

Lego EV3 Solar Station

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Abstract

With the aim of introducing school age children to the concepts of renewable energy generation, the researcher has adapted the Lego Mindstorms NXT2.0 Solar Station build to the new Lego Mindstorms EV3 kit. Solar Station build and programming instructions are detailed as well as the reasoning behind the research. The language of the paper is intended to be accessible to younger readers while still containing all pertinent information.

CONTENTS

I	Introduction	1
II	Required Parts	1
III	Building The Solar Station	1
III-A	First steps	1
III-B	Combining the sub-assemblies	1
III-C	Adding the energy meter and the solar panel	3
III-D	Attaching the cables	4
IV	Programming The Solar Station	4
IV-A	The goal of the solar station program	4
IV-B	The information display loop	4
IV-C	The motor positioning loops	5
IV-D	The motor angle loops	6
IV-E	The light intensity loops	6
V	Running the Solar Station Program	7
VI	Conclusion	7
VII	APPENDICES	8
VII-A	Building the base	8
VII-B	Building the x motor mount	16
VII-C	Building the y motor mount	34
VII-D	Readyng the EV3	44
References		51

LIST OF FIGURES

1	Solar Station Front		2
2	Solar Station Back		2
3	Connecting the Energy Meter		3
4	Connecting the Energy Meter - side view		3
5	Connecting the solar panel		4
6	Solar Station Program		5
7	Info Display Loop		6
8	Motor Positioning Loops		6
9	Motor Angle Loops		7
10	Light Intensity Loops		7

I. INTRODUCTION

MODERN life has seen a large number of electrical power hungry devices come into wide-spread use. The power needed to run these devices is currently generated largely by converting energy sources such as coal and natural gas that pollute our environment and will someday, maybe in the next generation, run out completely. The effect of these polluting energy sources will be felt very distinctly by the next generation and so they need to be taught about alternative energy sources that can be used, which do not pollute and are renewable. It is best to start with renewable energy education early to get young people interested in the technologies that will be so important to their future. One such energy source is our oldest energy source, the sun. This paper demonstrates how to build and program a robotic station equipped with a solar panel that can collect and store energy from the sun. It is built using the popular Lego EV3 robot kit and features an energy meter that shows the user how much energy is being collected. The robotic parts of the solar station are programmed to find a light source that can generate enough power to charge the power meter's batteries. Building the Solar station is easy enough for most middle school students. The programming of the solar station is done with the Lego software that is provided with the EV3 kit and teaches the users a basic example of a control program for the robot that is easy to understand. Finally the operation of the solar station is fun and interesting for budding renewable energy enthusiasts as well as others.

II. REQUIRED PARTS

The majority of the parts needed to build the EV3 Solar Station can be found in the retail EV3 kit. The solar panel and energy meter come in the Lego Renewable Energy add-on set #9688. The remaining parts that are needed are six 1x8 Lego Technic blocks and one Lego Technic turntable 4.85.

III. BUILDING THE SOLAR STATION

A. *First steps*

Building the Solar Station hardware is composed of six steps: building the base, building the x motor mount, building the y motor mount, readying the EV3, combining the sub-assemblies and adding the energy meter and solar panel. Instructions for building the base and the x and y motor mounts are found in the appendix. Build these sub-assemblies first. The instructions for building the sub-assemblies were generated using Lego's Digital Designer software. Because the Digital Designer software does not include the energy meter and solar panel components the instructions to attach those parts are detailed in the *Adding the energy meter and solar panel* section below.

B. *Combining the sub-assemblies*

Once the build of the various subsections is complete connect them together as in the following figures.

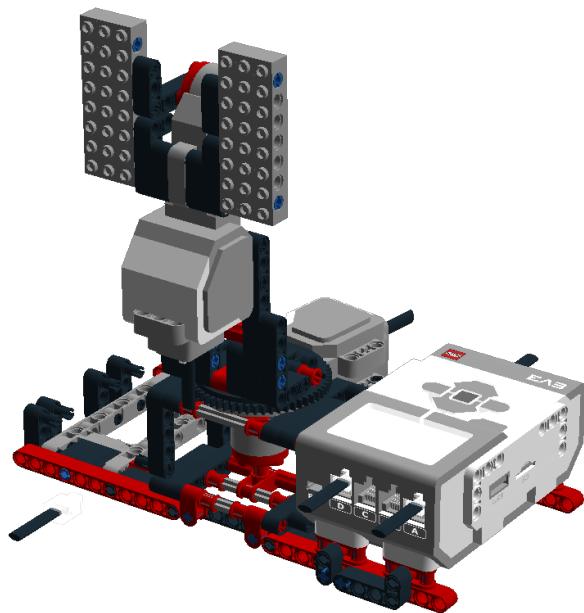


Fig. 1. Solar Station Front

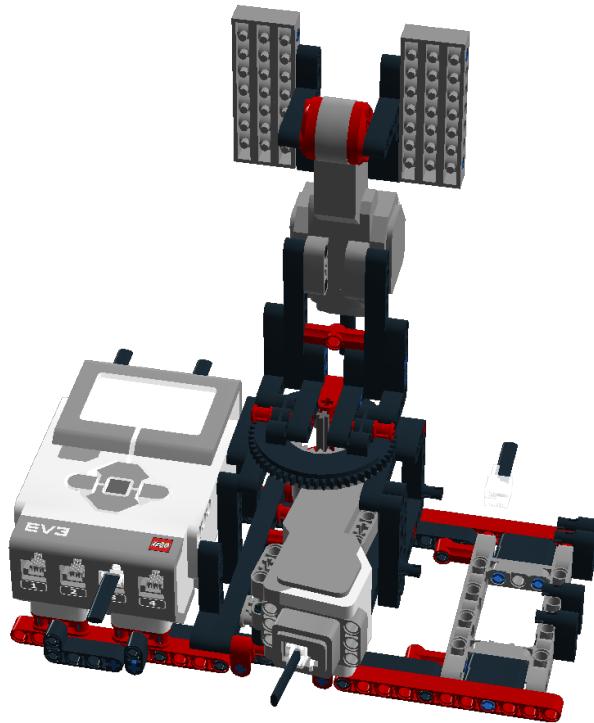


Fig. 2. Solar Station Back

C. Adding the energy meter and the solar panel

Once the sub-assemblies have been combined the solar panel and energy meter from the Lego renewable energy add on kit may be added to the solar station. First connect the four wire cable to the back of the energy meter and then connect a short EV3 connecting cable to the port at the top. The energy meter may now be connected on the left hand side of the solar station, when looking at it from the front, to the two black friction pegs sticking out from the x motor assembly as in figures 3 and 4. Make sure to route the cables underneath the energy meter so that they are sticking out underneath the bottom of the energy meter. The solar panel should be attached to the six 1x8 technic blocks on the y motor mount as in figure 5.

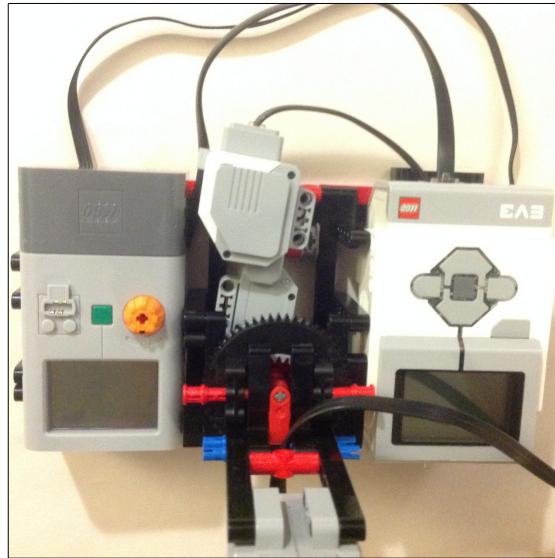


Fig. 3. Connecting the Energy Meter

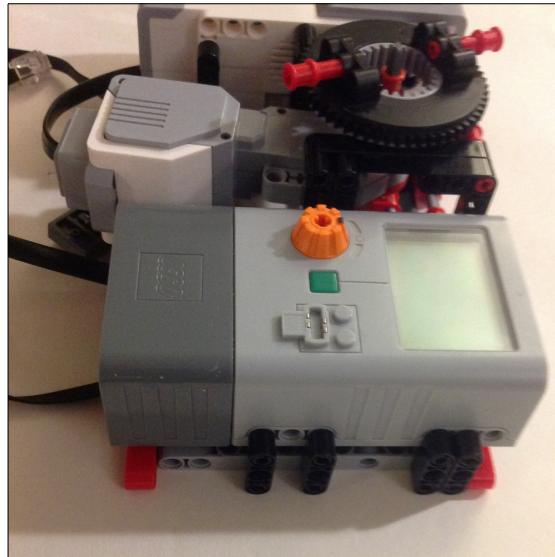


Fig. 4. Connecting the Energy Meter - side view

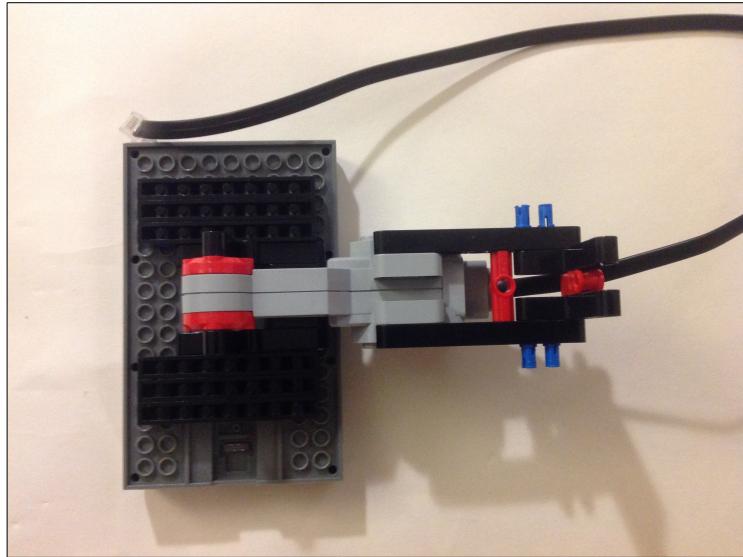


Fig. 5. Connecting the solar panel

D. Attaching the cables

The solar panel is connected to the energy meter by the four wire cable that comes in the Lego renewable energy add-on kit. One end of the cable plugs into the socket on the back of the energy meter. There is only one way to plug the end of the cable into the energy meter socket. The other end of the cable plugs into the socket on the back of the solar panel. On top of the energy meter is a socket for one of the cables that come with the EV3 kit. The other end of that cable should be plugged into port 3 on the bottom of the EV3 brick. The cable ends are keyed so they can only go in one way but if the cable is plugged into the wrong port the program as configured in this paper will not work. Two more cables connect the x and y axes motors to the EV3 brick. The x axis motor should be plugged into port D on the brick. The y axis motor should be plugged into port A on the brick. It is important that the cables be plugged into the right ports.

IV. PROGRAMMING THE SOLAR STATION

A. The goal of the solar station program

Solar panels convert light into electrical energy. In order to do this a solar panel must be facing the light source. The EV3 Solar Station ensures that the solar panel is always facing a light source by measuring the pressure, also called the voltage, of the electrical energy that is generated by the solar panel and when it is too low the solar station will move the solar panel around scanning for a light source. The program itself is made up of four subsections: the information display loop, the motor position loops, the motor angle loops and the light intensity loops. Figure 6 shows the whole program and how the subsections are connected. The details of each subsection are given in the order, from top to bottom, that they appear in figure 6.

B. The information display loop

Figure 7 shows the information display loop. The information display loop causes the EV3 to display information about what the solar station is doing on its screen. The information displayed has three parts: the voltage that is being generated by the solar panel, the angular position of the X axis motor and the angular position of the Y axis motor. Inside the loop are six Lego Mindstorms programming blocks. There are three blocks that collect information from the energy meter and the motors, and three blocks that cause the collected information to be displayed on the screen. The first block that collects information

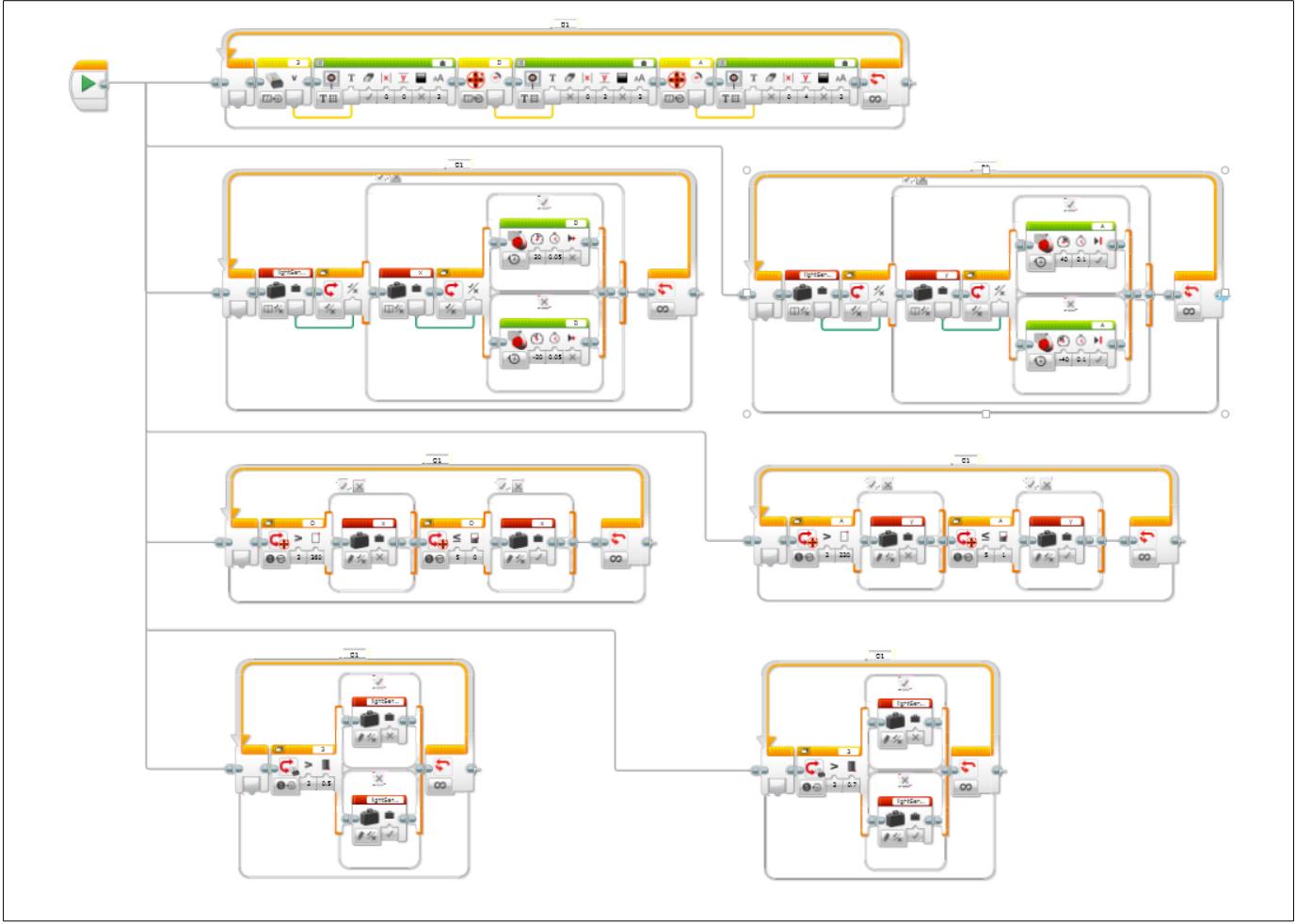


Fig. 6. Solar Station Program

is the energy meter block. This block does not come with the Lego Mindstorms programming software. It must be downloaded from <http://www.lego.com/en-us/mindstorms/downloads/ev3-blocks/energymeter/> and imported into the programming software before it can be used. The energy meter block is setup to measure voltage. The other two data collection blocks are motor rotation blocks that provide the angular position of each of the motors. One is setup to measure the angular position of the motor connected to port D on the EV3. The other block is setup to measure the angular position of the motor connected to port A. Each data collection block is connected by an orange wire to a display box that is setup to display the data as text, letters and numbers, on the screen of the EV3. The display blocks should be setup as in figure 7.

C. The motor positioning loops

The motor positioning loops shown in figure 8 control the position of the X and Y axes motors. The loops prevent the motors from turning when light has been sensed by the solar panel and also ensure that the motors do not turn too far in one direction. One loop controls the X axis motor and the other controls the Y axis motor. Each loop is actually two loops, an outer loop and an inner loop. The outer loop checks the value of a variable that can be either true or false. This type of variable is called a boolean variable. If the variable is true the outer loop runs the inner loop. The inner loop also checks the value of a boolean variable and chooses one of two motor blocks. One motor block runs the motor clockwise and the other

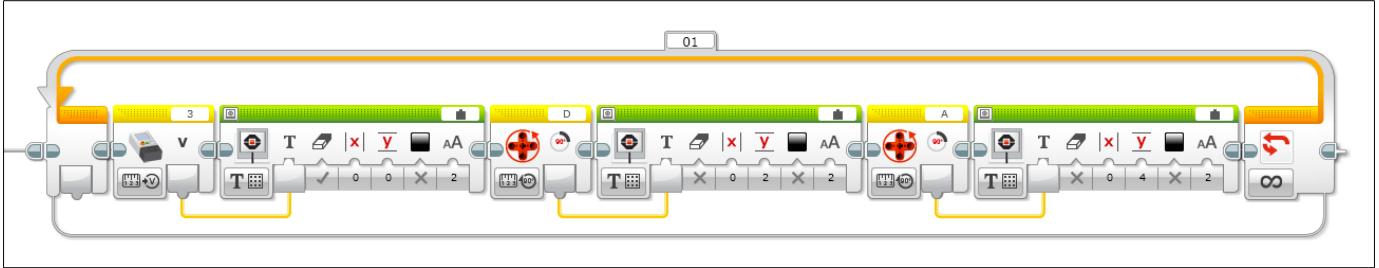


Fig. 7. Info Display Loop

counter-clockwise. If the motor has turned as far as it can go in one direction the variable chooses the motor block that turns the motor in the other direction. The X axis loop uses the lightSensed variable for its outer loop and the x variable for its inner loop. The Y axis loop uses the lightSensedY variable for its outer loop and the y for its inner loop. The motor positioning loop blocks should be setup as in figure 8.

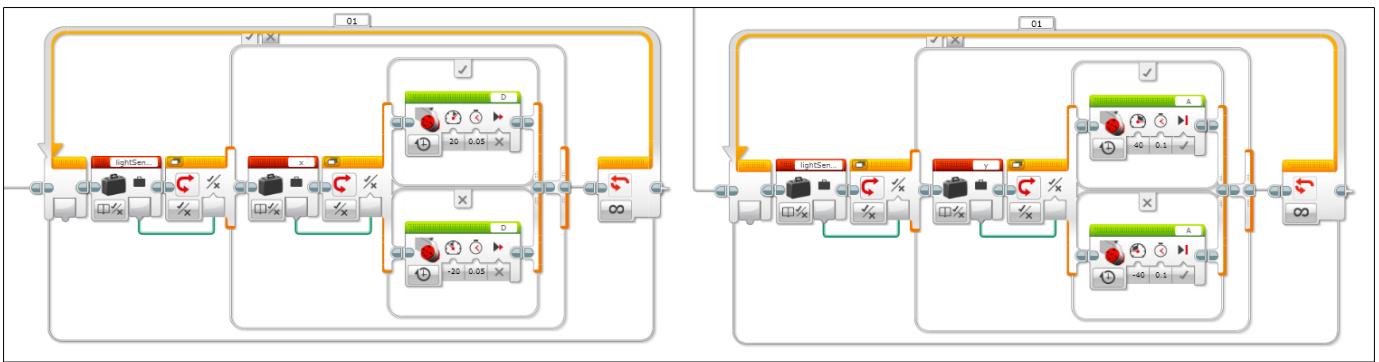


Fig. 8. Motor Positioning Loops

D. The motor angle loops

The motor angle loops shown in figure 9 set the variables that are used in the motor control loops to prevent the X and Y axes motors from over rotating. Those variables are called x and y. The x variable is set to false by the first block inside the left hand loop when the angle read from the x axis motor goes above 360 degrees and is set to true by the second block in the left hand loop when the angle is less than or equal to 0. The y variable is set to false by the first block inside the right hand loop when the angle read from the y axis motor goes above 220 degrees and is set to true by the second block in the right hand loop when the angle is less than or equal to 0. The setting of the x and y variables in this way tells the inner loops of the motor positioning loops to switch direction when the motors have gone too far in one direction or the other. The motor angle loop blocks should be setup as in figure 9.

E. The light intensity loops

On the EV3 solar station the solar panel is connected by a cable to the Lego energy meter. When light hits the solar panel the energy meter can measure the voltage that the solar panel is generating. The more light that hits the solar panel, the higher the voltage the energy meter measures. This fact is used in the solar station program to figure out when to stop the motors so that the solar panel will be facing the light source. The light intensity loops shown in figure 10 set two variables that tell the program if bright enough light has been detected. The variables are named lightSensed and lightSensedY. The lightSensed

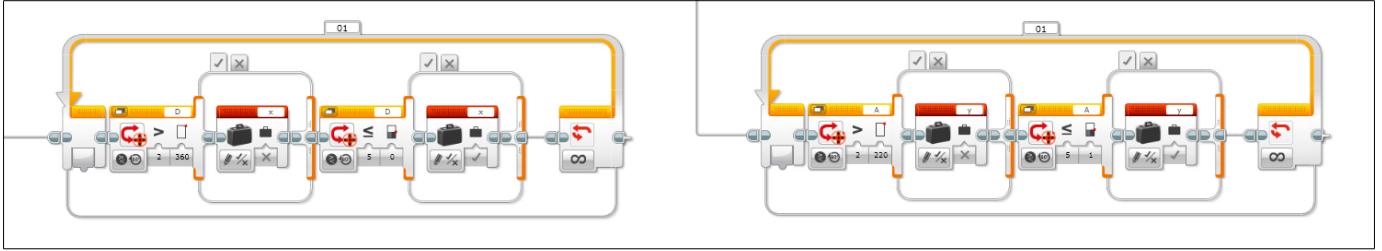


Fig. 9. Motor Angle Loops

variable is set to true by the left hand loop when the voltage that is measured by the energy meter, from the solar panel, is higher than 0.5V and it is set to false when the voltage is lower than 0.5V. The other variable, lightSensedY, is set to true by the right hand loop when the voltage measured by the energy meter, from the solar panel, is higher than 0.7V and it is set to false when the voltage measured is less than 0.7V. These two variables are used in the outer loops of the motor positioning loops by the program to figure out when to stop the motors. Two variables of different values are used so that each motor can scan for light independently of the other to get the solar panel facing more intense light. The light intensity loops should be setup as in figure 10.

