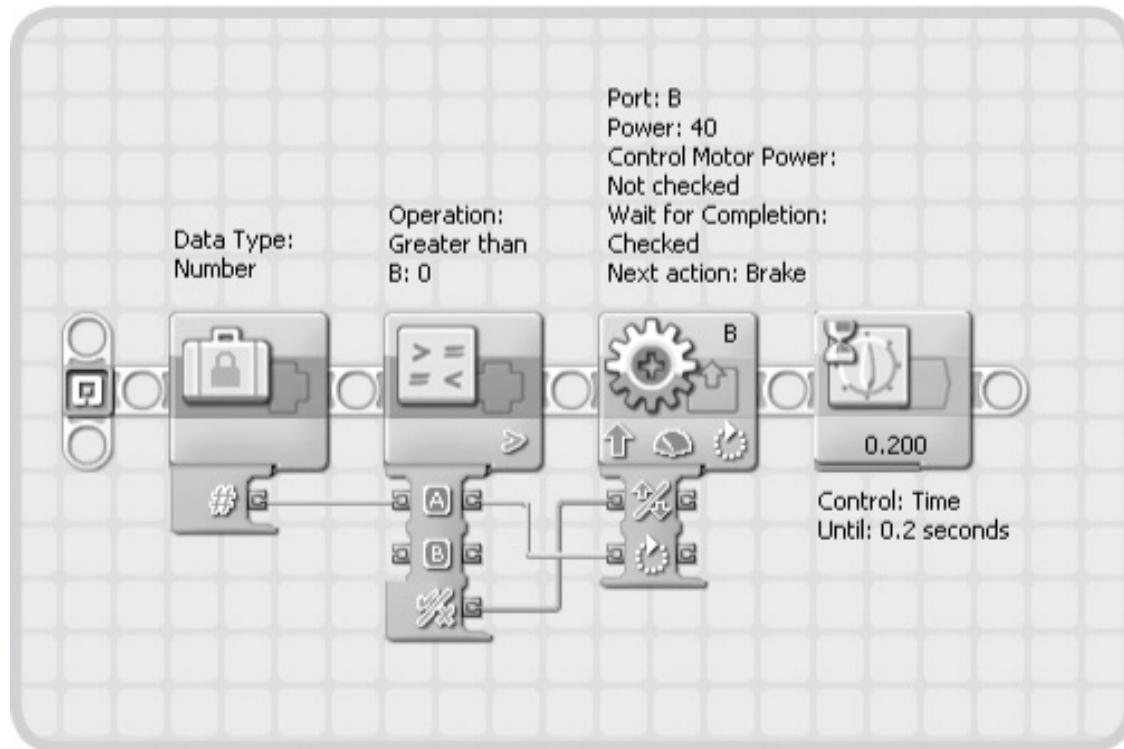


Figure 16-13. Use the Constant block to generate a data wire that acts as an input for the Compare block. The Compare block checks whether the value is greater than 0. If it is, the direction is forward; otherwise, the direction is backward. The Compare block also transfers the number of degrees to the Motor block. A Wait block at the end makes sure that the motor has fully stopped when the My Block finishes.

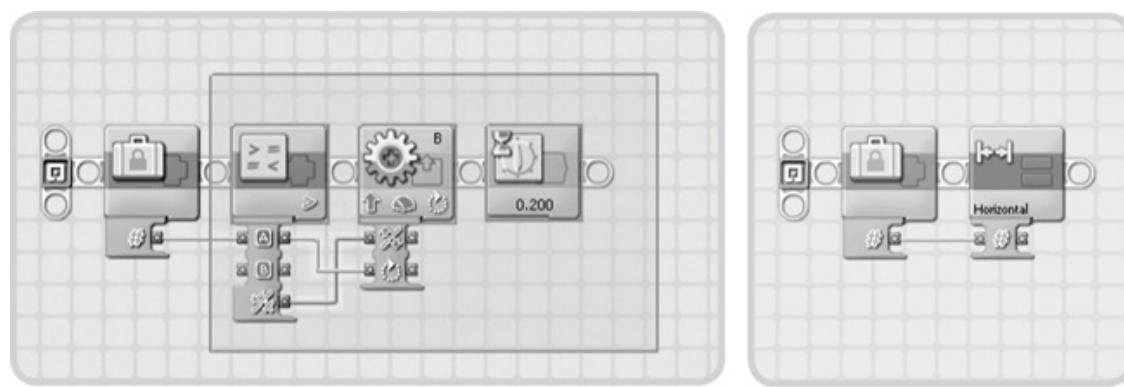


Figure 16-14. Select the latter three blocks as shown (left), and then convert them into a My Block called Horizontal. The result should be the figure shown on the right. Be sure to choose an appropriate icon for your My Block, such as the two horizontal arrows shown here (right).