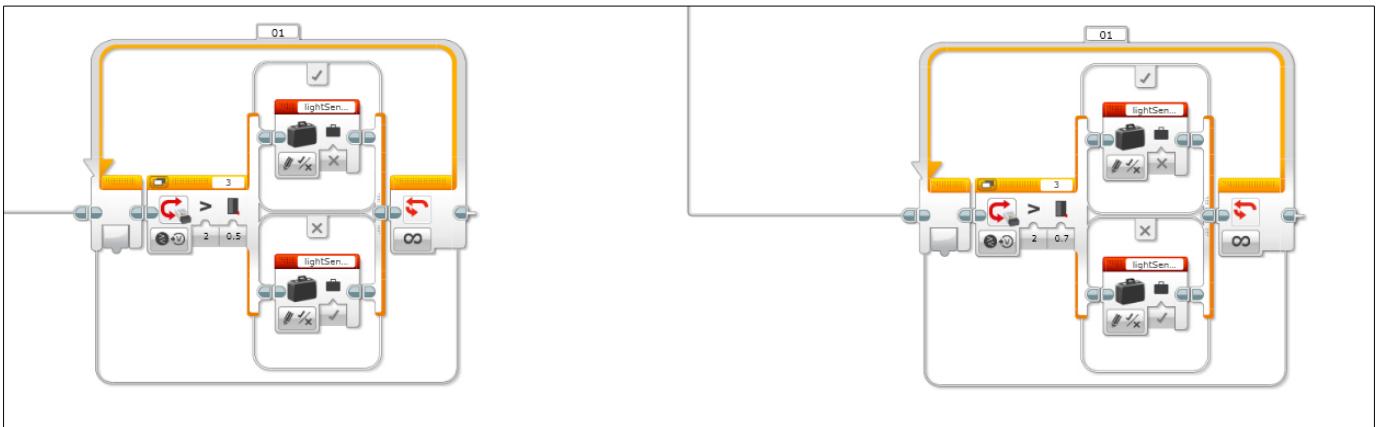


Fig. 10. Light Intensity Loops

V. RUNNING THE SOLAR STATION PROGRAM

Once the program is complete and downloaded to the EV3 brick the program can be run by simply selecting it from the menu on the brick and running it. Before running the program the solar panel must be facing toward the front of the solar station or the cables will bind as it is searching for light. The front of the solar station is the side where the tops of the EV3 brick and energy meter are. If the program is stopped while the solar panel is not facing toward the front of the solar station it must be turned so that it is facing toward the front before running the program again.

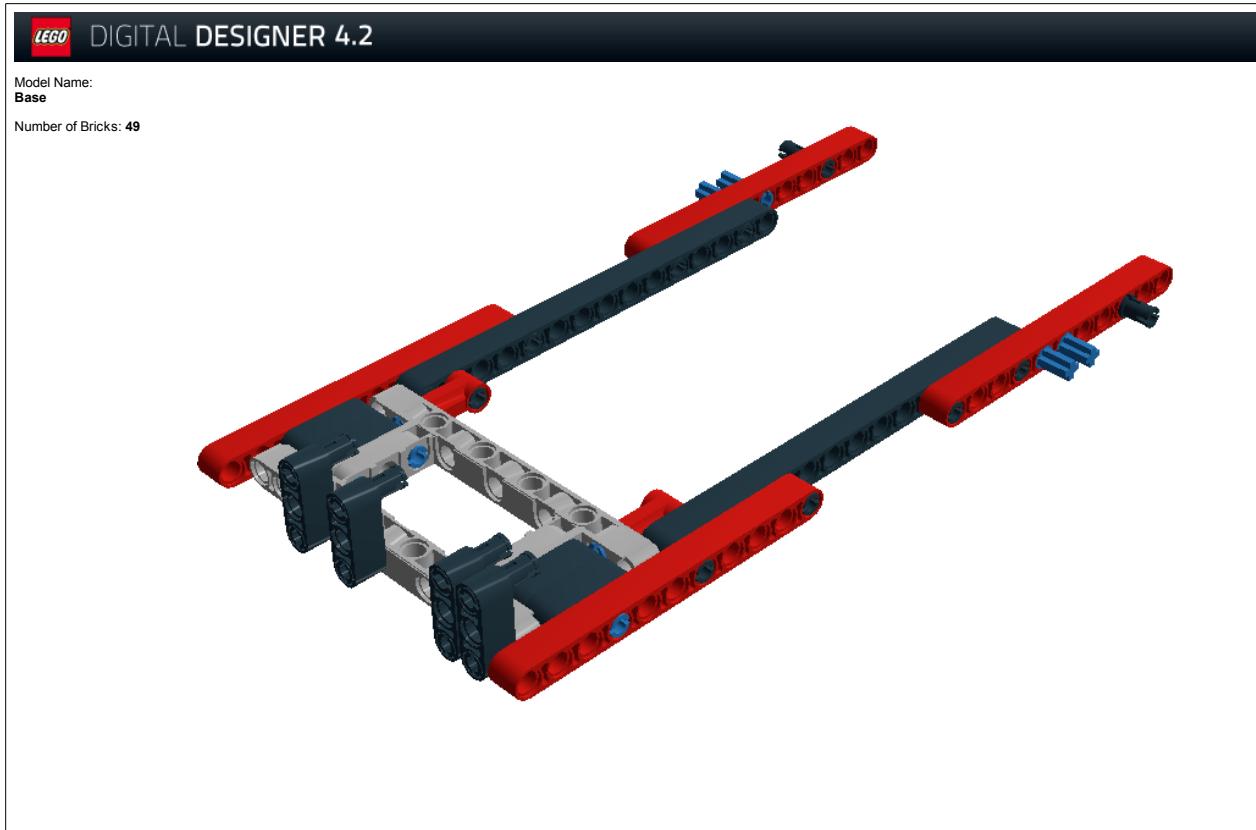
VI. CONCLUSION

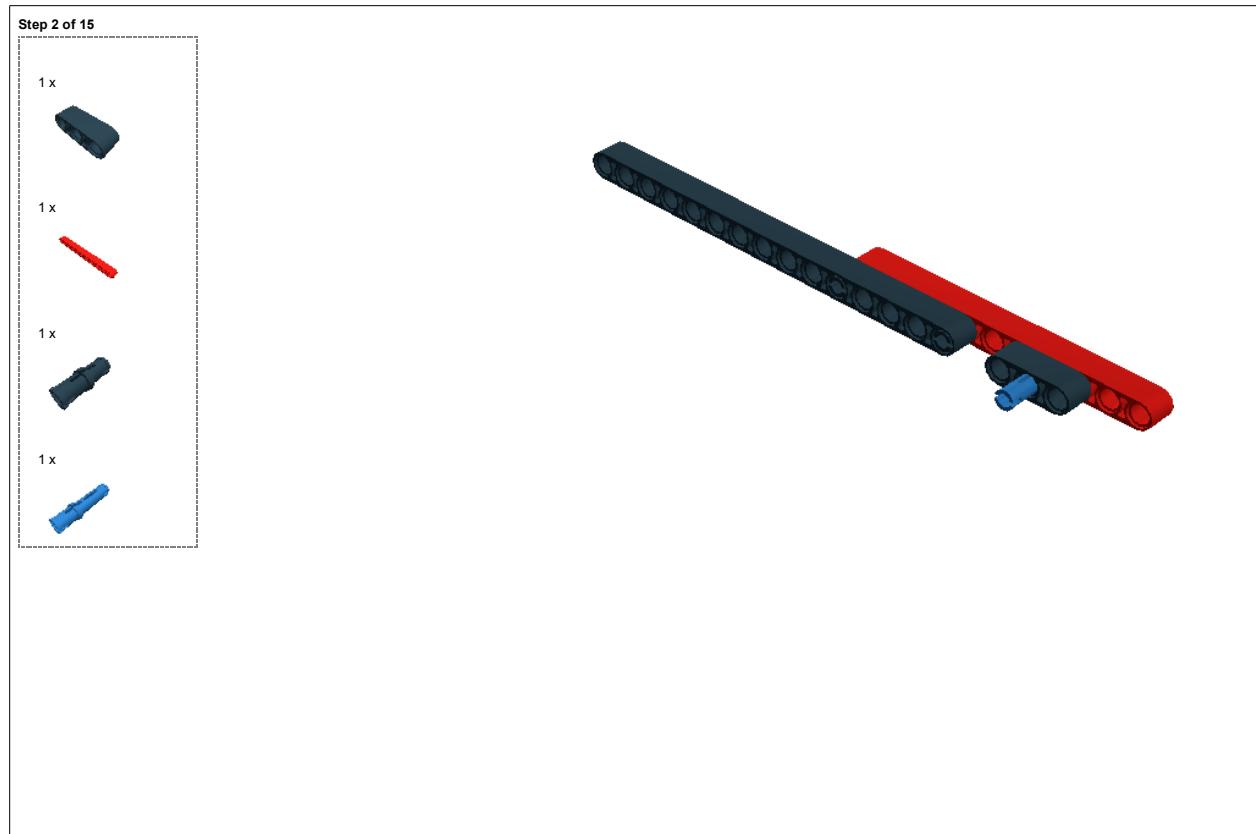
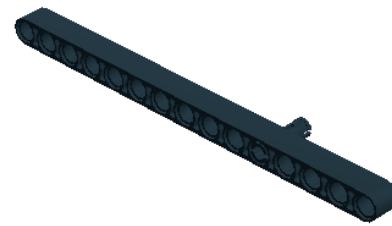
The reality of increased energy usage in modern society and the limited nature of our current energy sources require that new, renewable sources of energy be developed. Because these energy sources will be most important to the next generation it is important that we provide the next generation with the education and tools that they need to understand, create and maintain these energy sources. The Lego EV3 Solar

Station has been designed to introduce school age children to basic concepts of energy generation with solar panels and robotics to automate the collection of solar energy. This paper has outlined what is needed to build the solar station and instructions for building and programming the solar station.

VII. APPENDICES

A. Building the base





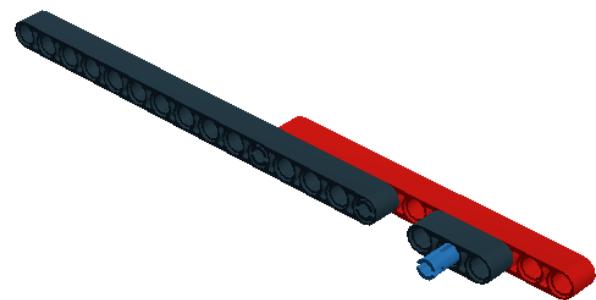
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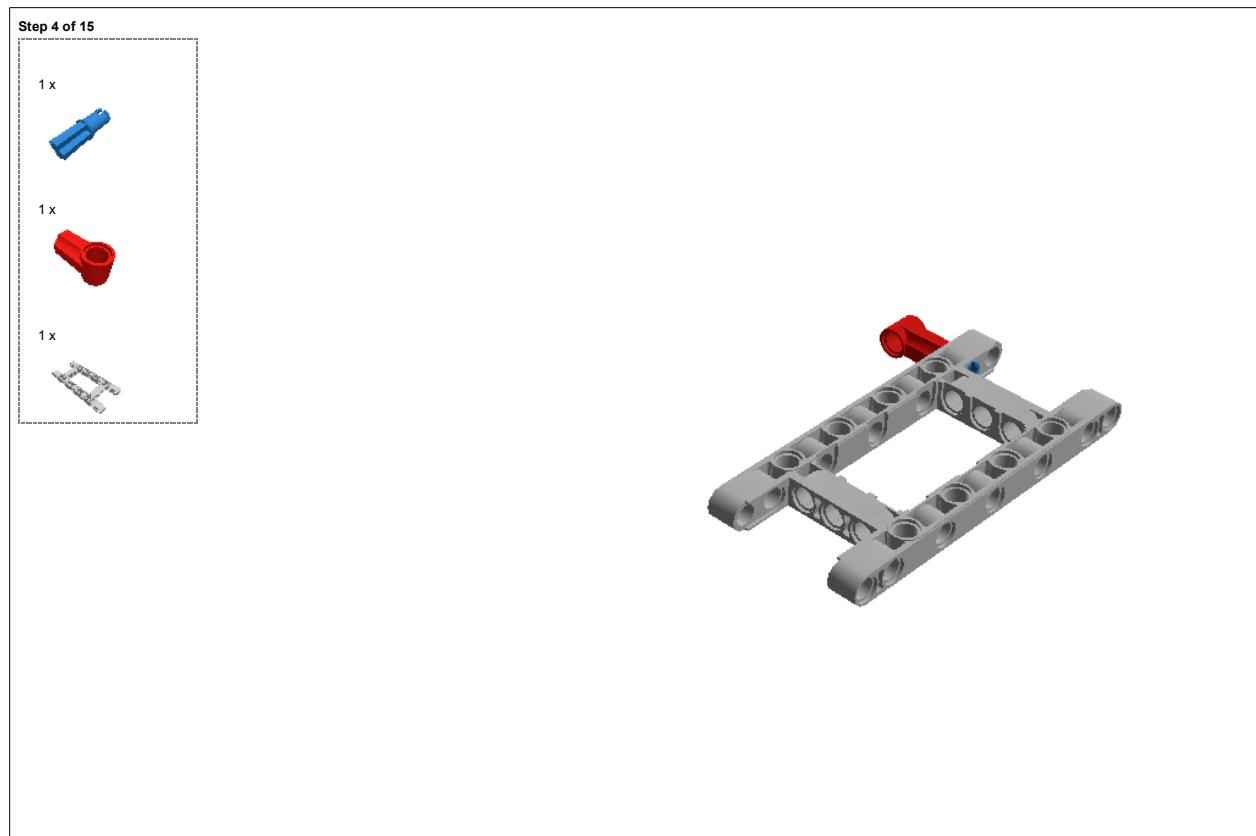


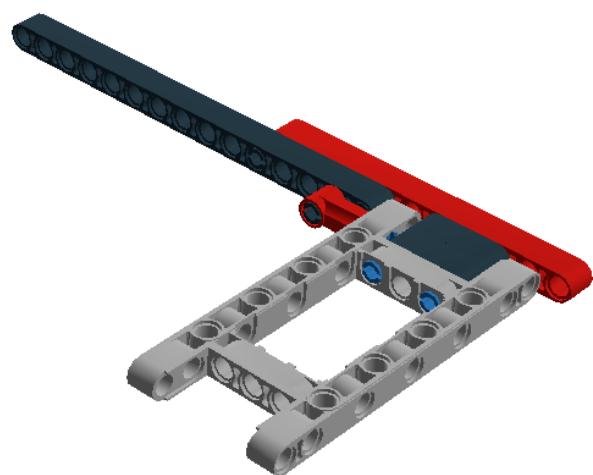
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Step 5 of 15**Step 6 of 15**

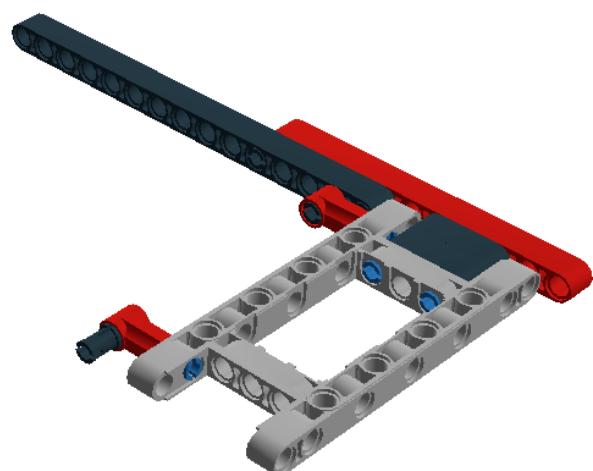
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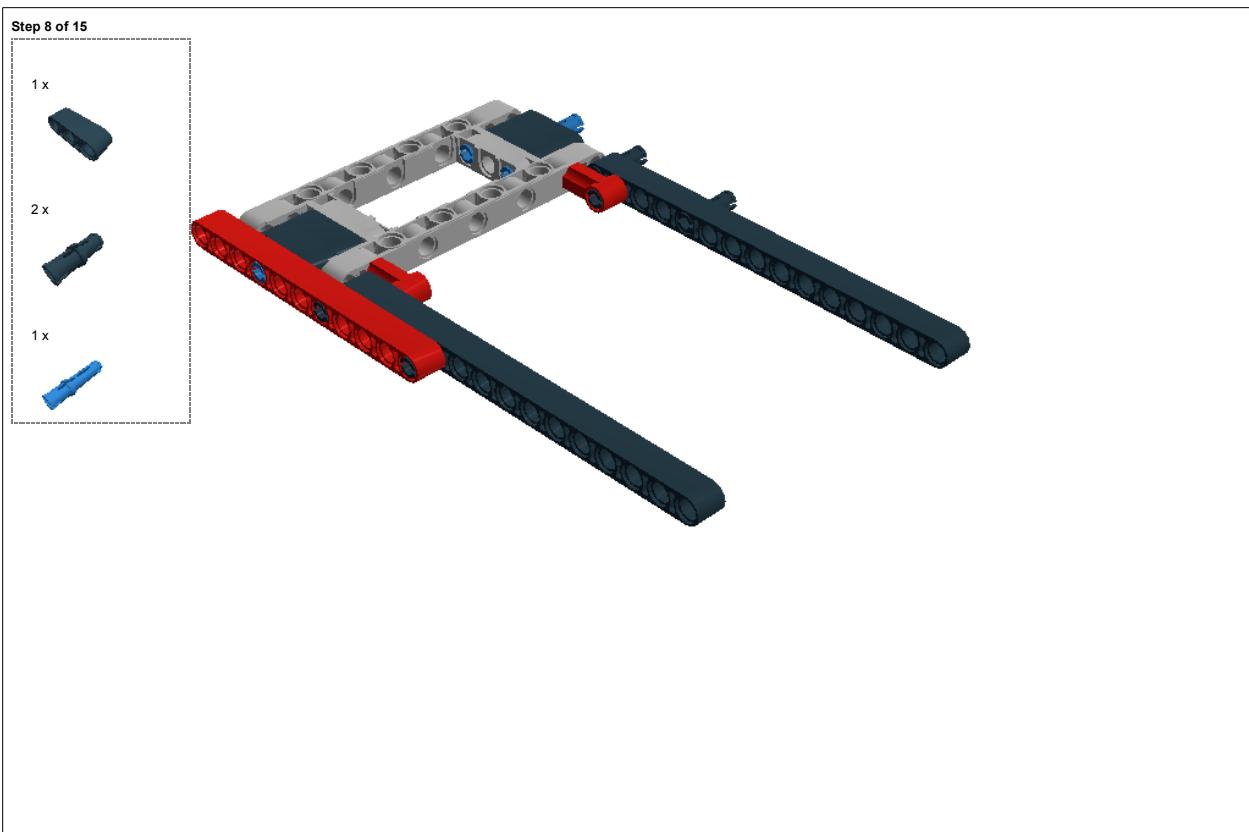
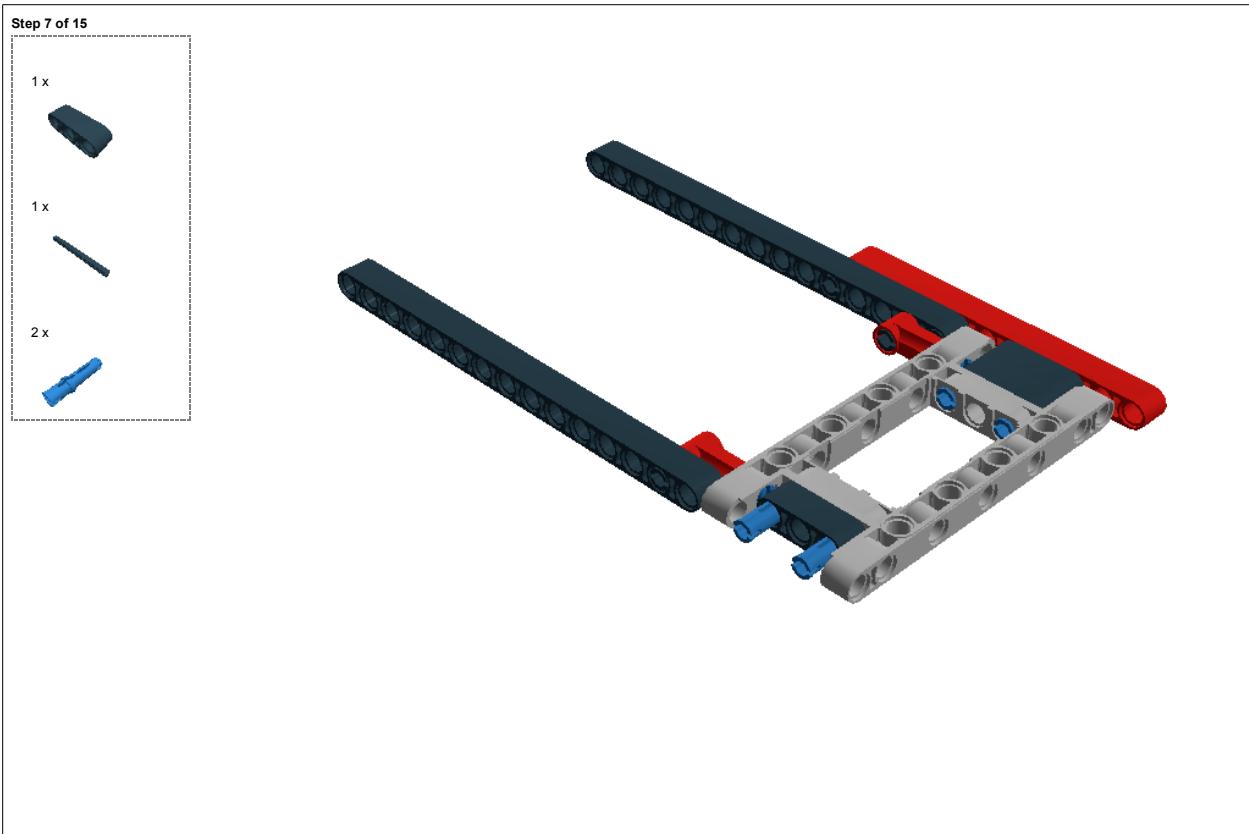


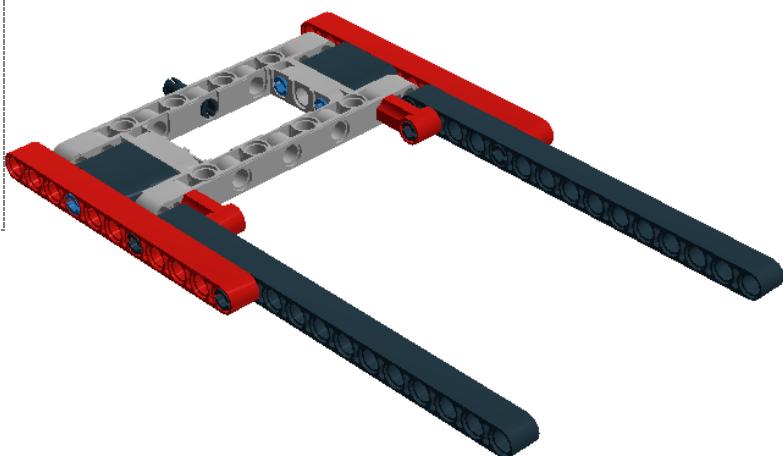
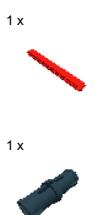
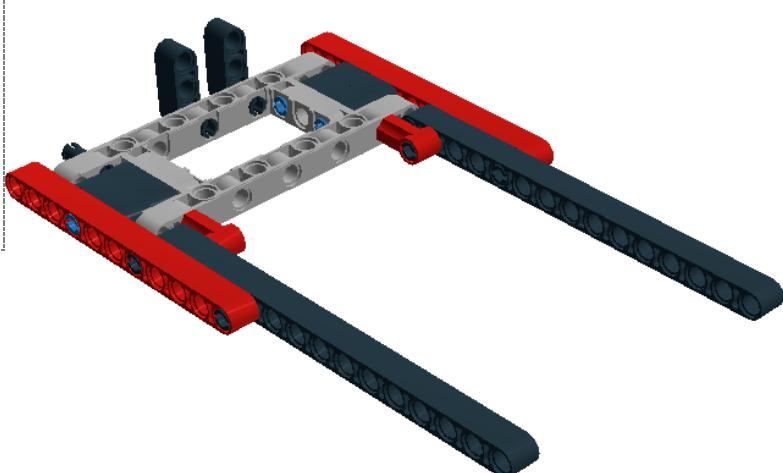
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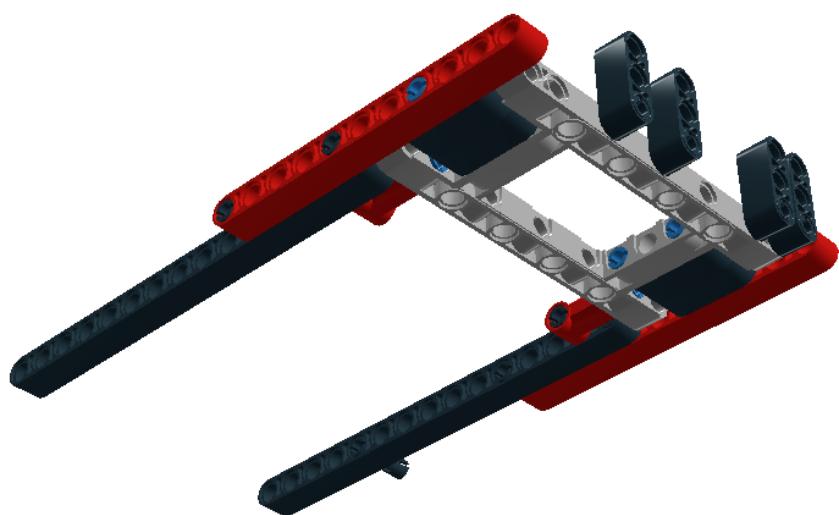
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Step 11 of 15

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2 x



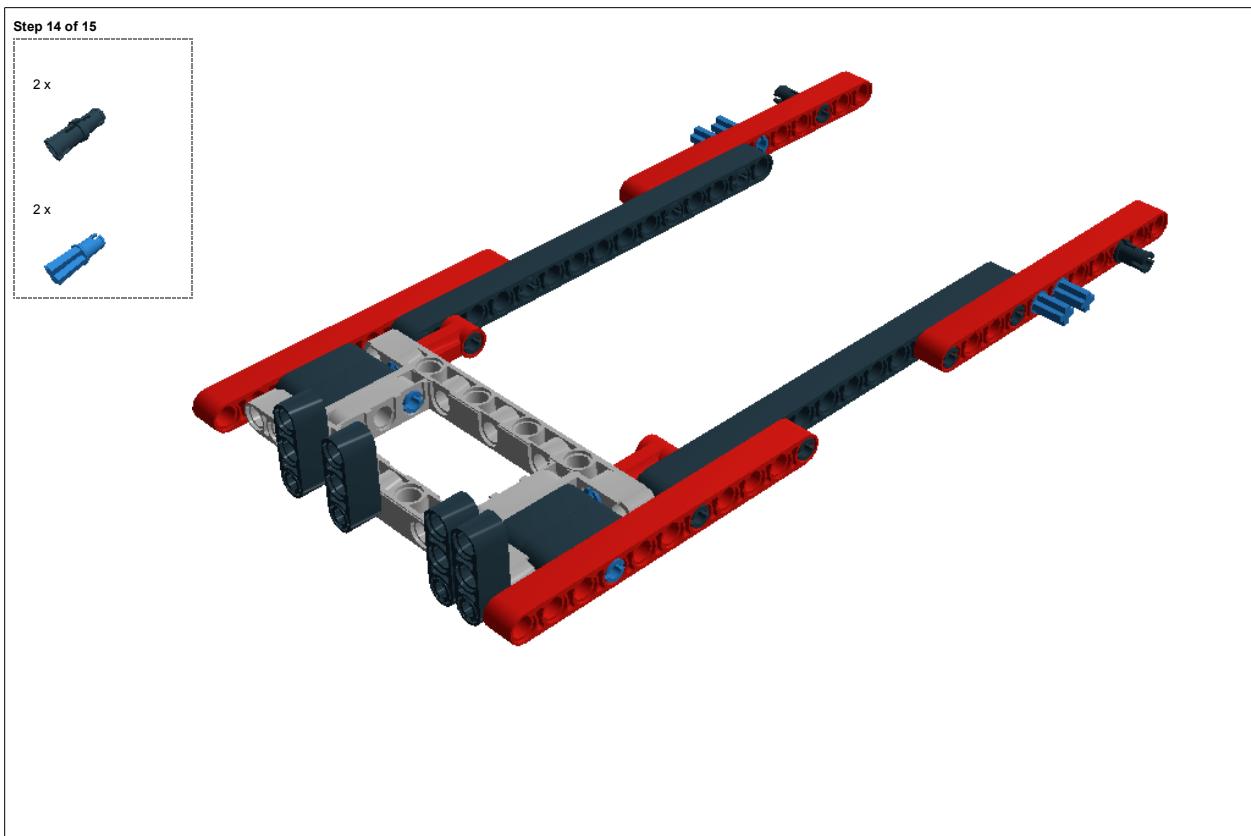
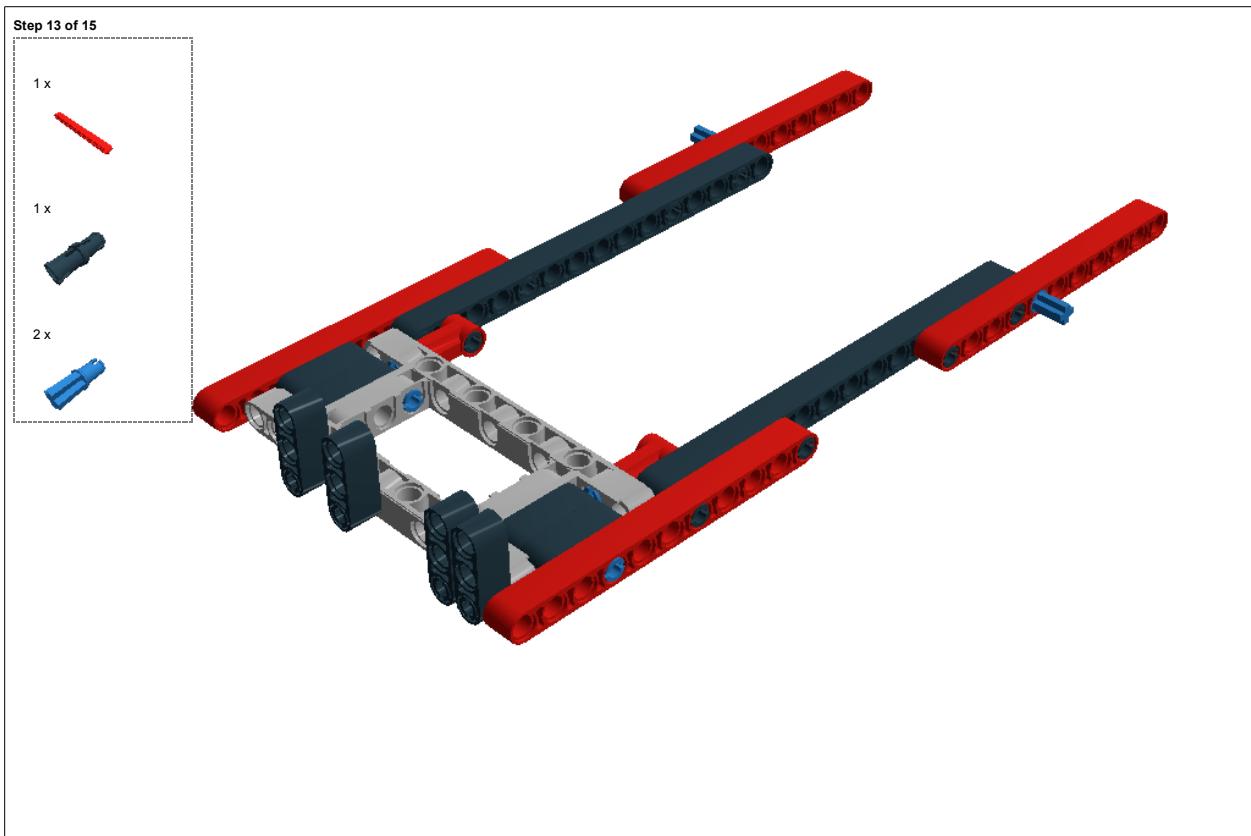
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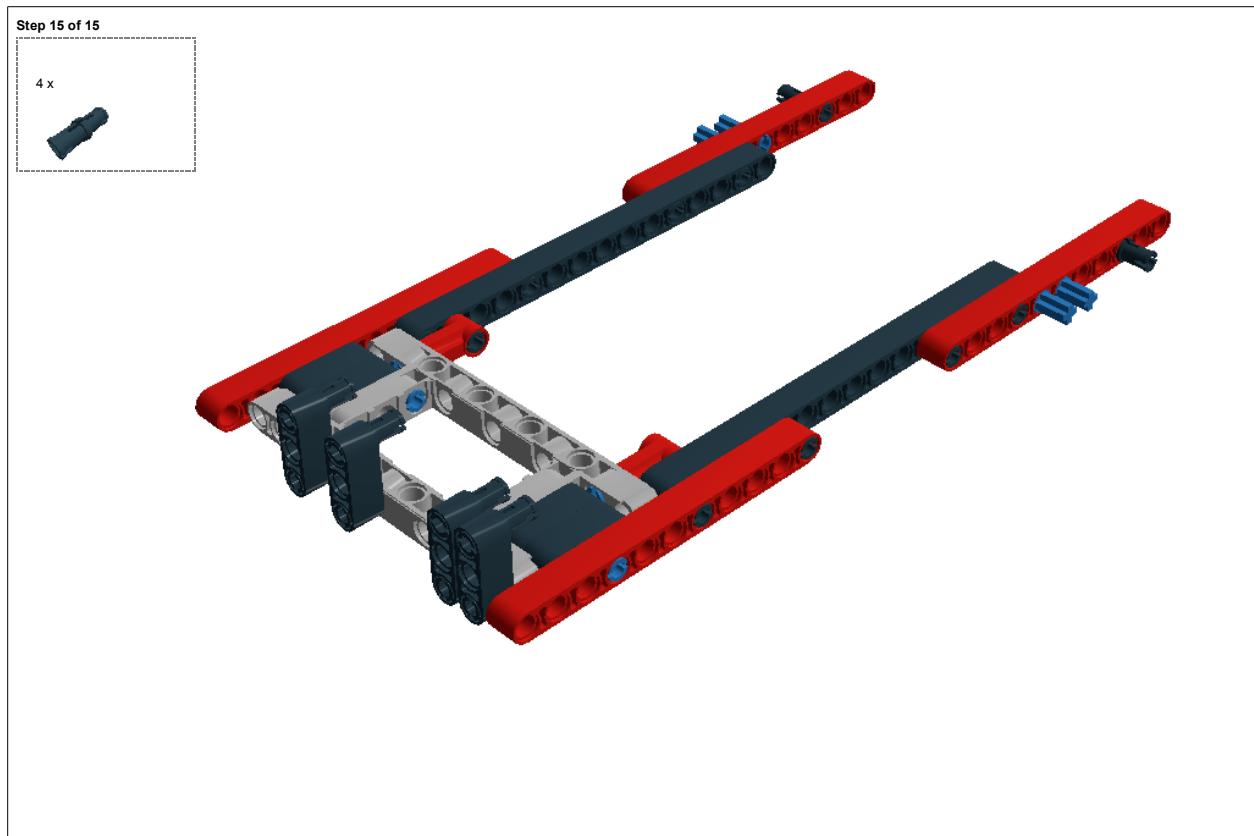
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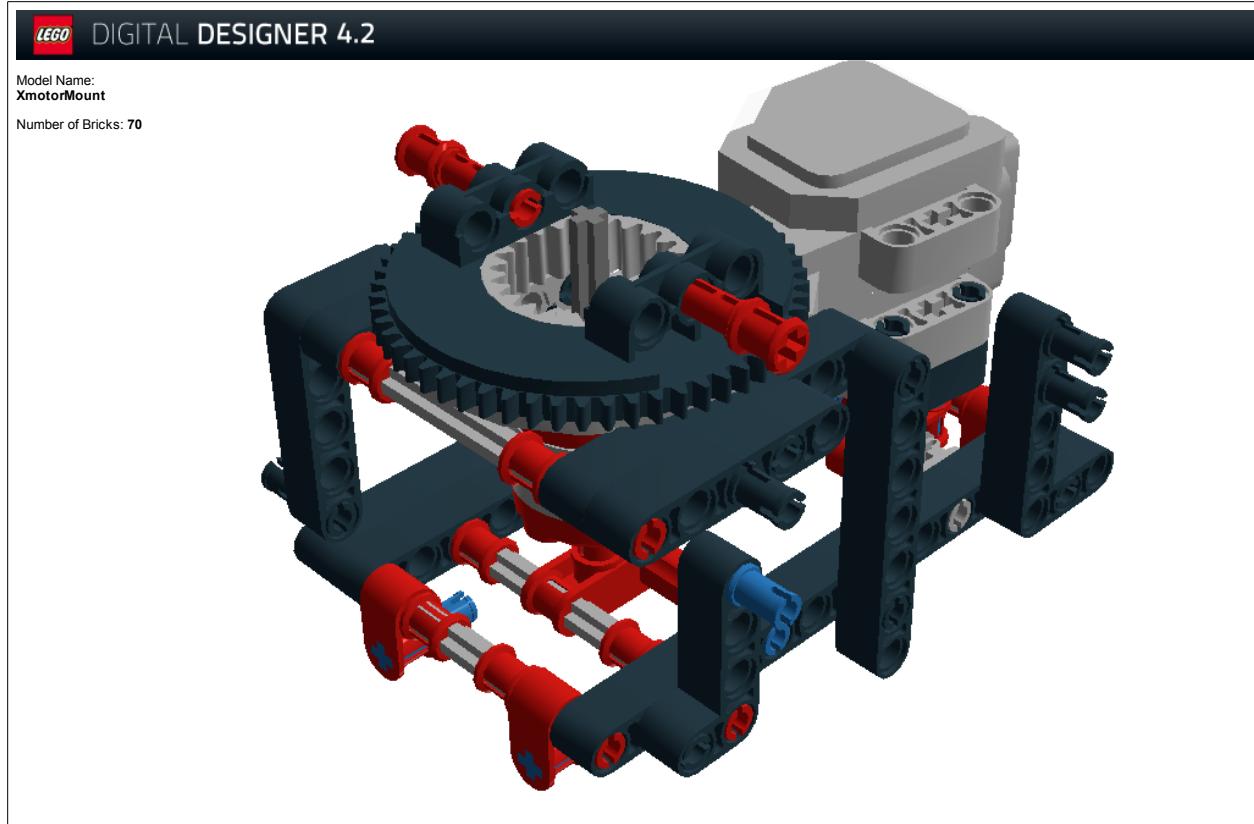
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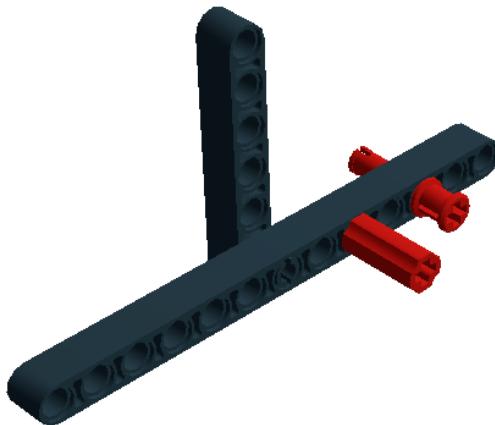
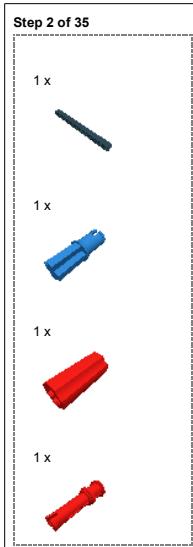
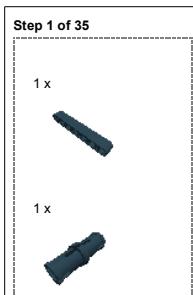


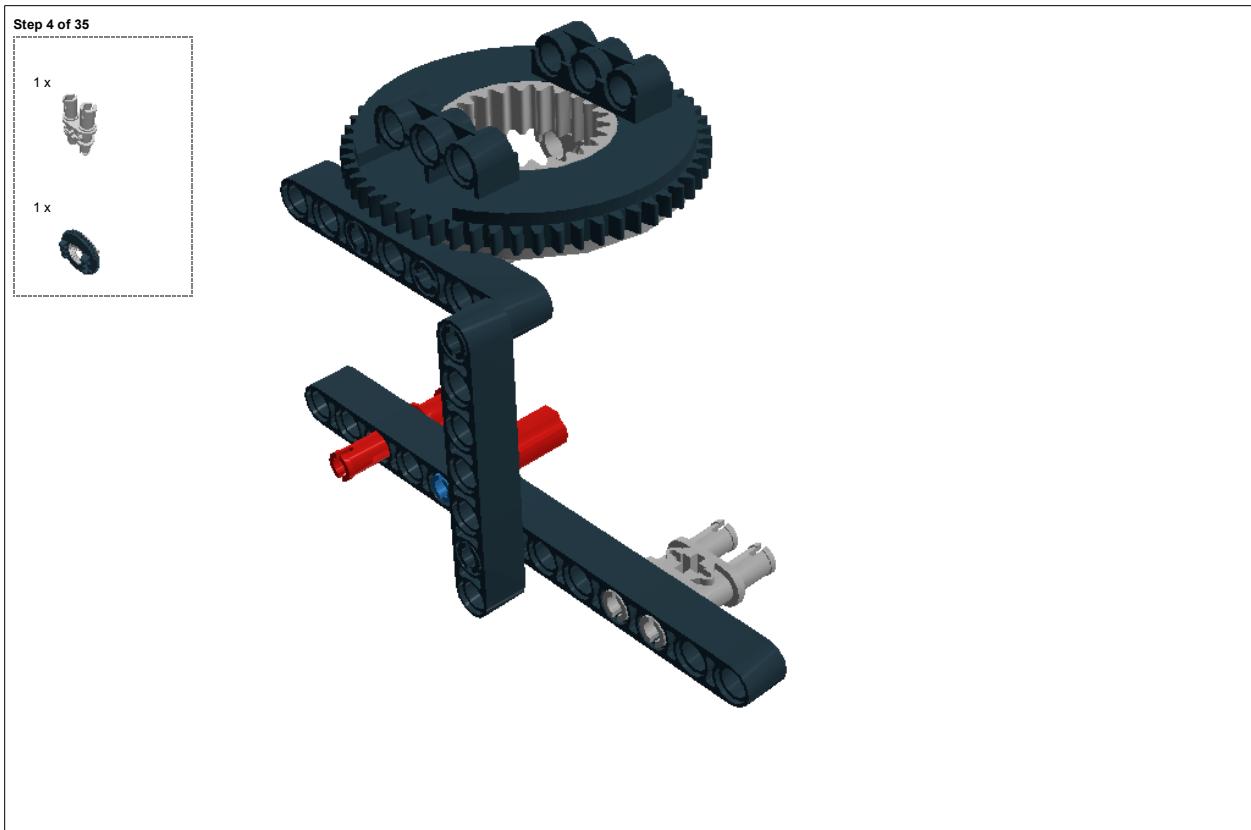
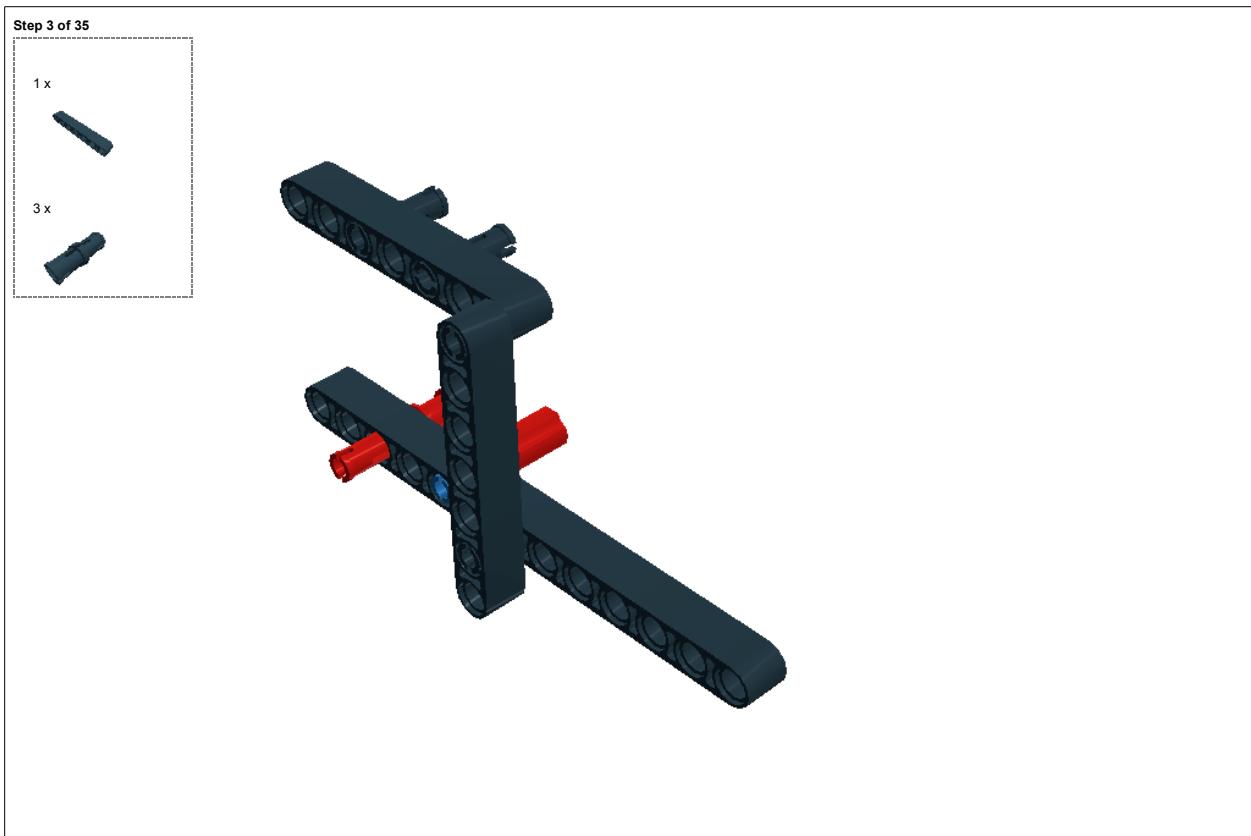