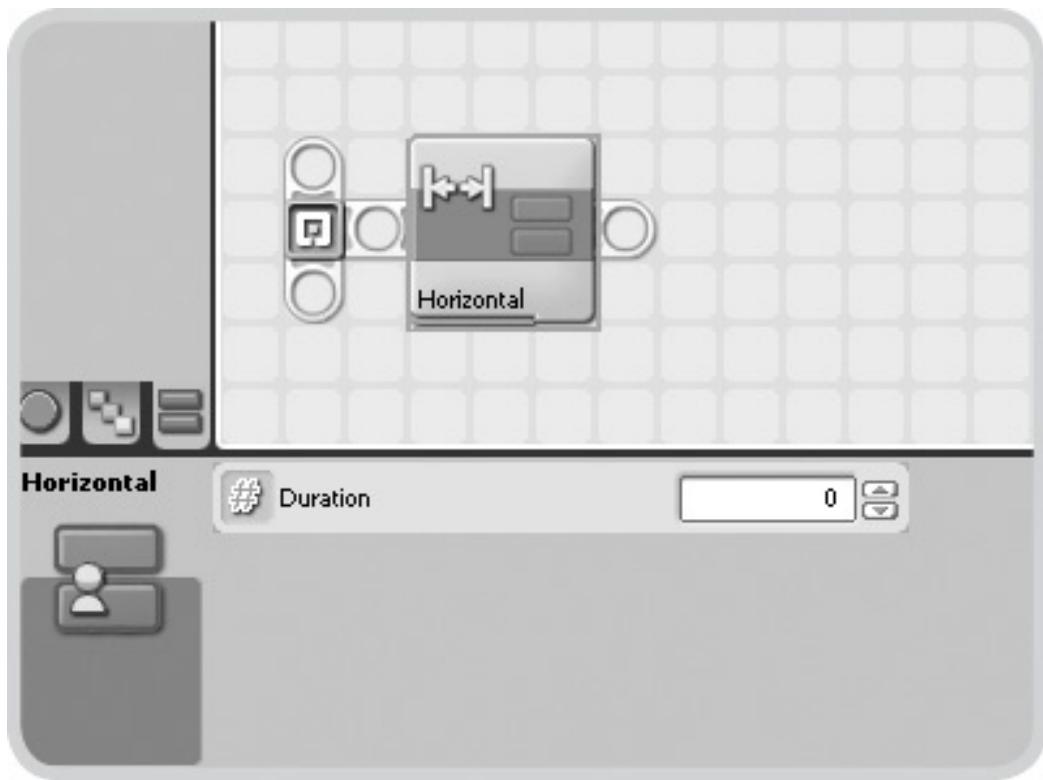


Figure 16-15. Delete the Constant block, and hide the Horizontal block's data hub. You have now created a My Block with a configuration panel.