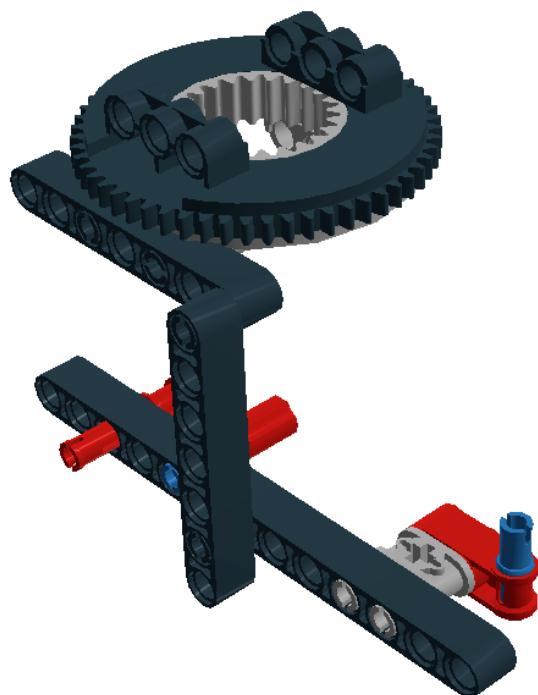


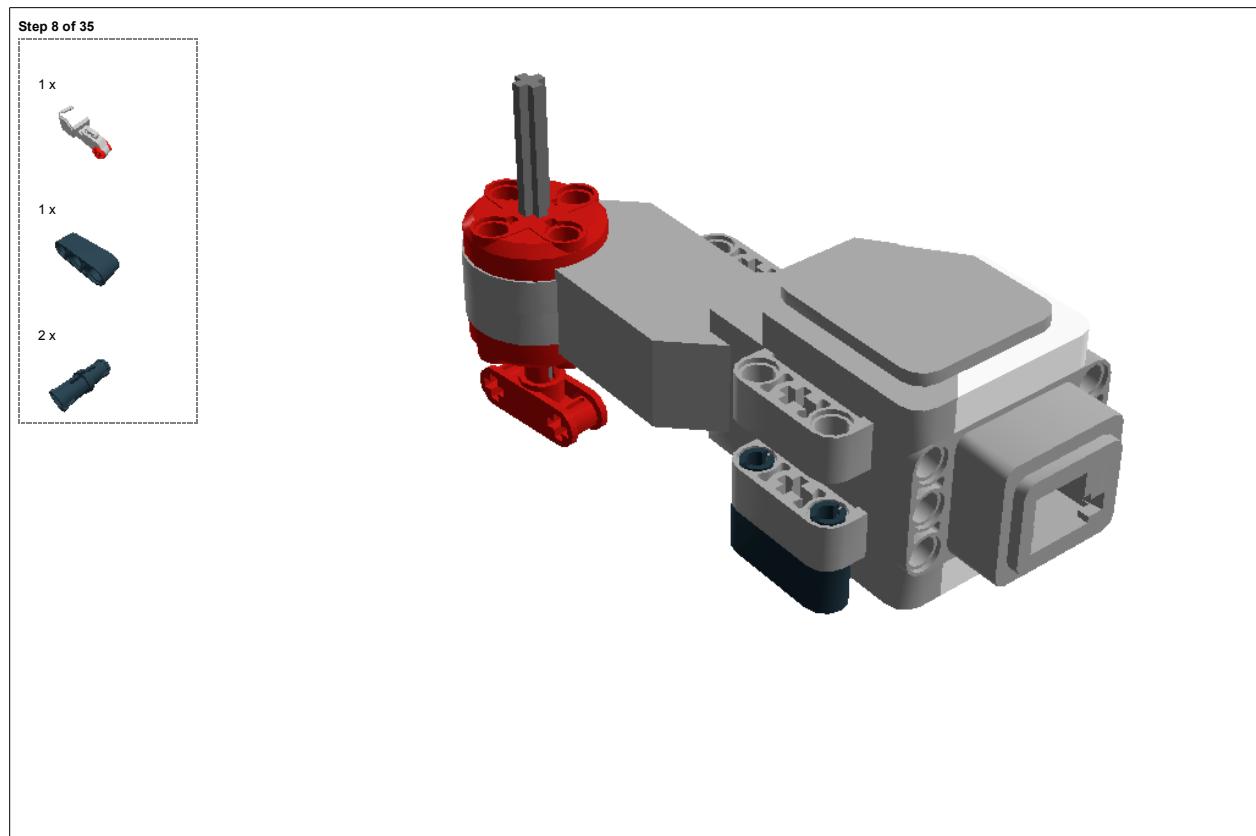
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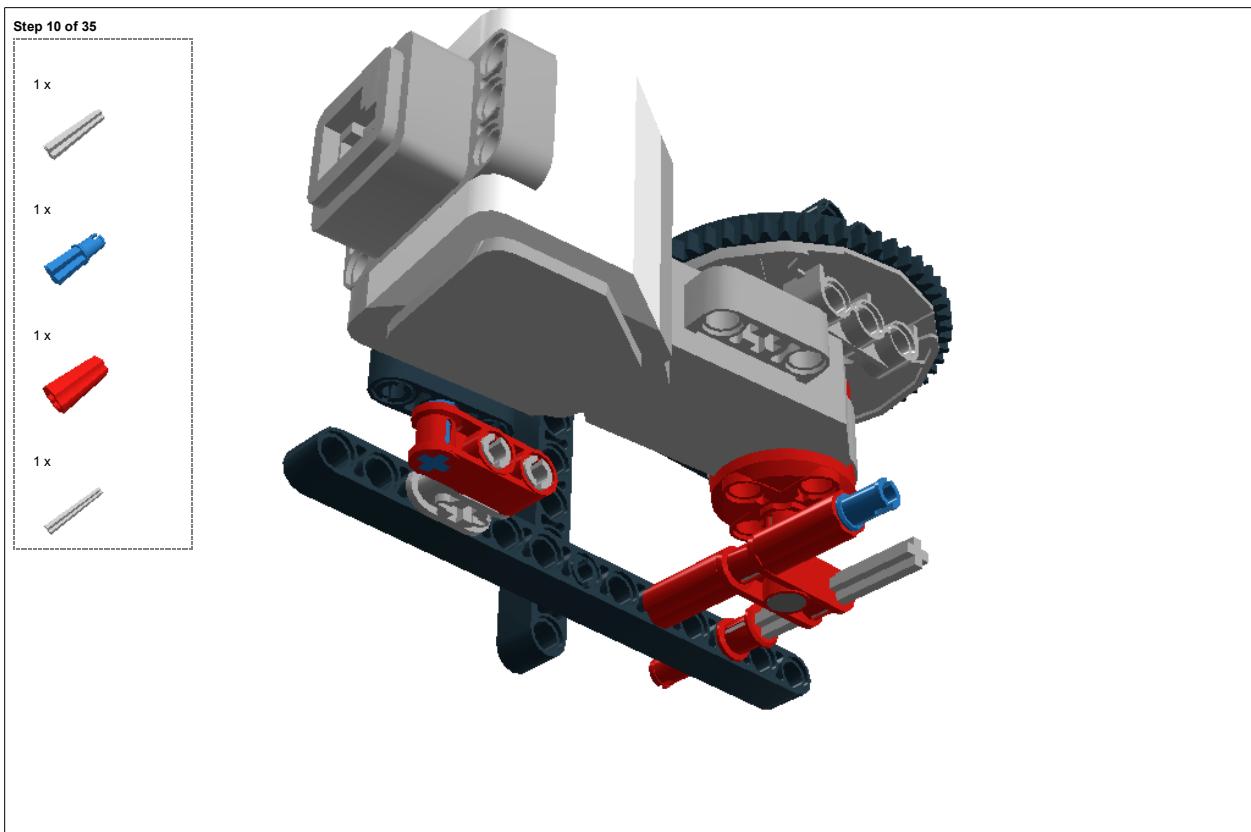
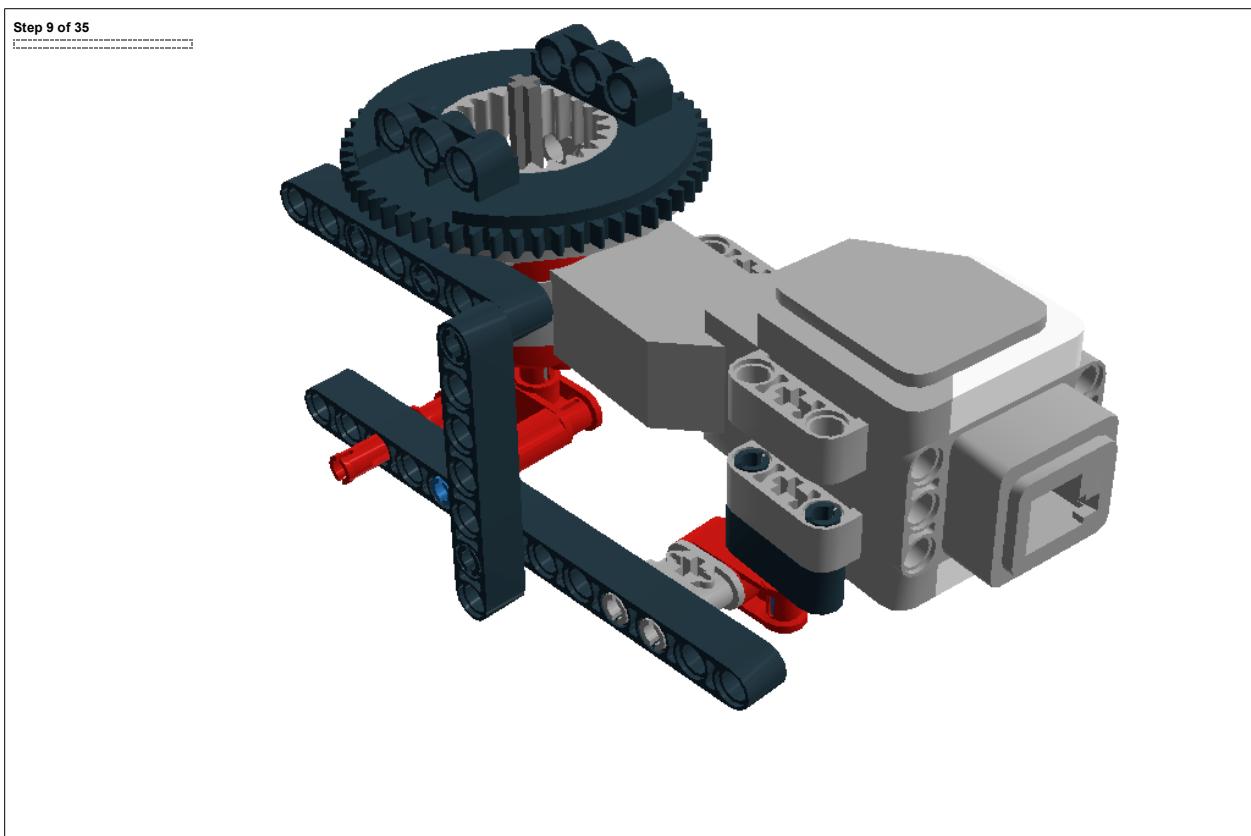






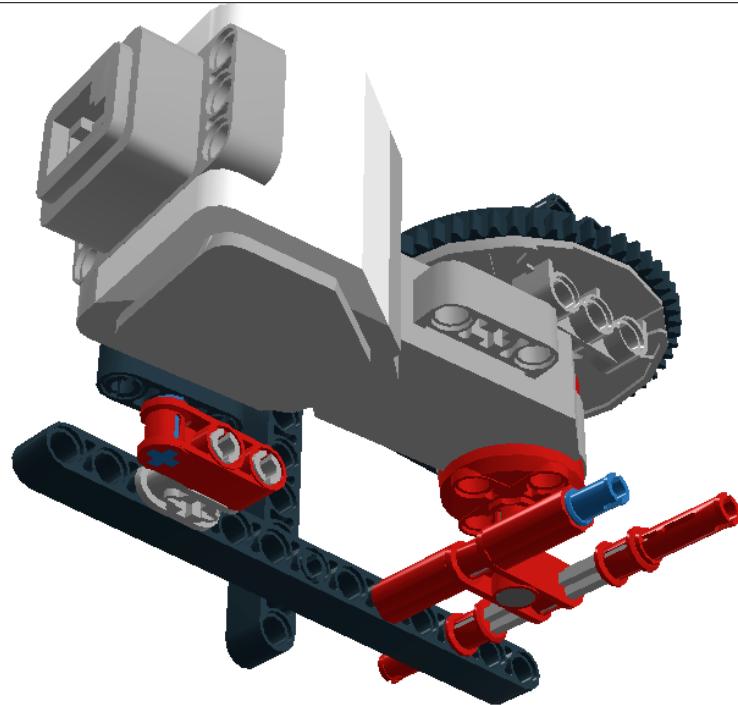
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Step 11 of 35

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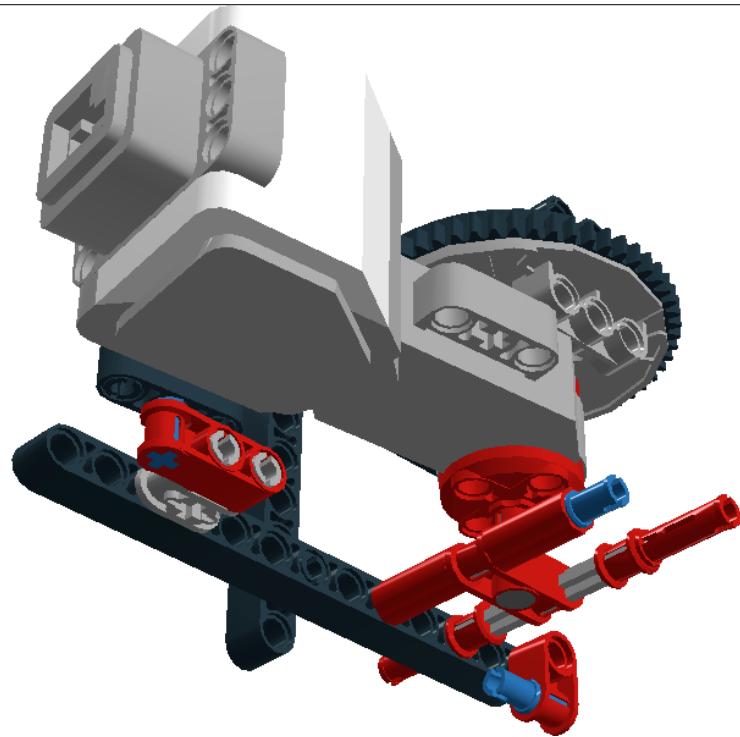
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1 x



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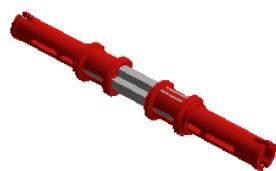


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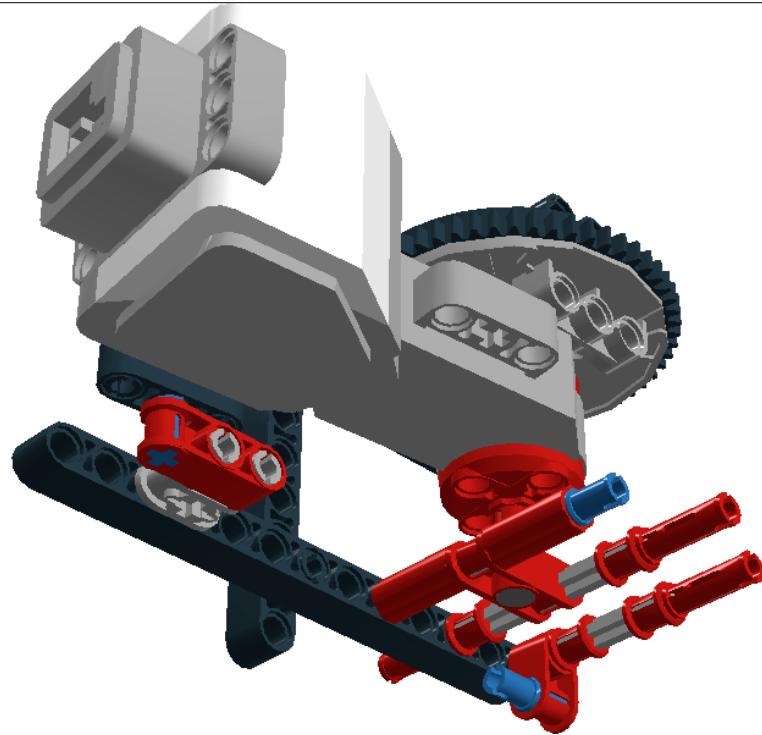
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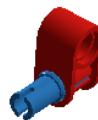
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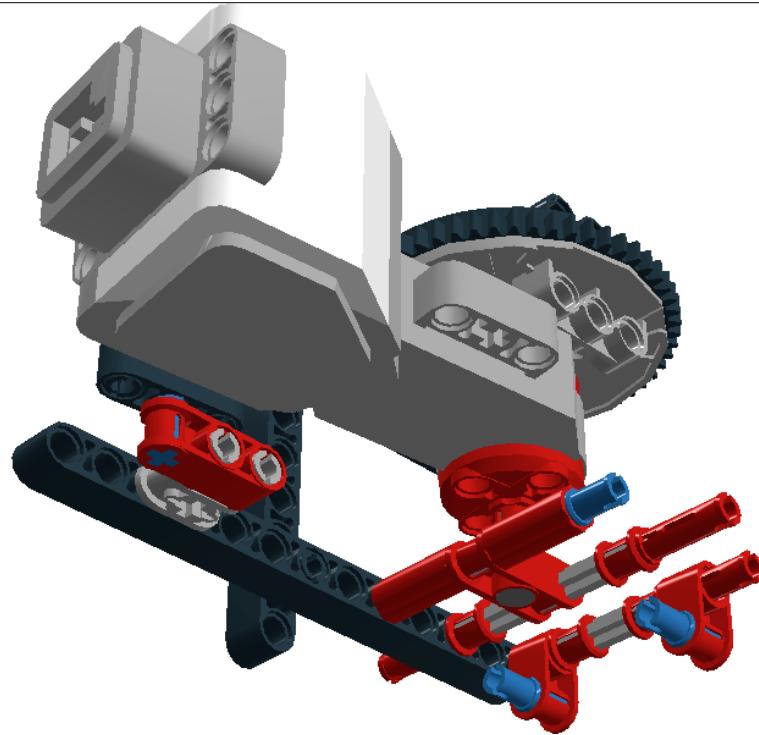
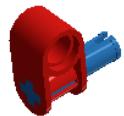


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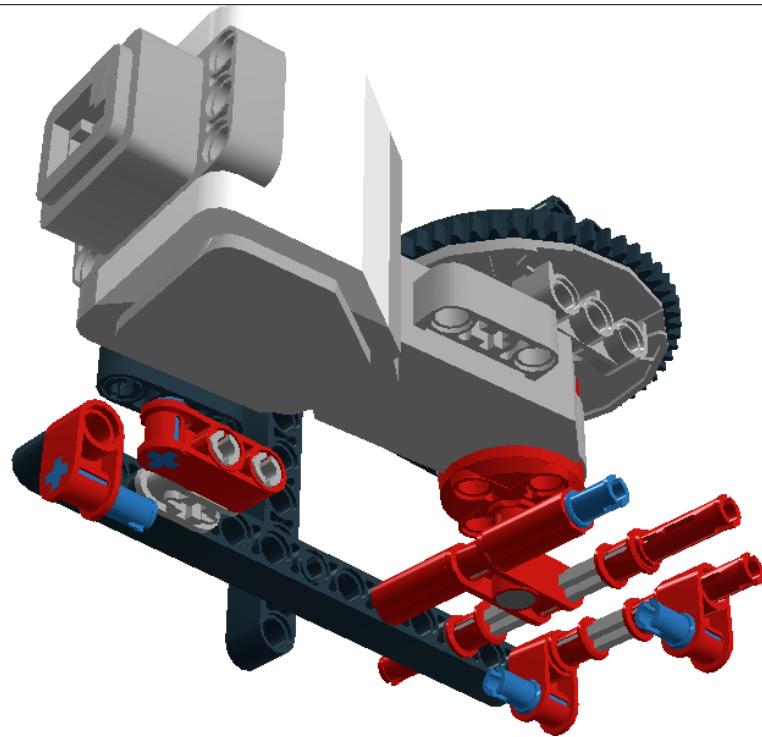


Step 16 of 35



Step 17 of 35**Step 18 of 35**

Step 19 of 35

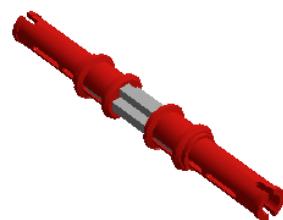


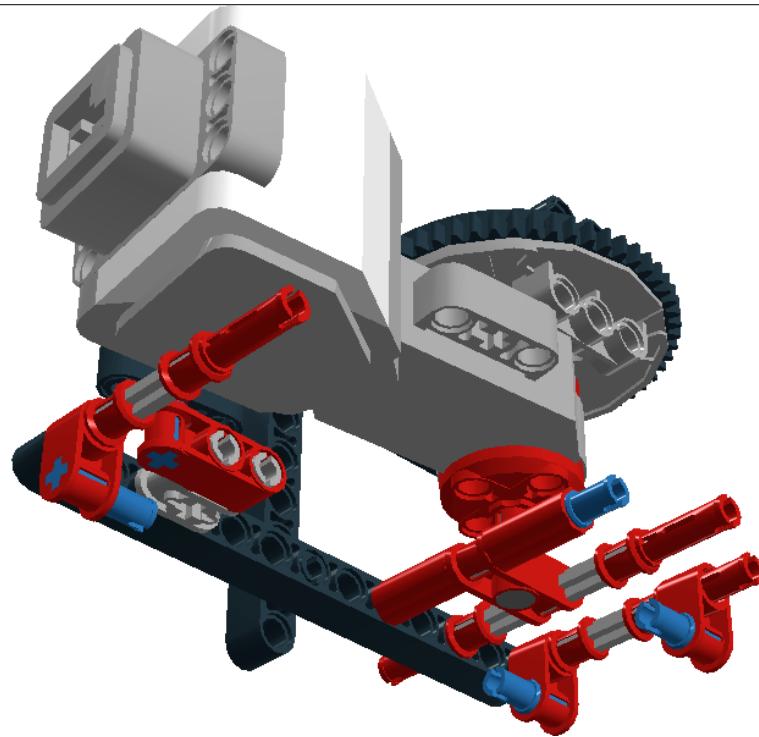
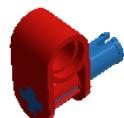
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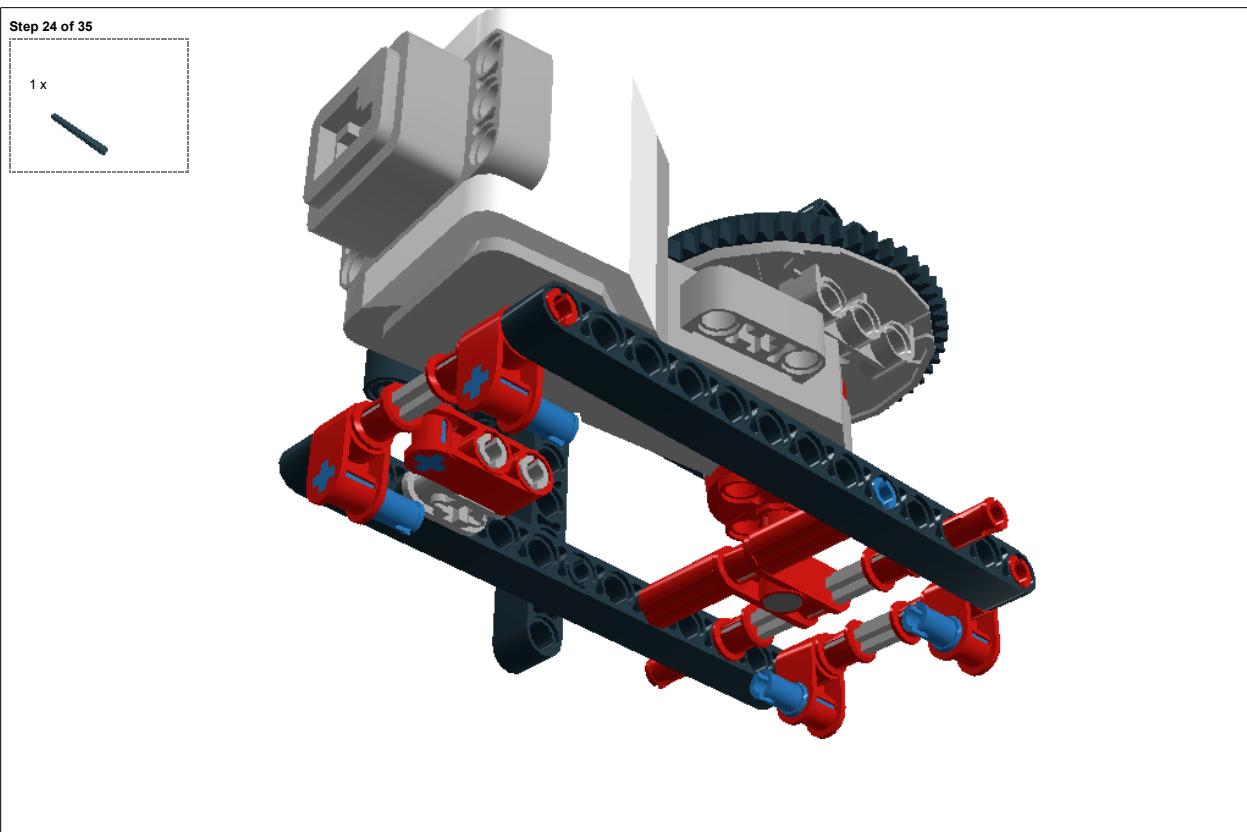
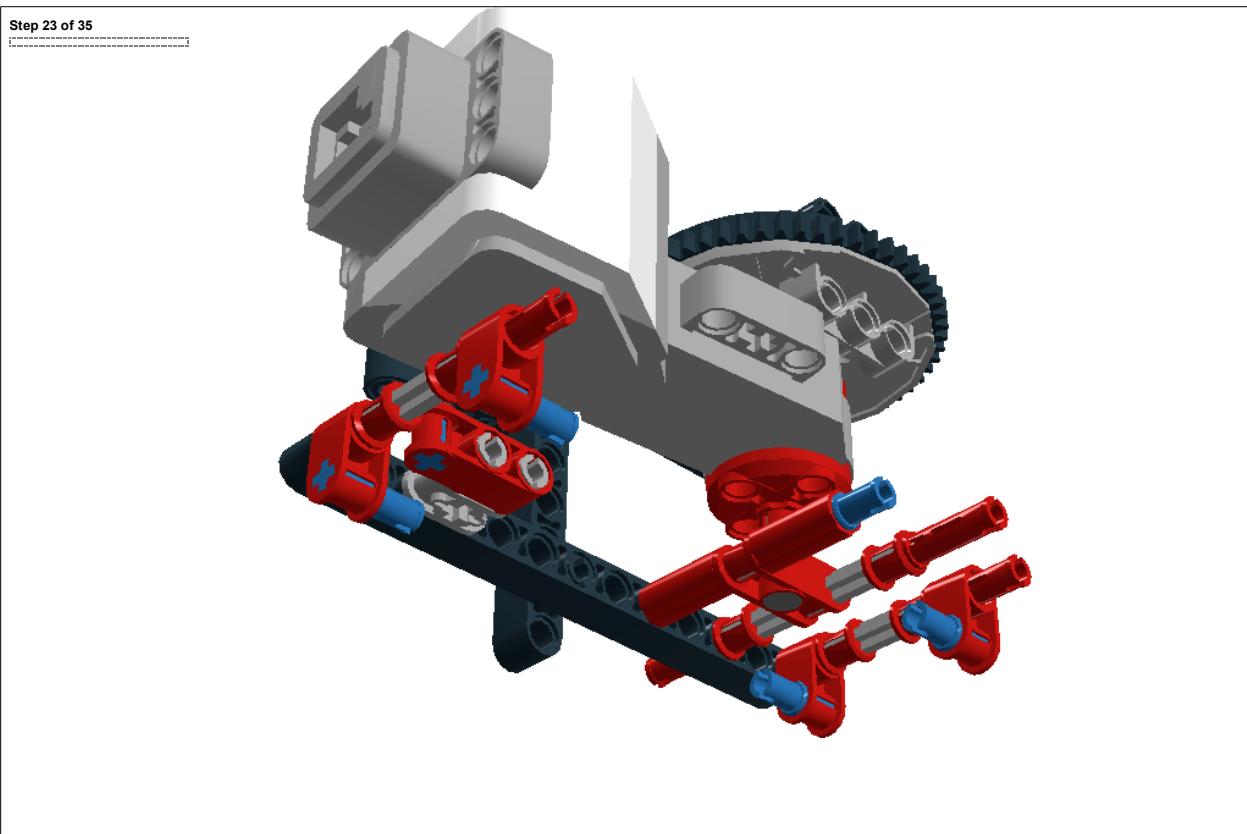
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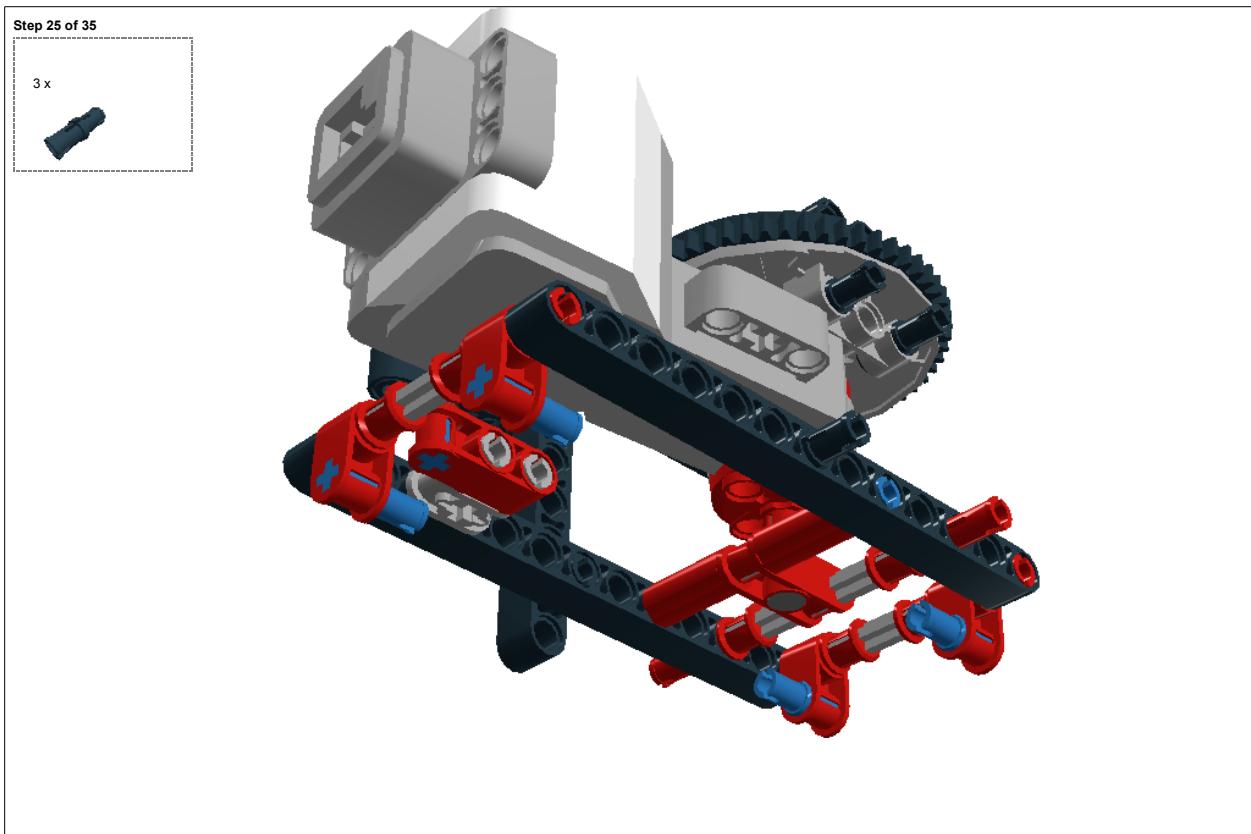


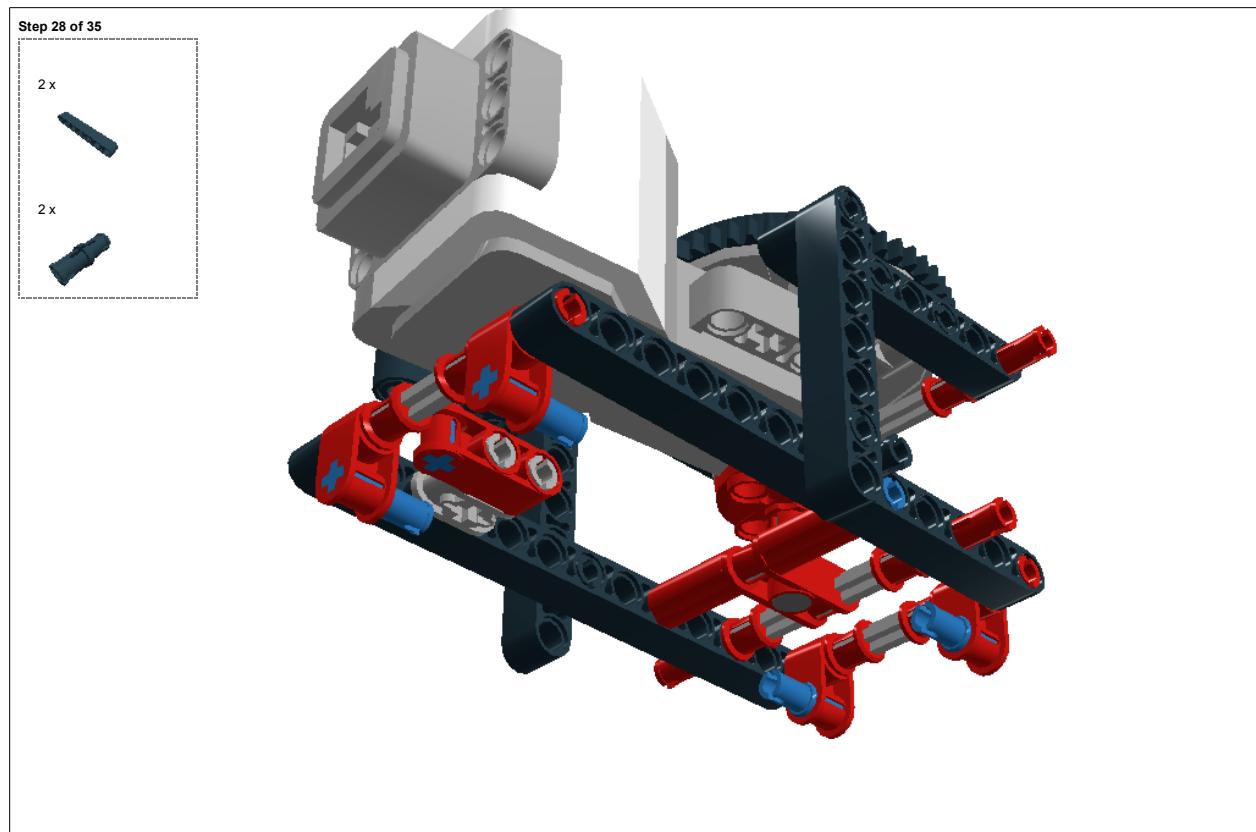
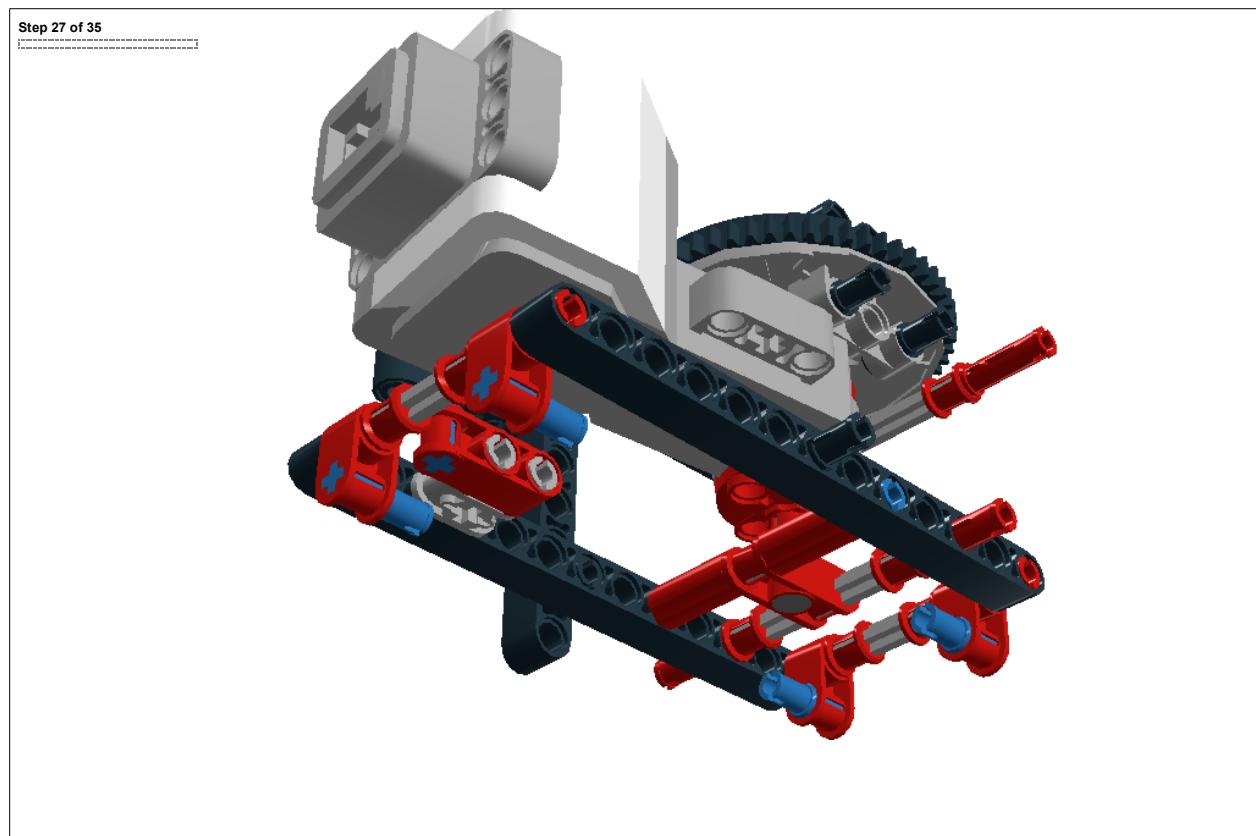
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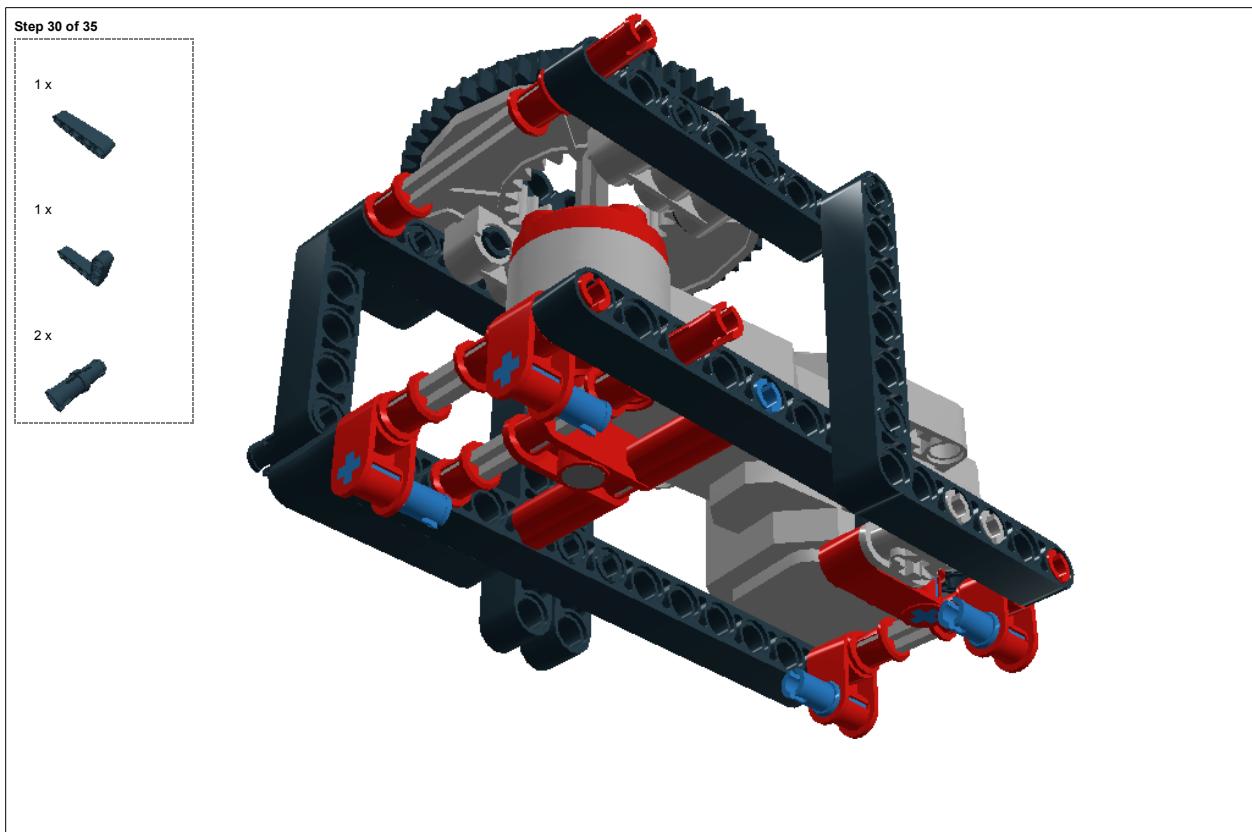
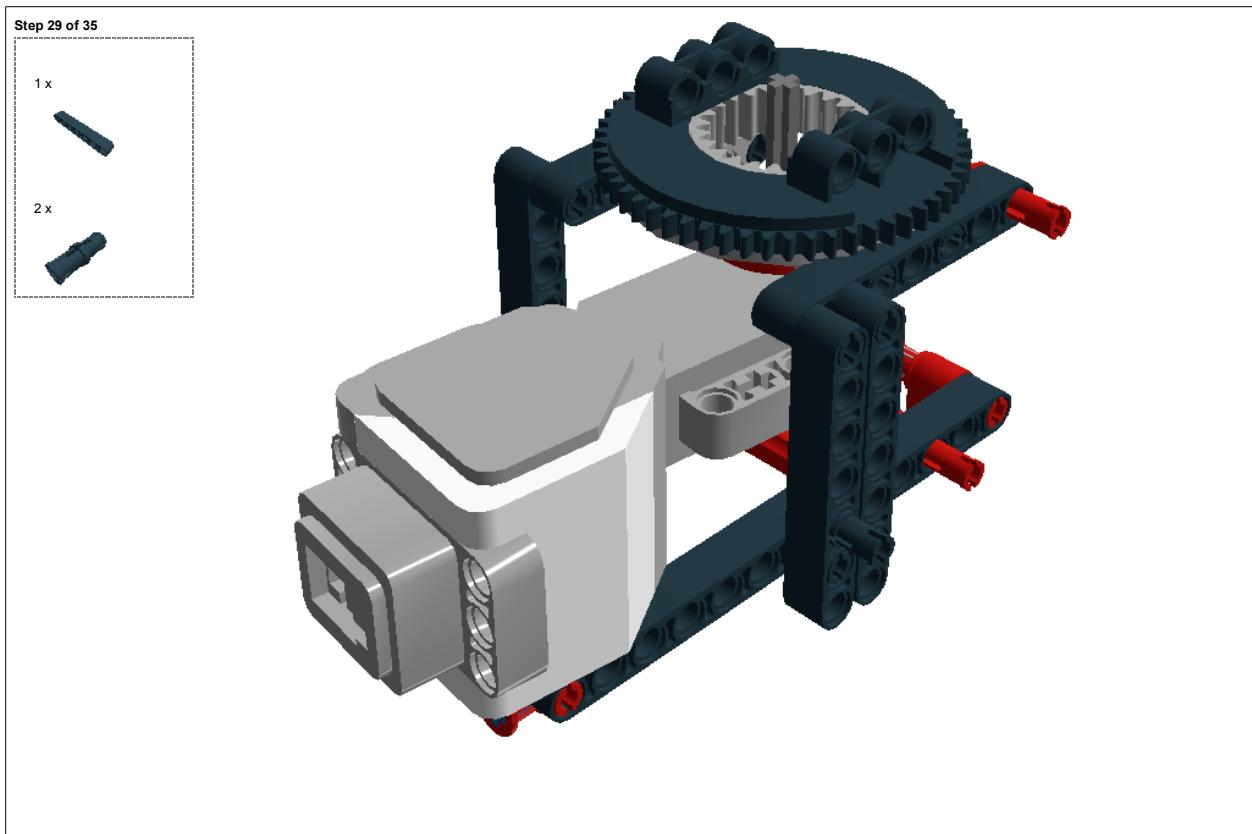