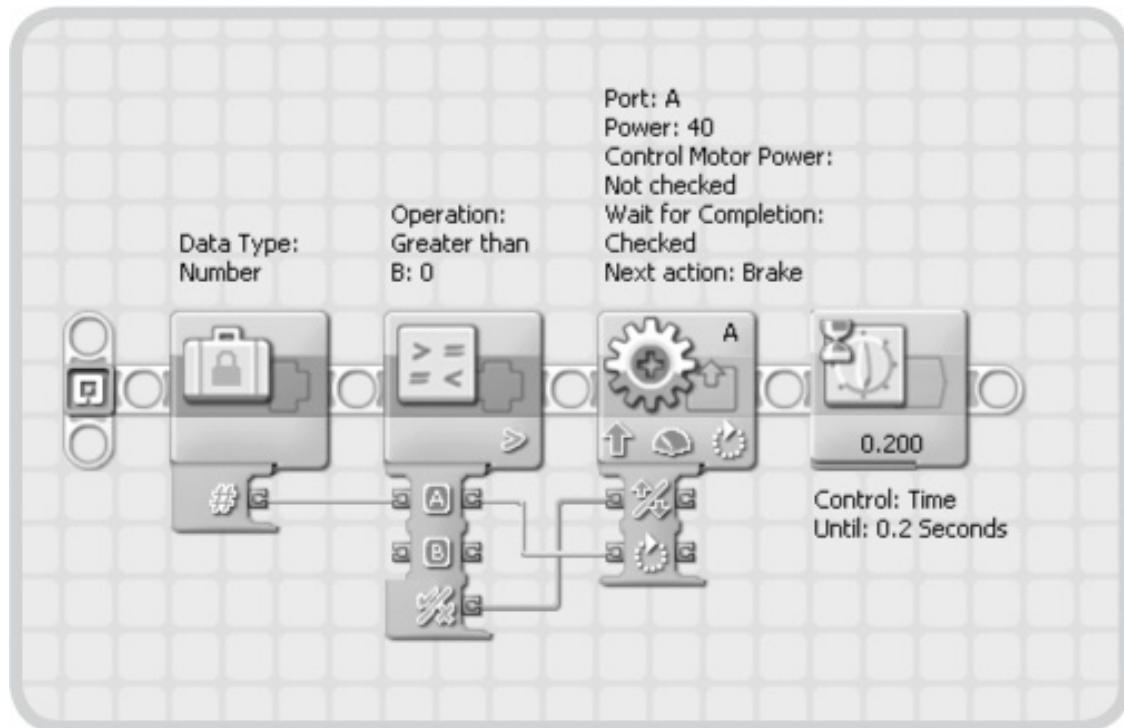


Figure 16-16. Configure these four blocks as shown.

My Block #7: Vertical

You'll now repeat the steps from the Horizontal My Block to create a similar block called **Vertical**, which controls the position of the paper in the machine. A positive value pulls the paper into the Printer, and a negative one pushes the paper away from the Printer. Create the Vertical My Block now by following the steps in [Figure 16-16](#) and [Figure 16-17](#).

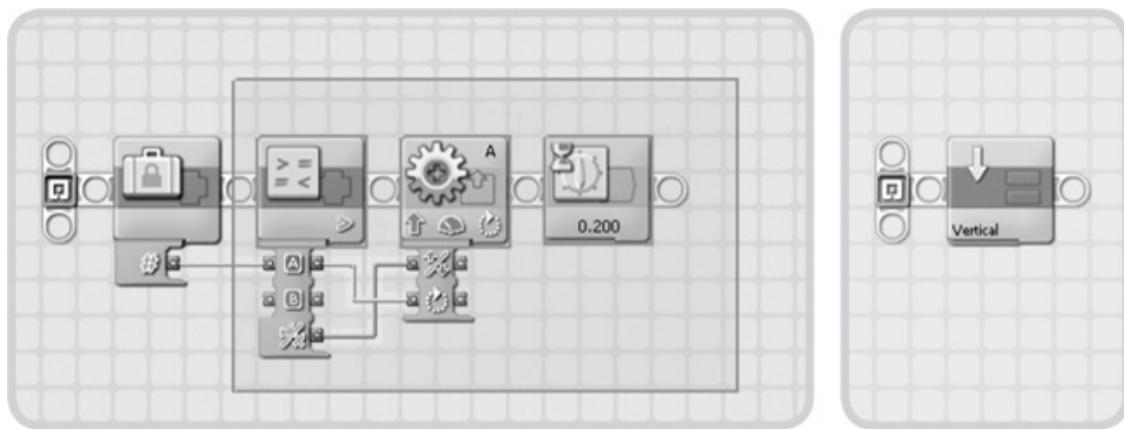


Figure 16-17. Select the latter three blocks, turn them into a My Block called Vertical (left), and select a vertical arrow as an icon for your block (right). Also, delete the Constant block, and hide the My Block's data plug.

Testing and Troubleshooting the Printer

You've just completed the essential programming for the Printer. Before you begin drawing lines and figures, however, you should test and troubleshoot the My Blocks to be sure that you won't run into unexpected problems.

[Figure 16-18](#) shows the basics of each program for the Printer. The first and last blocks will always be the same in your program. The blocks in the middle control what the Printer will eventually draw on paper.