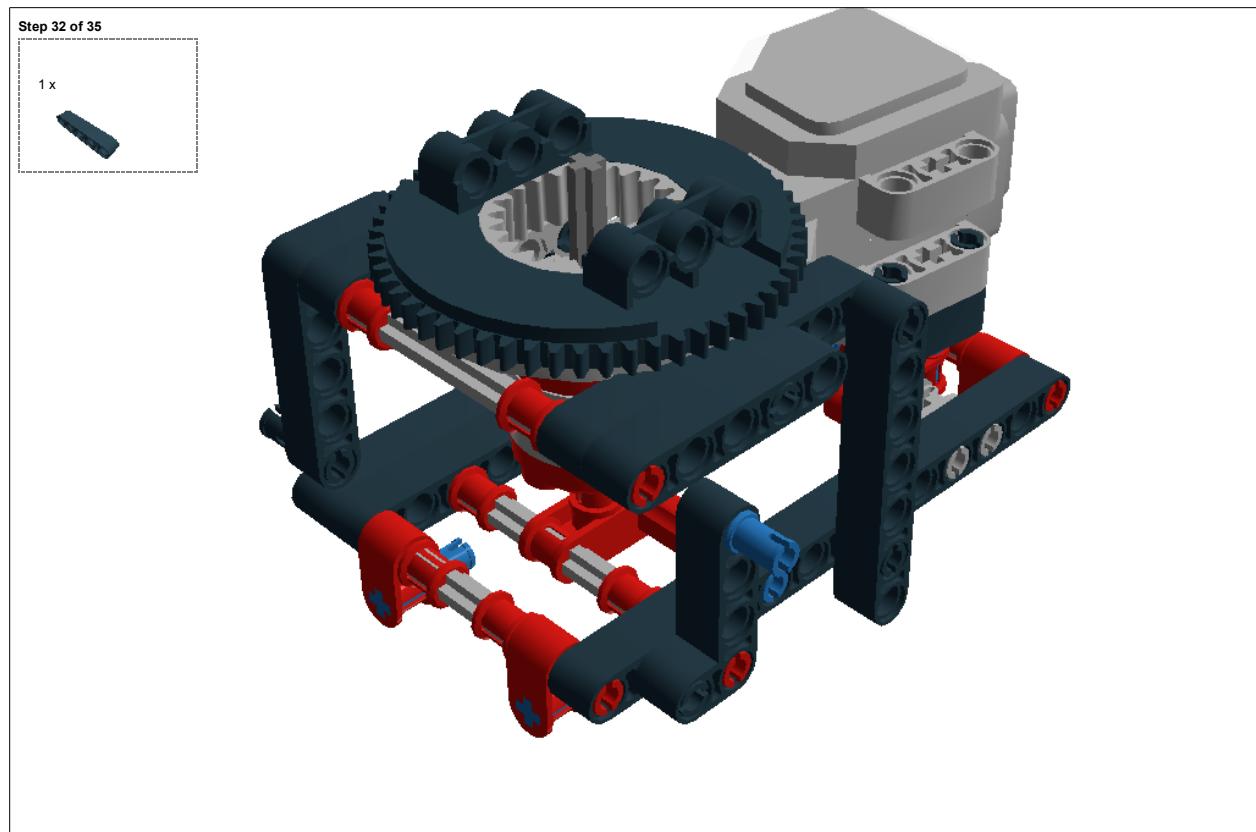
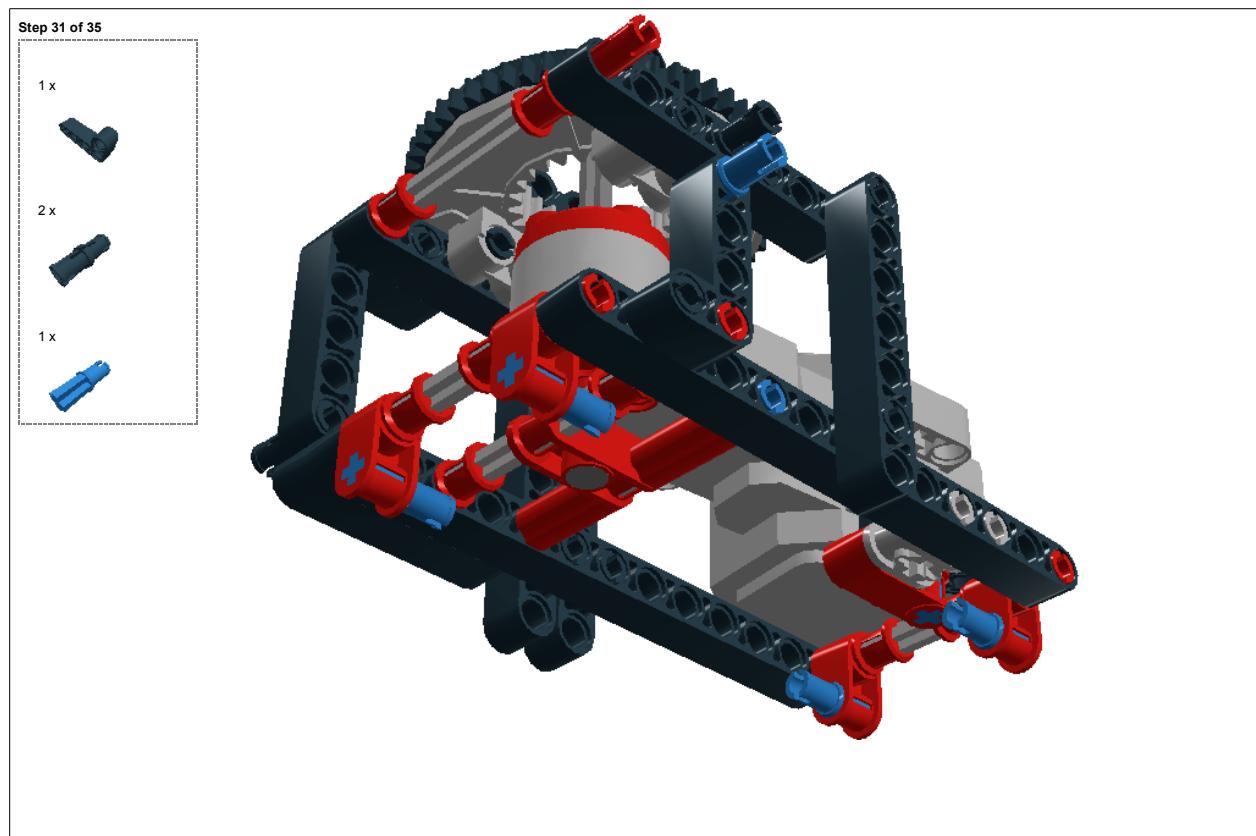
Step 21 of 35**Step 22 of 35**









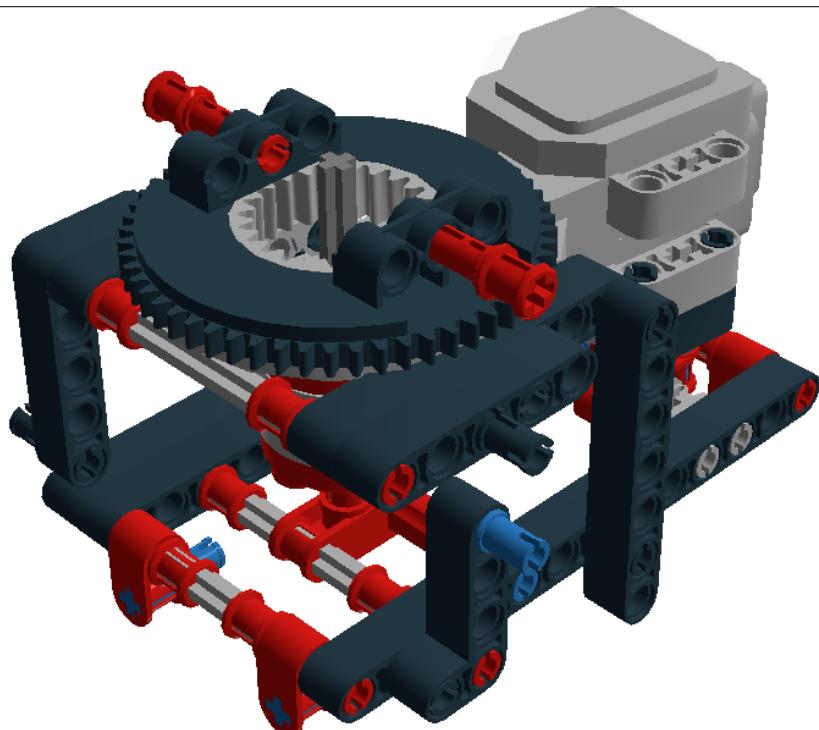


Step 33 of 35

1 x



2 x



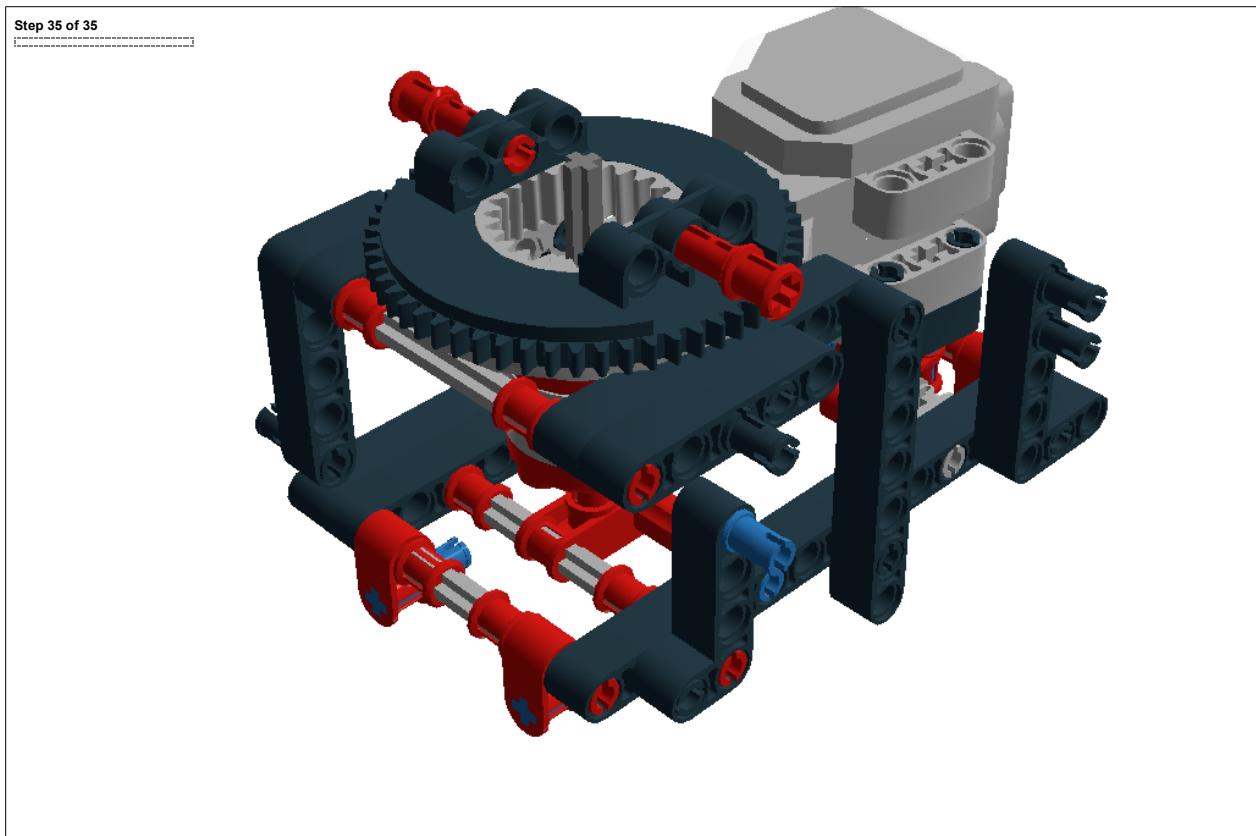
Step 34 of 35

1 x

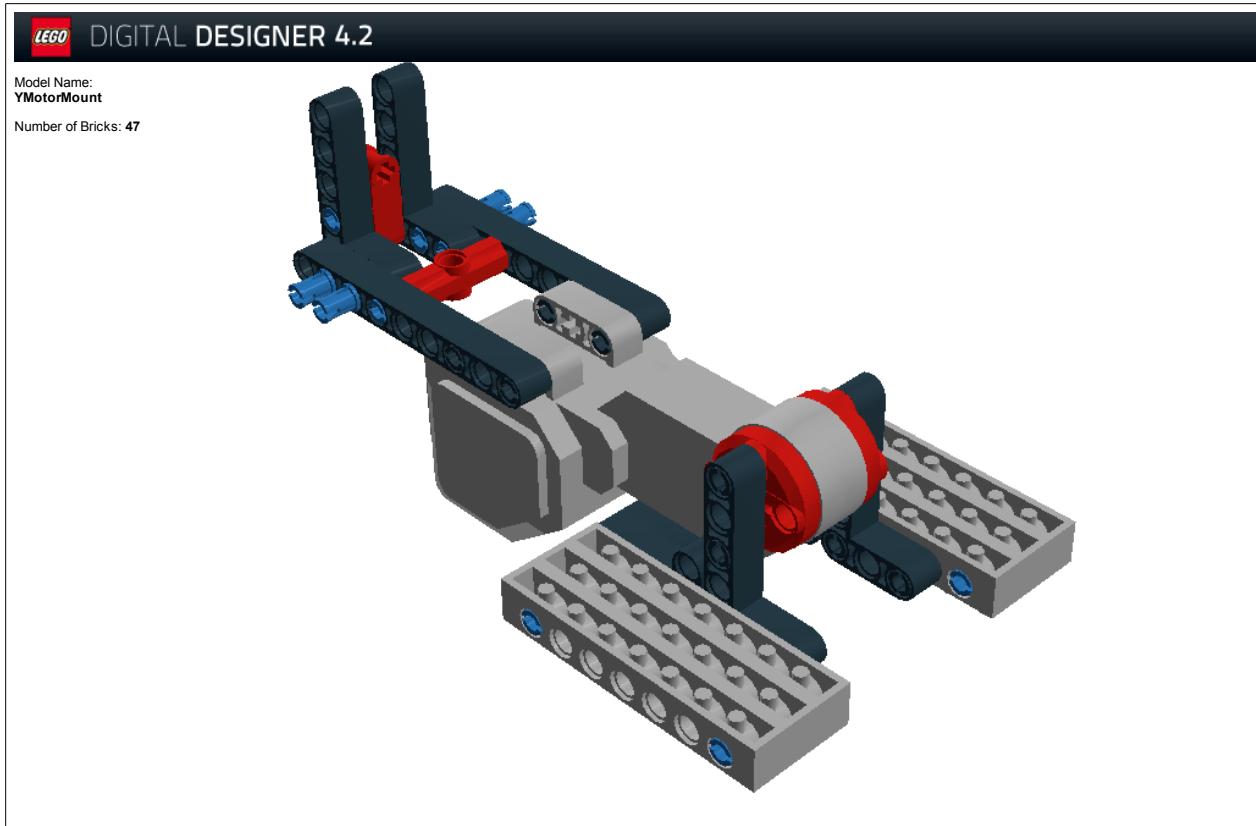


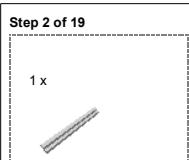
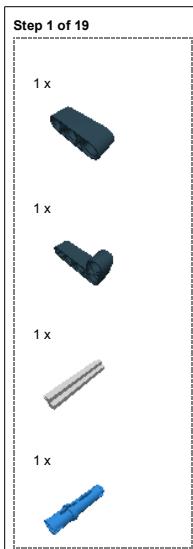
3 x

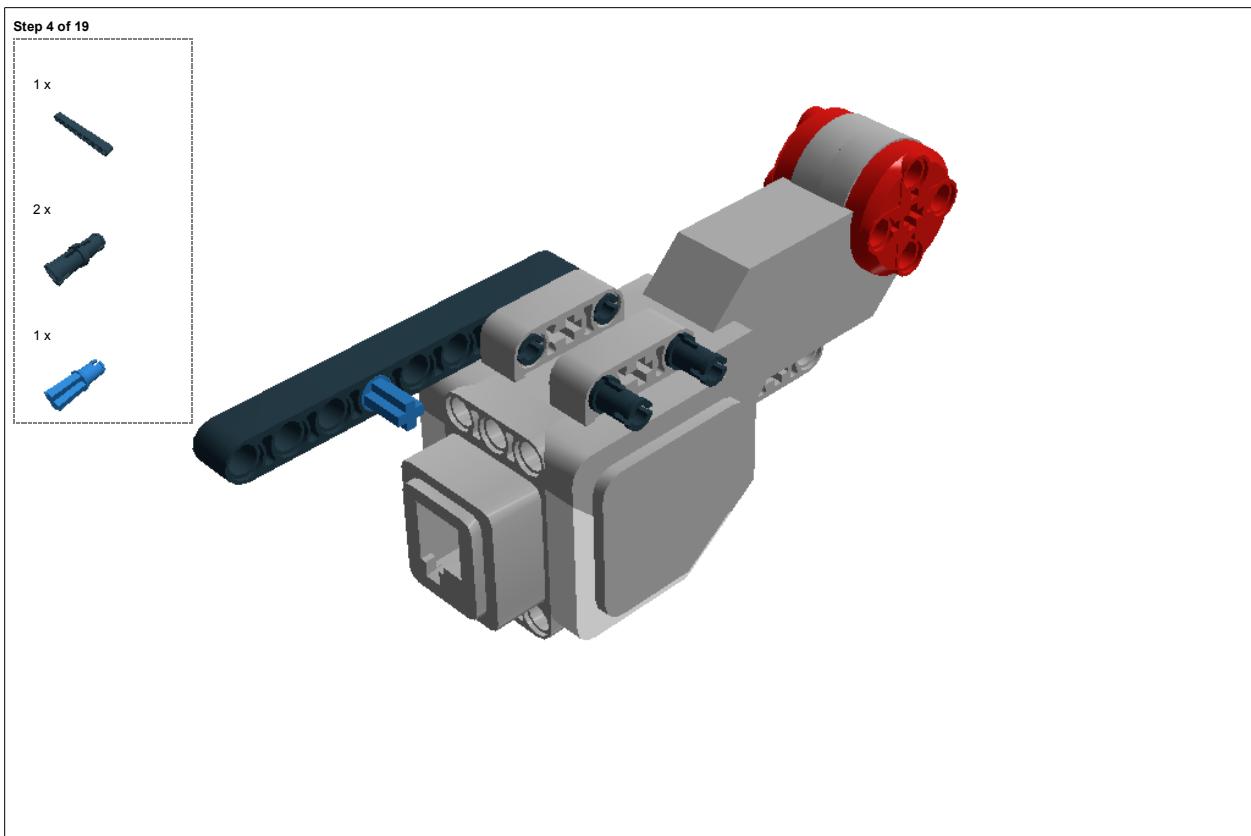
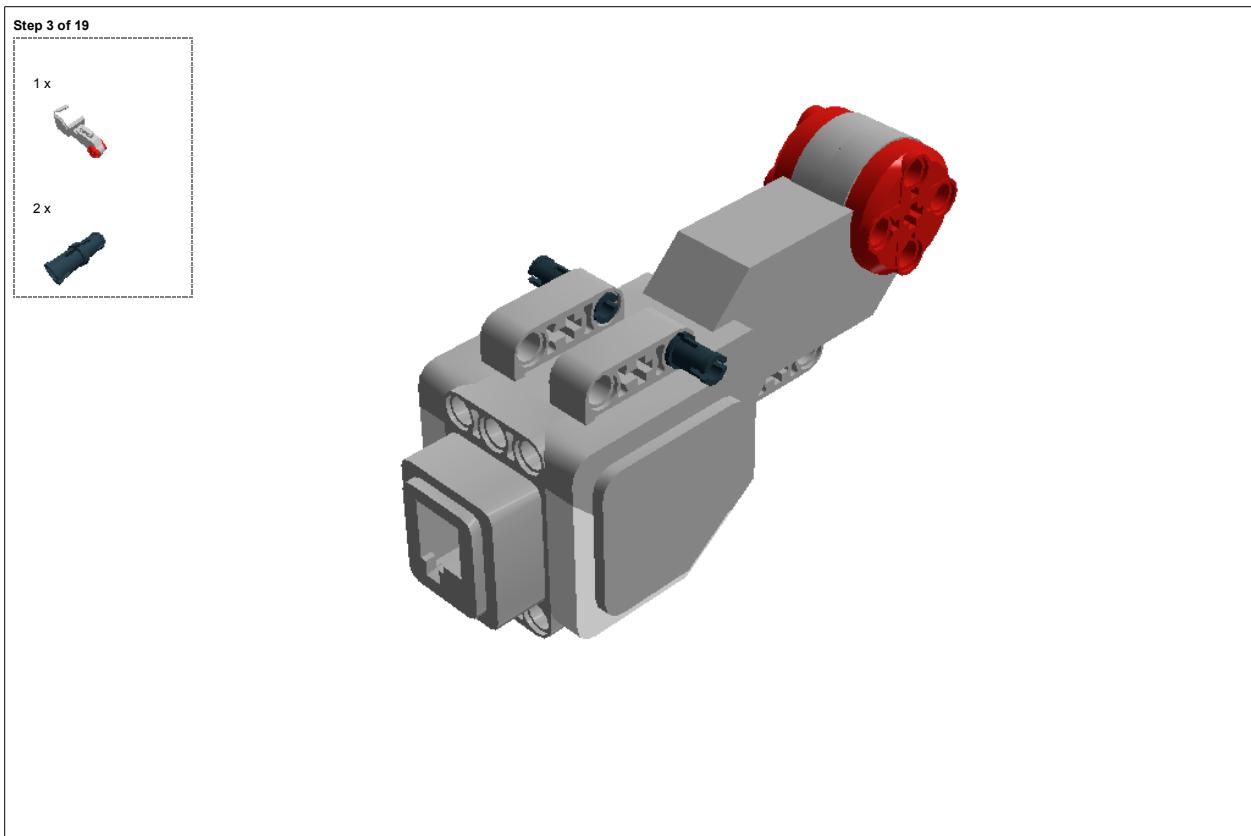