The Test Program

To test the My Blocks, you'll create a program that uses each of them. See [Figure 16-18](#) for the overall setup of your program, and see [Figure 16-19](#) for the blocks you'll place in the middle of your program.

Run the program, and insert a sheet of paper into the Printer's drawer (see [Figure 16-1](#))

when the vertical motor begins to turn. If running the test program gives a result like the one shown in [Figure 16-20](#), skip to [Creating the Final Program](#). If this is not the result, go to [Troubleshooting the Printer](#).

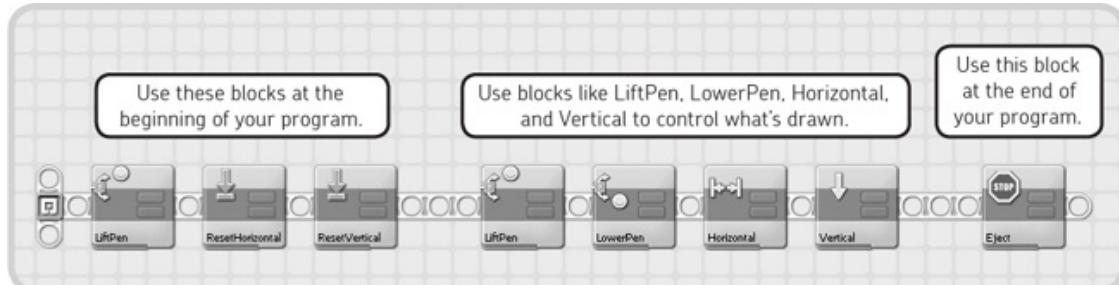


Figure 16-18. The basics of a program for the Printer

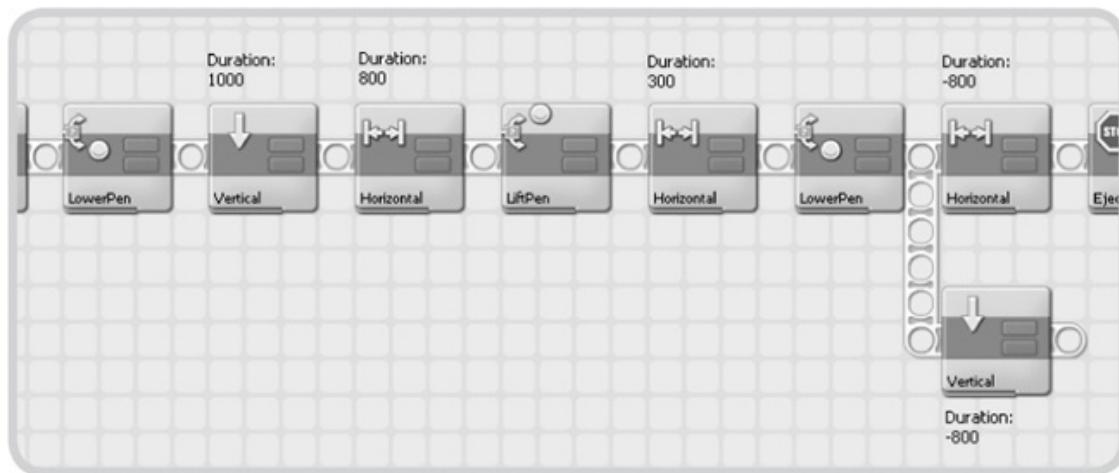


Figure 16-19. The blocks in the middle of the test program

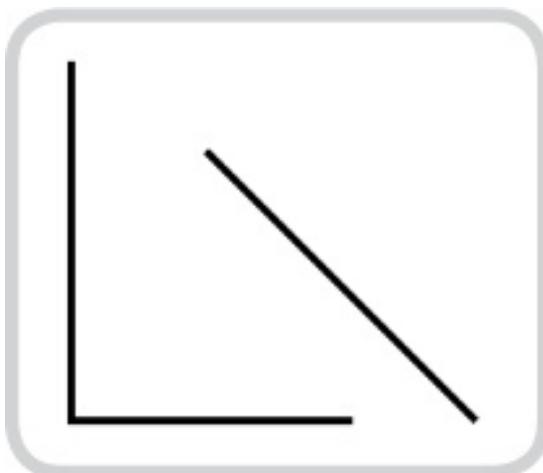


Figure 16-20. The expected result of the test program. The tilted line is the result of a Horizontal block and a Vertical block running in parallel at the

same time.

Troubleshooting the Printer

For several reasons, the Printer may not work right the first time you use it. In fact, you will most likely need to make a few adjustments before the Printer works smoothly, so don't be discouraged if the test program doesn't work well. The point of the test program is to help you get the Printer running smoothly. The following are solutions to a few common problems.

Creased or Crumpled Paper in the Machine

Once you insert the paper into the machine and the ResetVertical My Block has finished running, the uppermost part of the sheet in the machine should lie completely flat, resting on the beam to which you've added a strip of tape. If the paper is not lying flat because it's slightly crumpled or creased, the Printer won't be able to draw properly. Use a fresh sheet of paper, or try using thinner, less stiff paper.

The Pen Doesn't Write

In some instances, the pen won't write because not enough pressure is being applied or because it doesn't touch the paper. If the pen sits above the paper by more than 0.5 cm (0.2 inches), check the building instructions in [7](#).

If the pen is close to the paper but not close enough or if not enough pressure is applied to the pen, the solution lies in the program. In the LowerPen My Block, modify the Duration setting in the first Motor block, which is currently set to 0.40 seconds. Try 0.45 seconds or longer if necessary.

The Pen Presses Too Hard

The pen may press too hard on the paper, making it impossible to move the paper vertically. To fix this, see [The Pen Doesn't Write](#) above, and change the Duration to a number less than 0.40, such as 0.35 seconds.

The ResetVertical My Block Doesn't Work

In areas of very bright sunlight, the color sensor cannot detect the paper sheet properly

because it reads white even when no paper is present. When this occurs, the ResetVertical My Block will behave incorrectly. To fix this, move the Printer to an area with less light and try again.

The Cable for Motor a Snags the Paper

When the paper is moving backward into the machine so that the pen can write on the bottom portion of the paper, the paper can sometimes catch on motor A's cable. To prevent this, twist, tuck, or otherwise move the motor's cable out of the paper's path.

Creating the Final Program

Now that you've mastered the basic Printer controls (and ideally have it running smoothly), it's easy to draw anything you like as long as the drawing consists of straight lines. For example, we'll now make a drawing of the NXT logo and the text "NXT 2.0." You can see an overview of the drawing in [Figure 16-21](#).

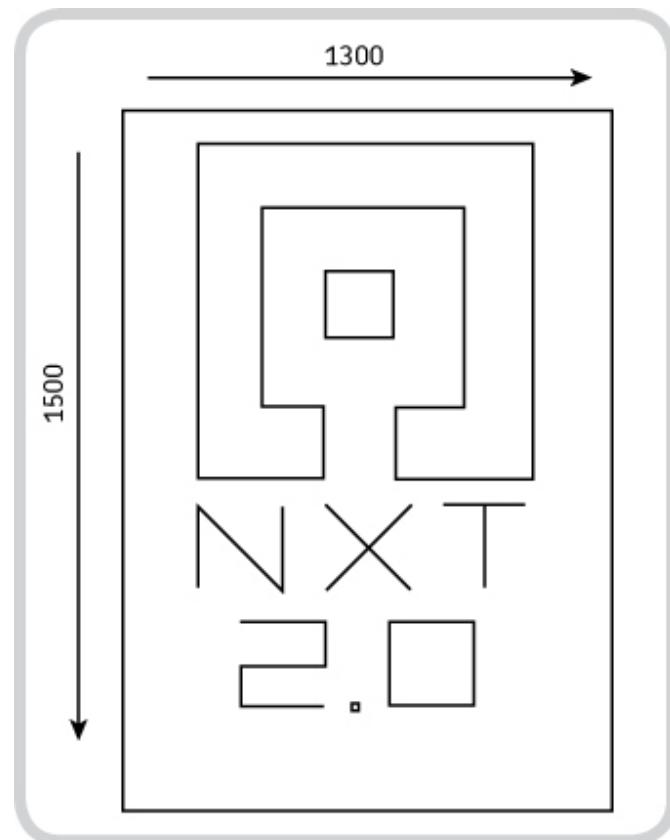


Figure 16-21. In this drawing of the NXT 2.0 logo, the arrows indicate the estimated printable area, and the numbers indicate the number of degrees re-

quired to move from one end of the printable area to the other.