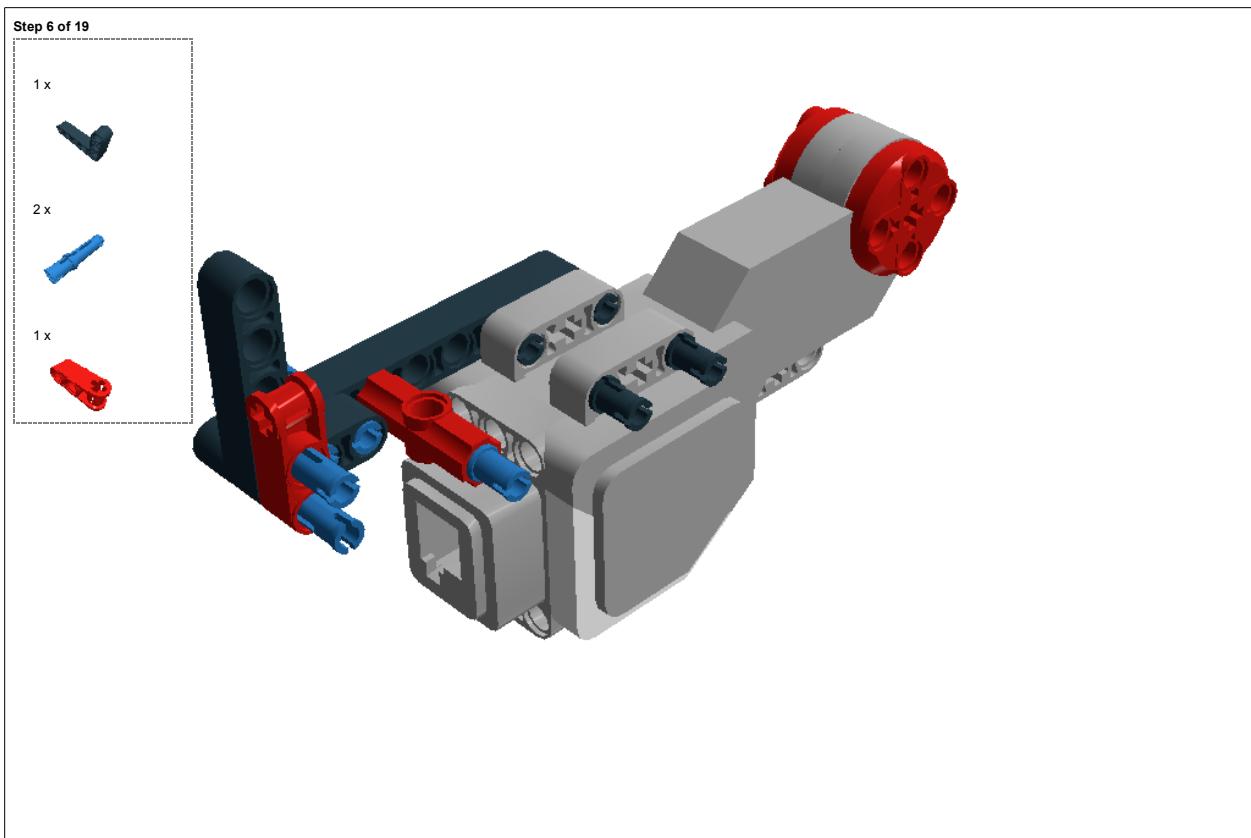
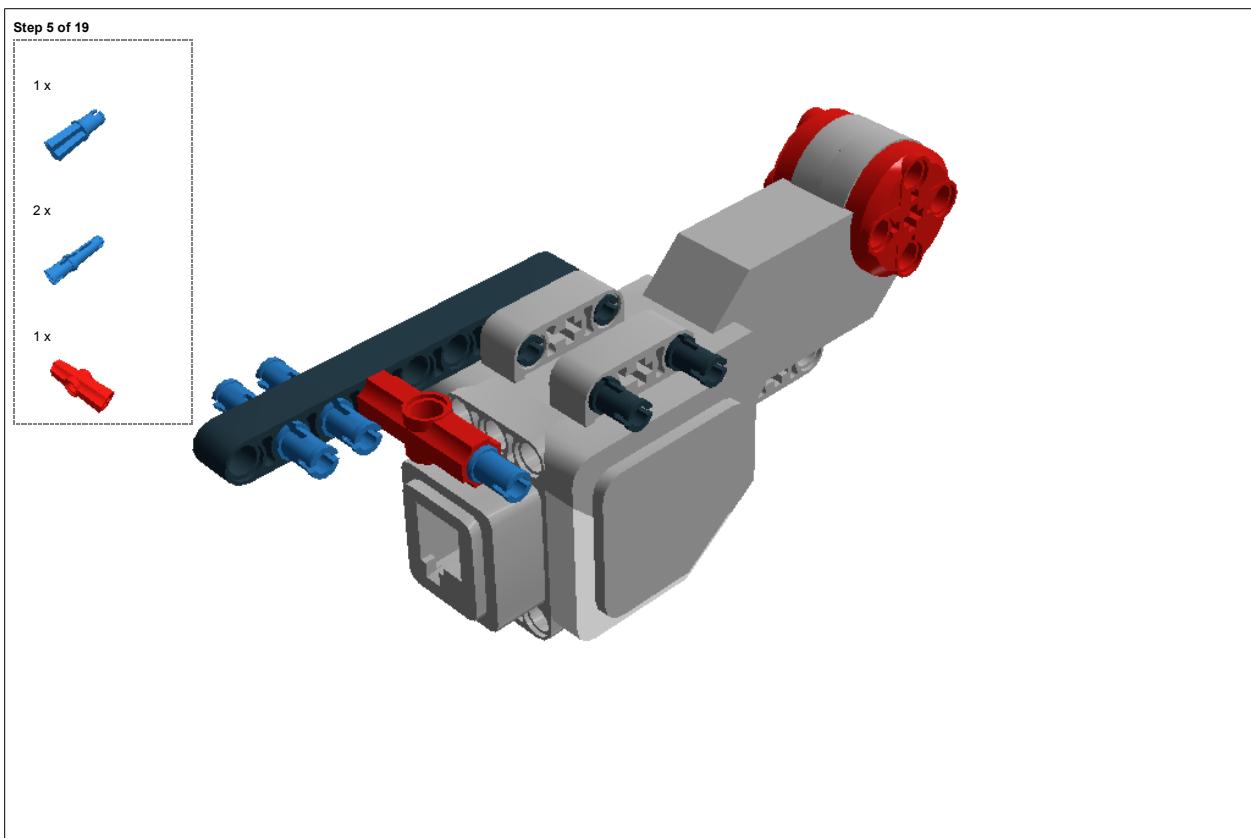


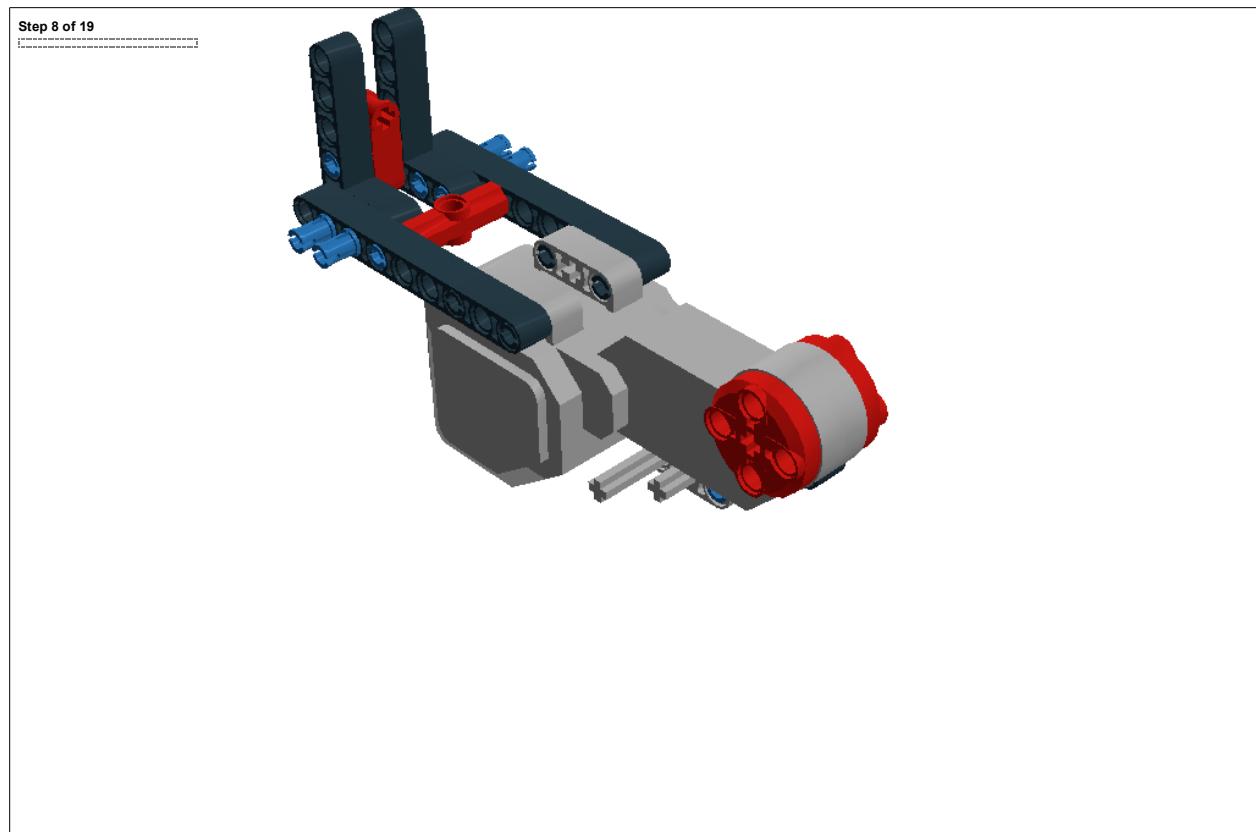
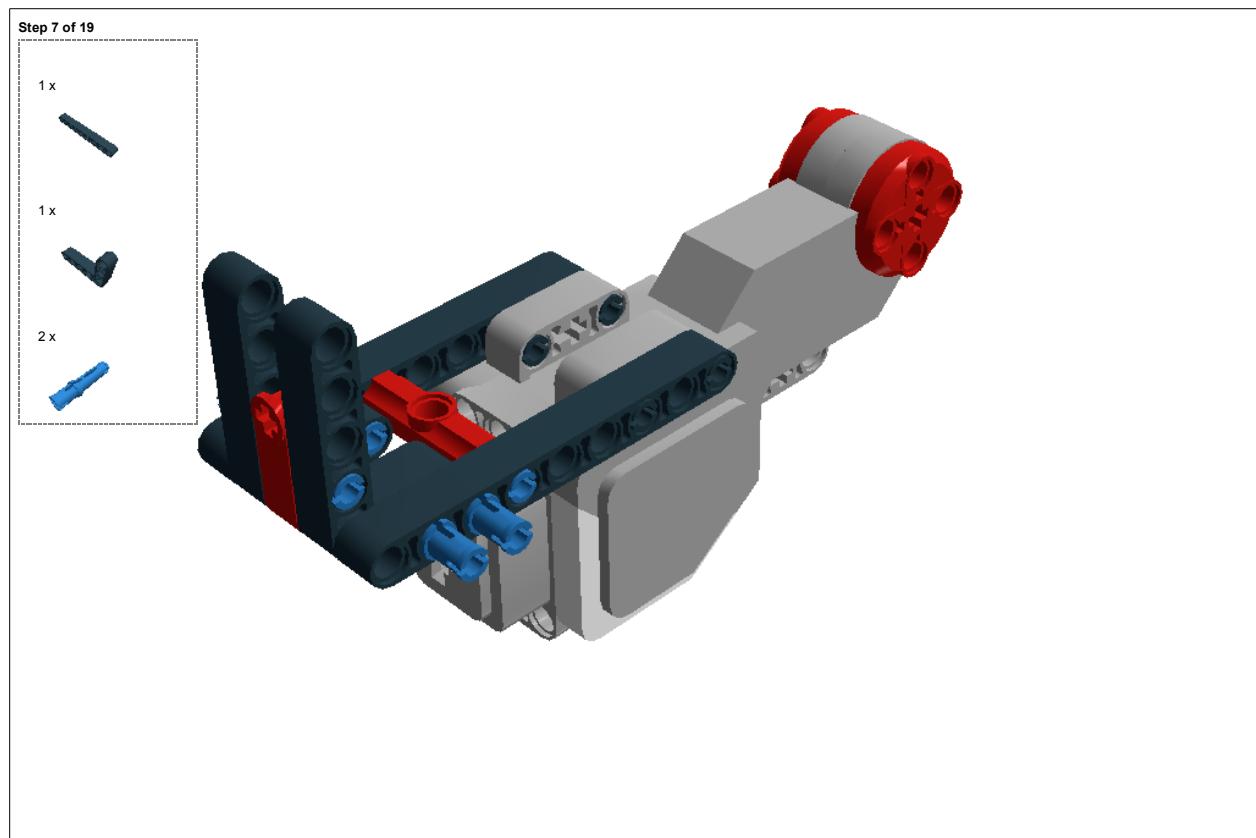
C. Building the y motor mount

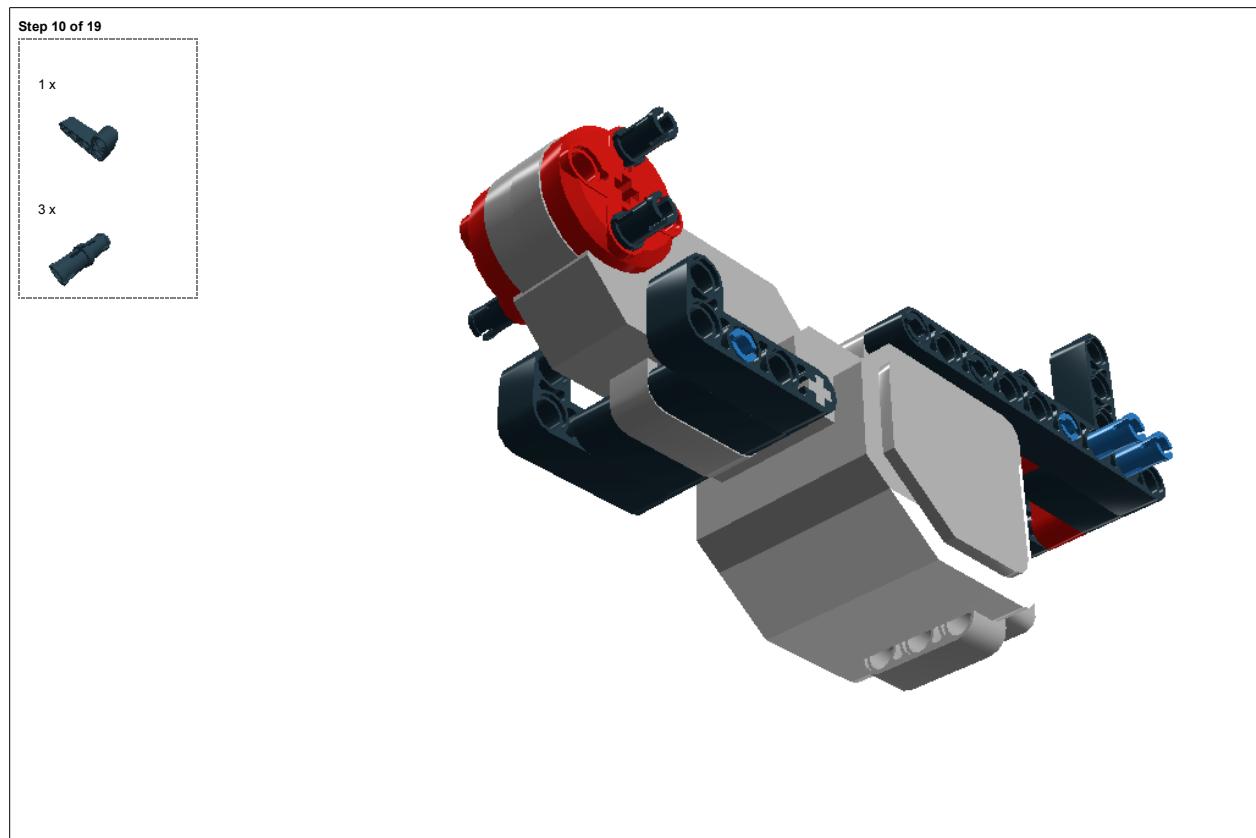
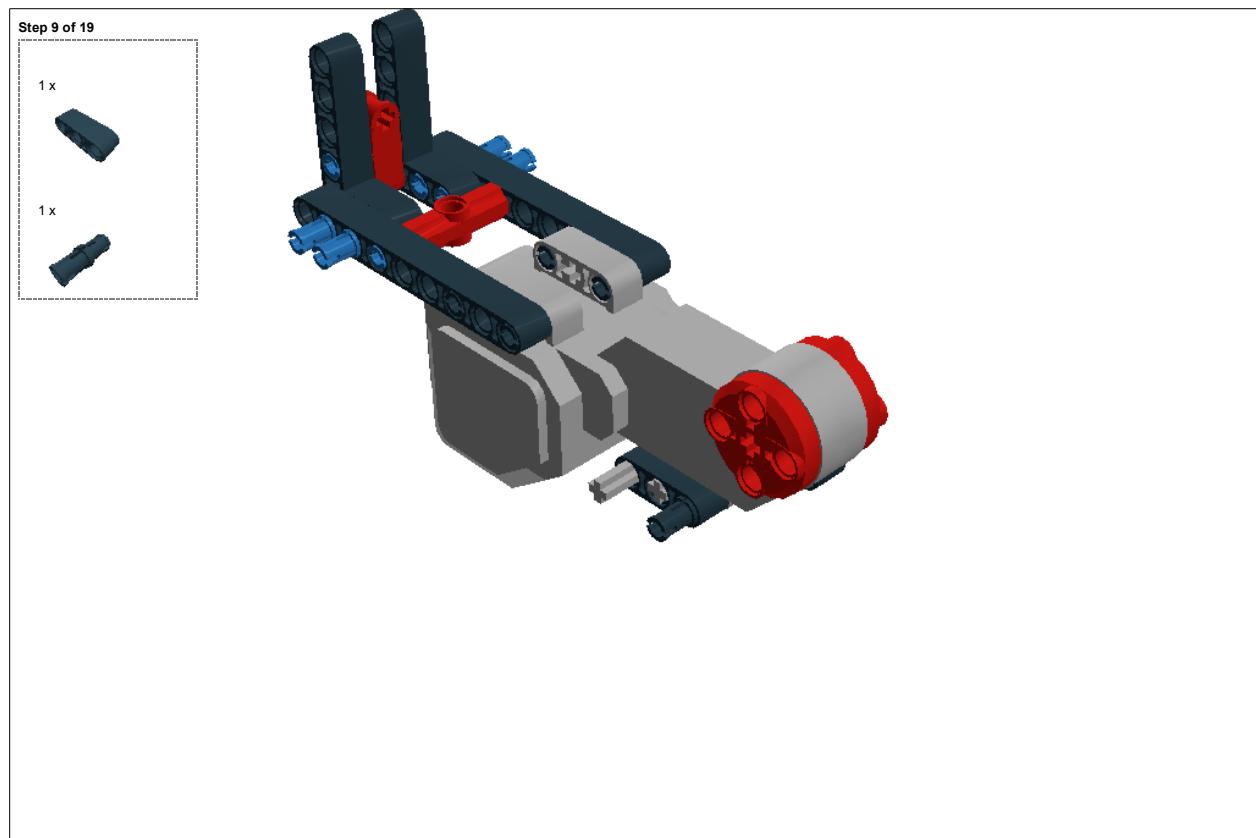


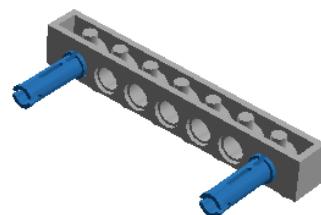
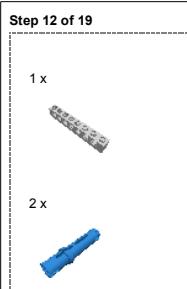
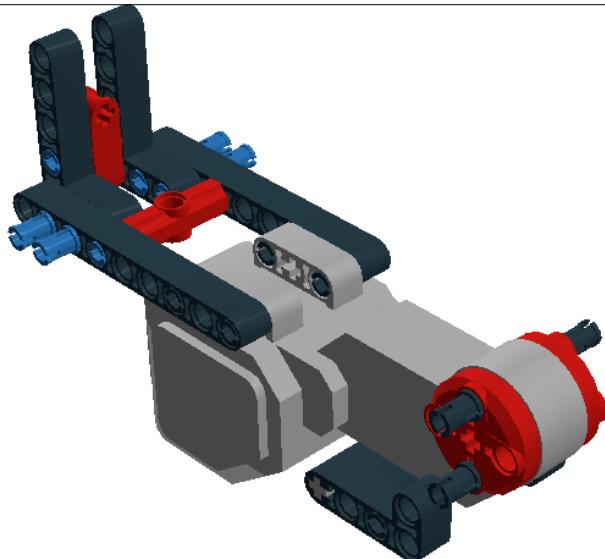
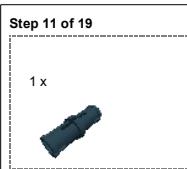