The complete **NXT Logo** program that will print these figures is actually just a long list of My Blocks that you place one after the other. **Table 16-1** lists all the blocks and their configurations. Where the table shows the words *In parallel*, you need to create a parallel sequence beam at that point with a single block on it (see **Figure 16-19** for an example). If you'd rather not create this program manually, you can download it from this book's companion website at <http://www.nxtguide.davidjperdue.com/>.

Table 16-1. The Complete List of My Blocks in the NXT Logo Program

My block Name	Du-ration				My block Name	Du-ration			
Lift-Pen					Lift-Pen				
ResetHorizontal					Horizontal	-25 0			
ResetVertical					Lower-Pen				
Horizontal	100				Horizontal	250	In parallel:	Vertical	-25 0
Vertical	-10 0				Lift-Pen				

Lo-wer-Pen					<i>Hori-zontal</i>	125			
<i>Hori-zontal</i>	100 0				Lo-wer-Pen				
Verti-cal	100 0				<i>Hori-zontal</i>	250			
<i>Hori-zontal</i>	-40 0				<i>Hori-zontal</i>	-12 5			
Verti-cal	-20 0				Verti-cal	250			
<i>Hori-zontal</i>	200				Lift-Pen				
Verti-cal	-60 0				Rese-thori-zontal				
<i>Hori-zontal</i>	-60 0				<i>Hori-zontal</i>	200			
Verti-cal	600				Verti-cal	50			
<i>Hori-zontal</i>	200				Lo-wer-Pen				

Vertical	200				Horizontal	300			
Horizontal	-40 0				Vertical	100			
Vertical	-10 00				Horizontal	-30 0			
Lift-Pen					Vertical	100			
Horizontal	400				Horizontal	300			
Vertical	400				Lift-Pen				
Lower-Pen					Horizontal	100			
Horizontal	200				Lower-Pen				
Vertical	200				Horizontal	20			
Horizontal	-20 0				Vertical	-20			

Verti- cal	-20 0				<i>Hori- zontal</i>	-20			
Lift- Pen					Verti- cal	20			
Rese- tHori- zontal					Lift- Pen				
<i>Hori- zontal</i>	100				<i>Hori- zontal</i>	100			
Verti- cal	900				Lo- wer- Pen				
Lo- wer- Pen					Verti- cal	-20 0			
Verti- cal	-25 0				<i>Hori- zontal</i>	300			
<i>Hori- zontal</i>	250	In pa- ral- lel:	Ve rti- cal	25 0	Verti- cal	200			
Verti- cal	-25 0				<i>Hori- zontal</i>	-30 0			
Lift-					Eject				

Pen									
<i>Horiz-</i> <i>ontal</i>	125								
Lo- wer- Pen									
<i>Horiz-</i> <i>ontal</i>	250	In pa- ral- lel:	Ve rti- cal	25 0					

Once you have your program, run it and insert a sheet of paper as you did with the test program earlier. Sit back and enjoy watching the artistic abilities of the Printer, and if you run into any problems, consult [Troubleshooting the Printer](#).

Exploring the Printer Further

So far, you've made the Printer perform preprogrammed actions. However, the machine can do much more. The following sections suggest ways to further explore this robot.

Idea #1: Progress Update

Modify the NXT Logo program to make the NXT display tell you about the printing process. Use different Display blocks throughout the program to do this, and add some sounds as well. For example, you can have the display tell you the following:

- Pen's current state: down (drawing) or up (not drawing)
- Current direction of the pen's movement
- Picture/text being drawn

- Time elapsed since the program started
- Current percentage of the printing process completed

Idea #2: Morse Code

Expand the Printer to write pieces of Morse code. Have the horizontal motor move the pen from the left all the way to the right at a steady but slow speed. Connect a second touch sensor to the NXT, and program the robot to lower the pen as long as the sensor is pressed and to lift the pen when the touch sensor is released. Since the pen moves to the right slowly, this will create a pattern of lines. Control the touch sensor with your hand to create long and short lines.

Idea #3: Data Logging

Add an ultrasonic sensor to the Printer. Connect the sensor to the base so that it faces away from the machine. Can you create a program that will plot a graph of sensor readings over time? As with idea #2, you can make the pen move to the right at a constant slow speed. Next, all you have to do is contro