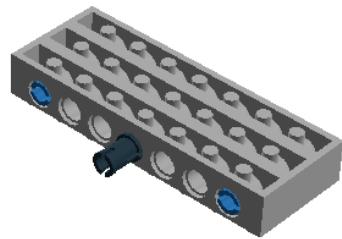


Step 13 of 19

2 x



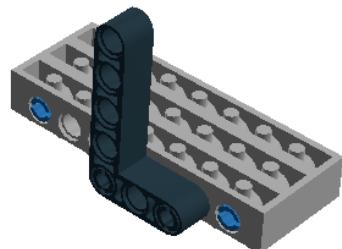
1 x

**Step 14 of 19**

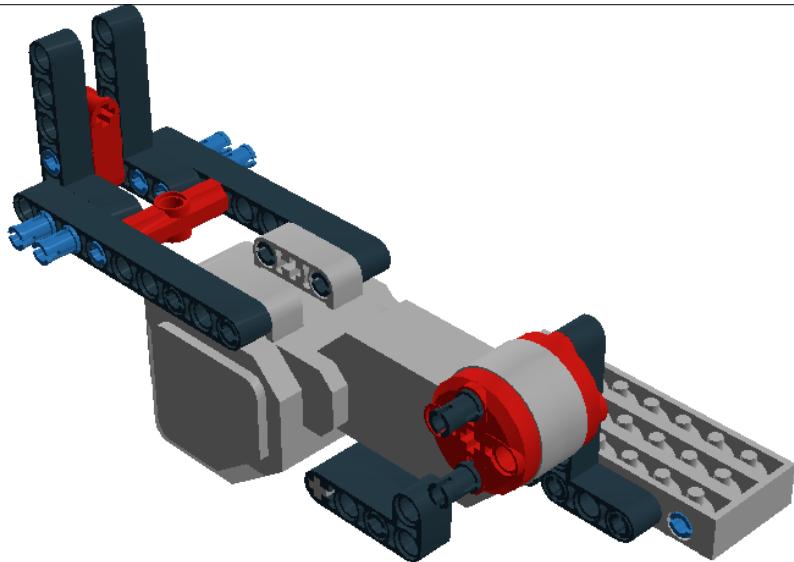
1 x



1 x



Step 15 of 19

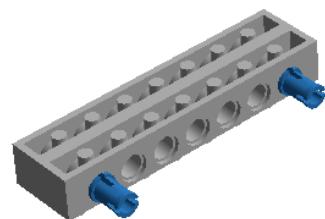


Step 16 of 19

2 x



2 x

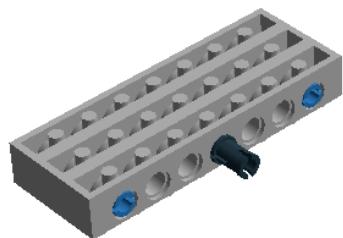


Step 17 of 19

1 x



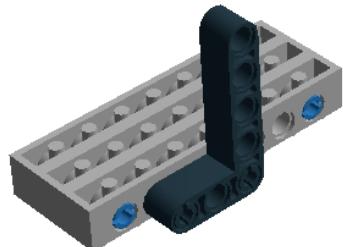
1 x

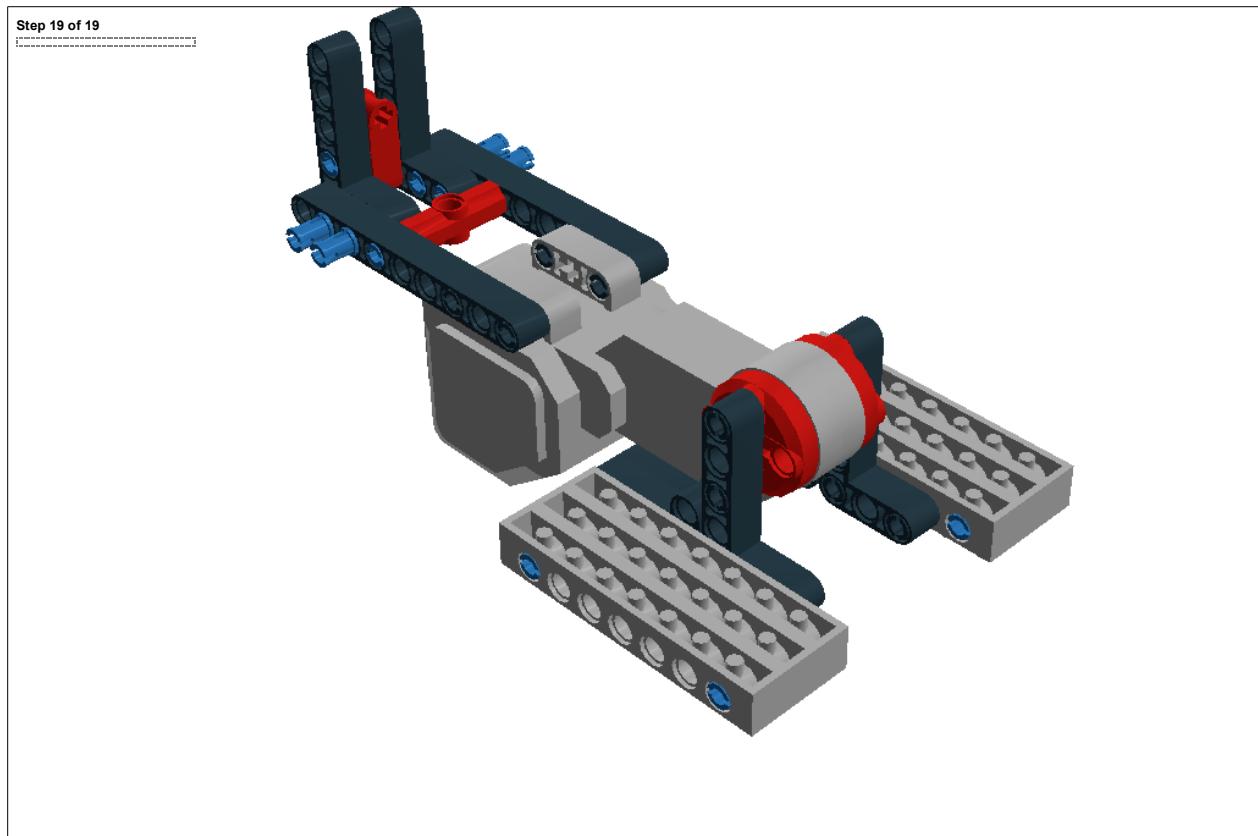
**Step 18 of 19**

1 x

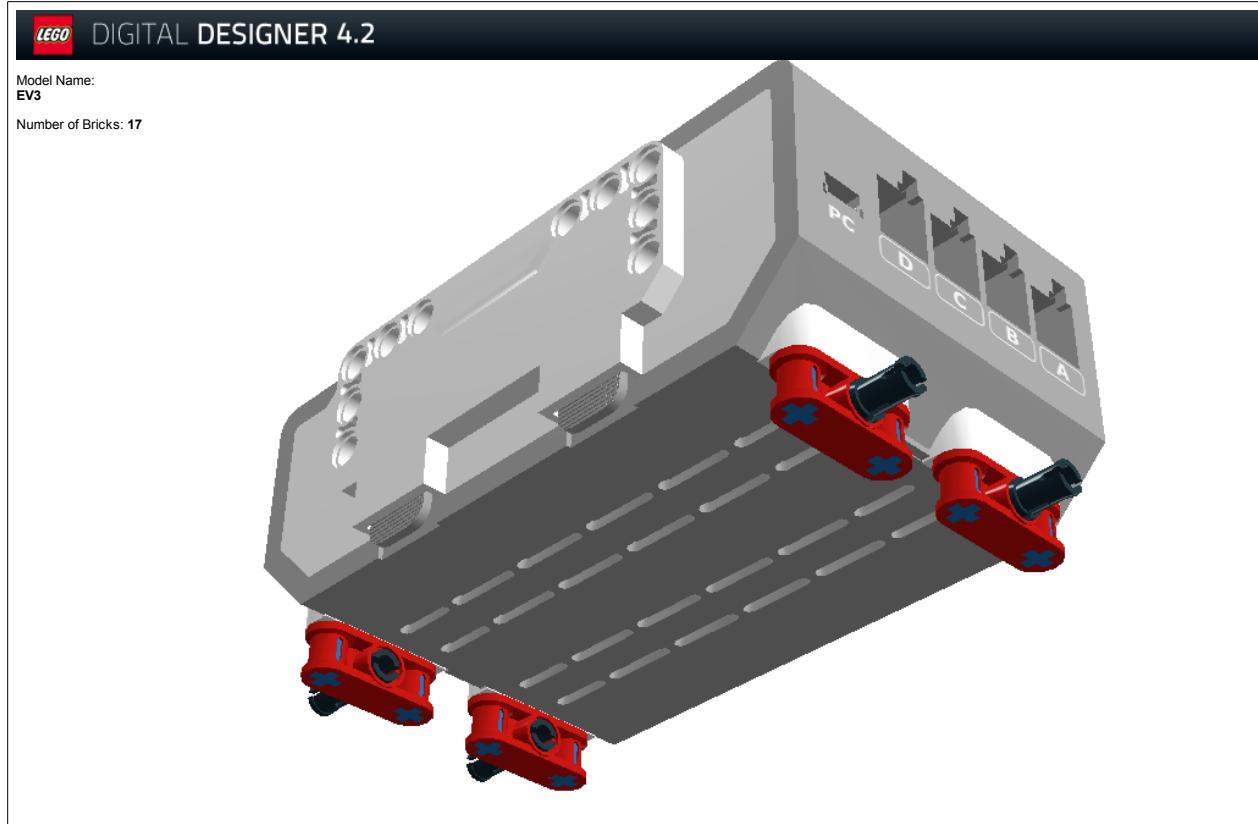


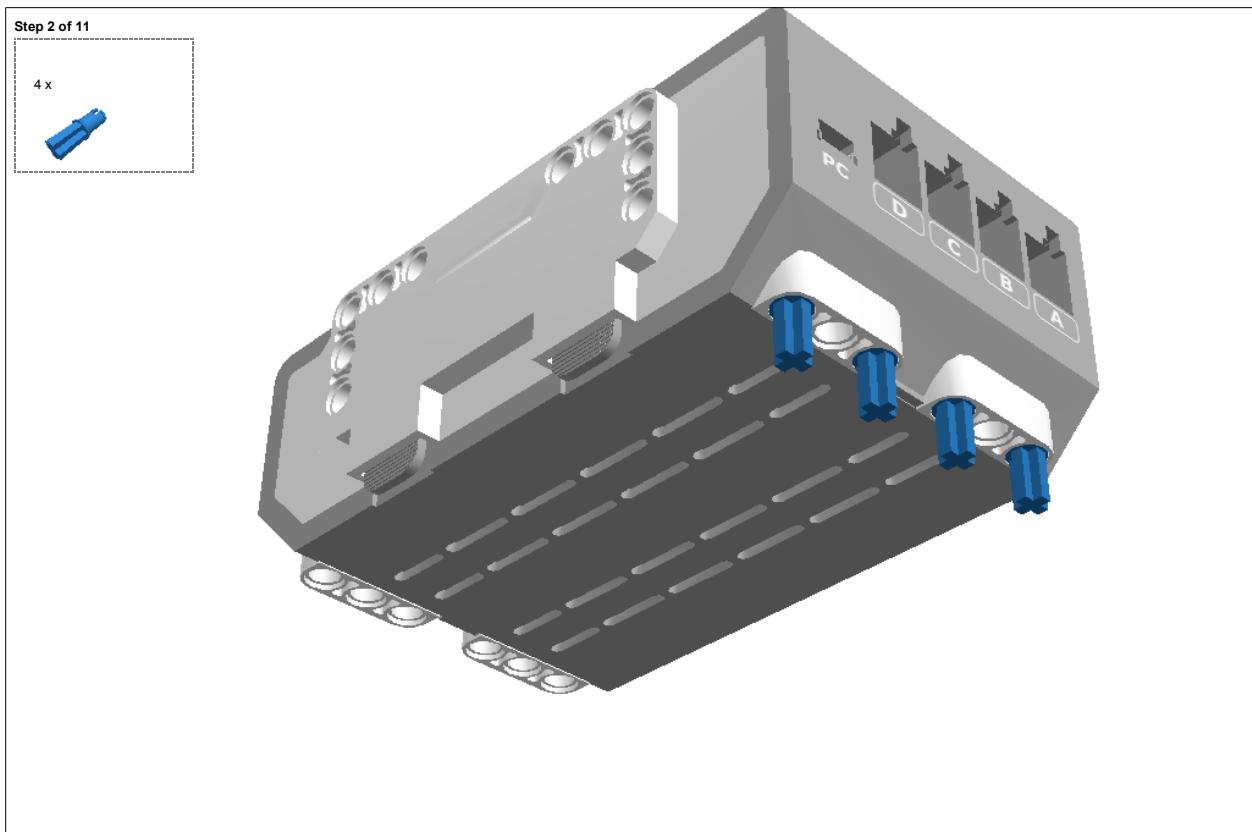
1 x

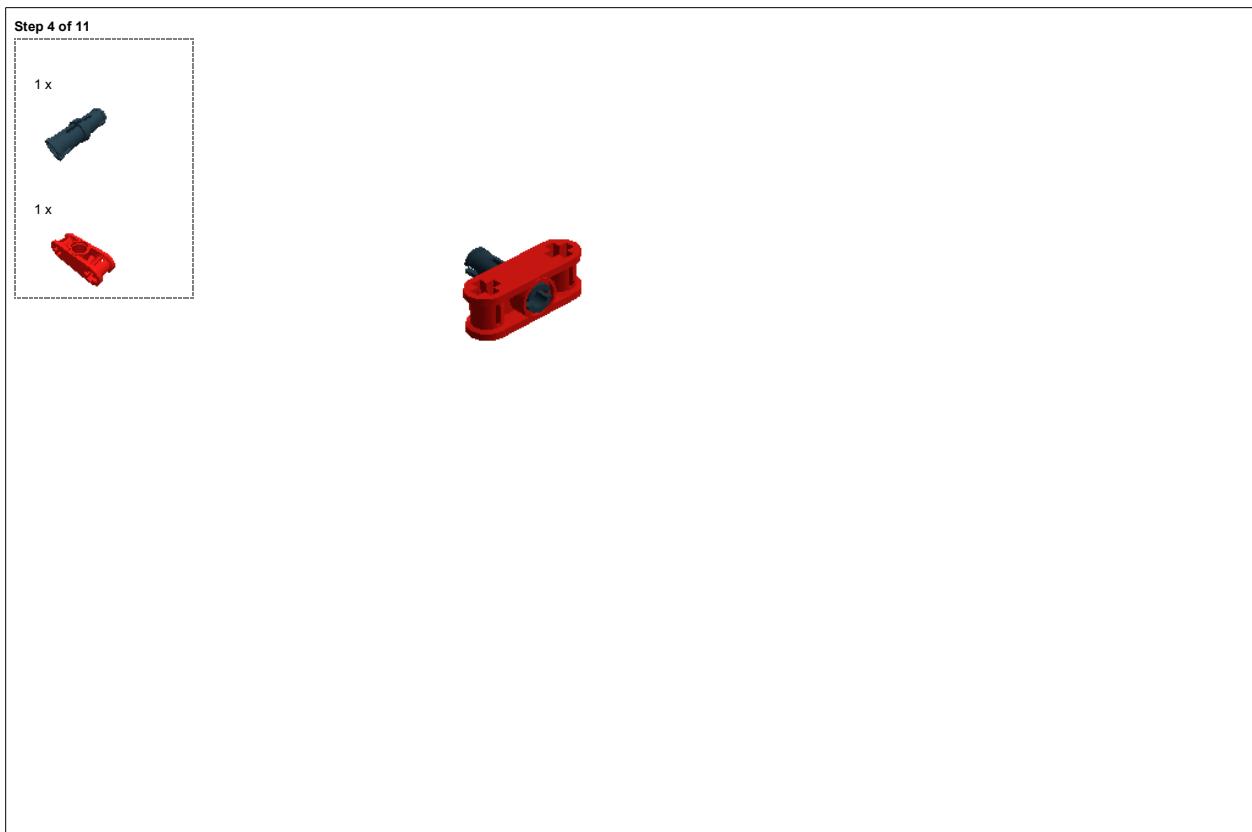
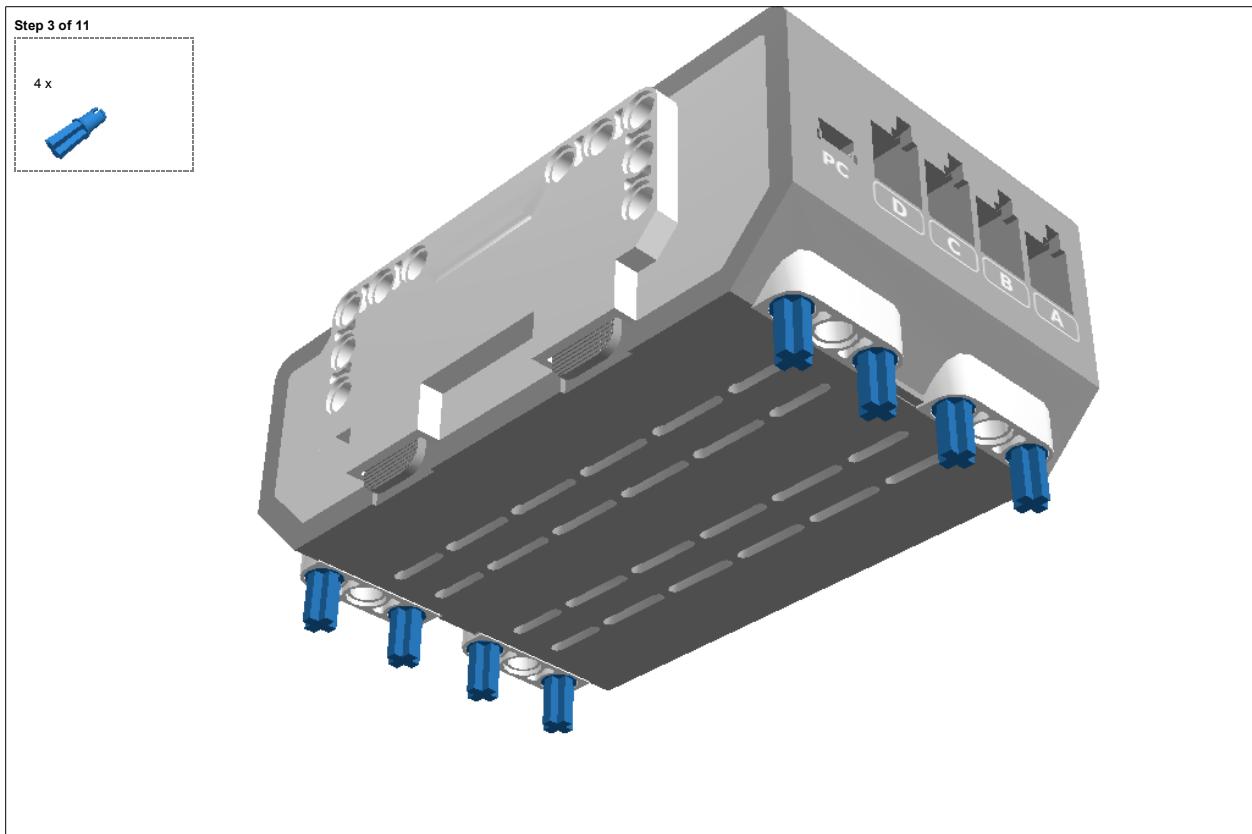


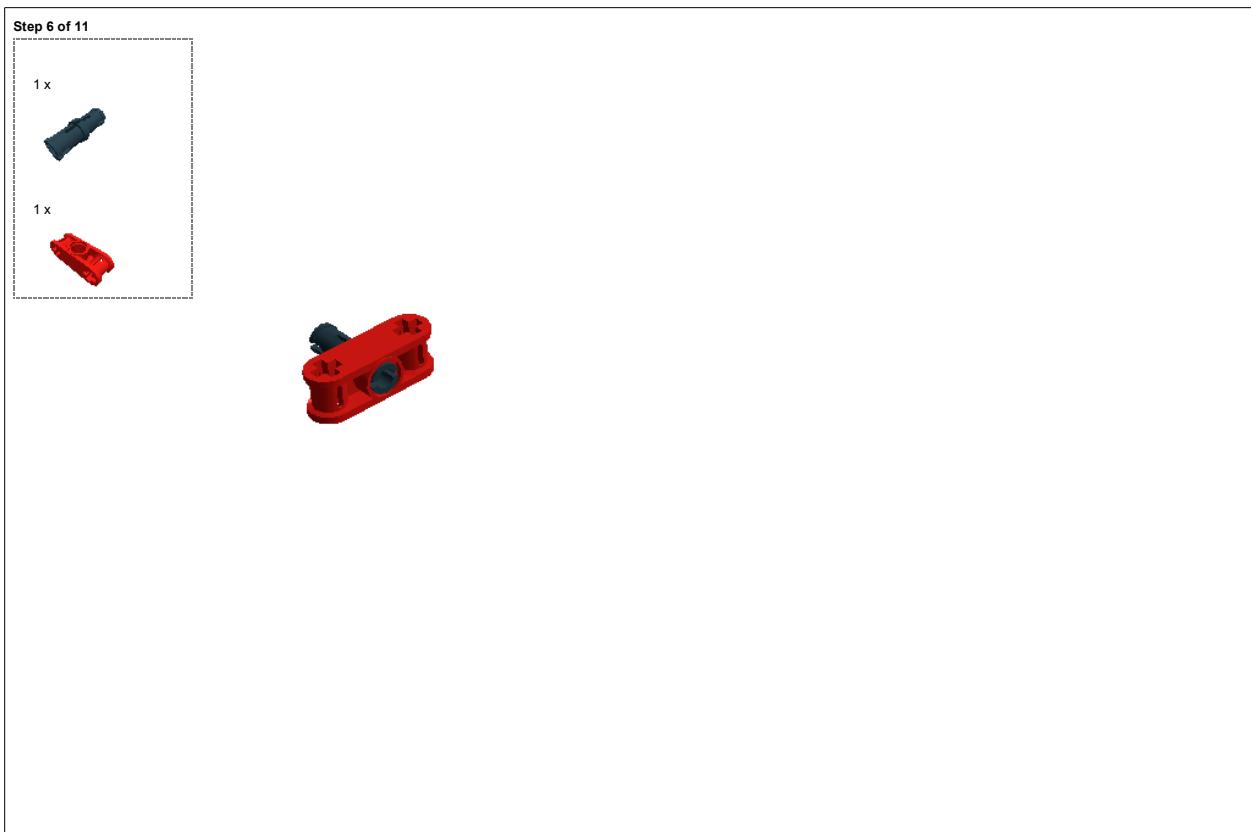
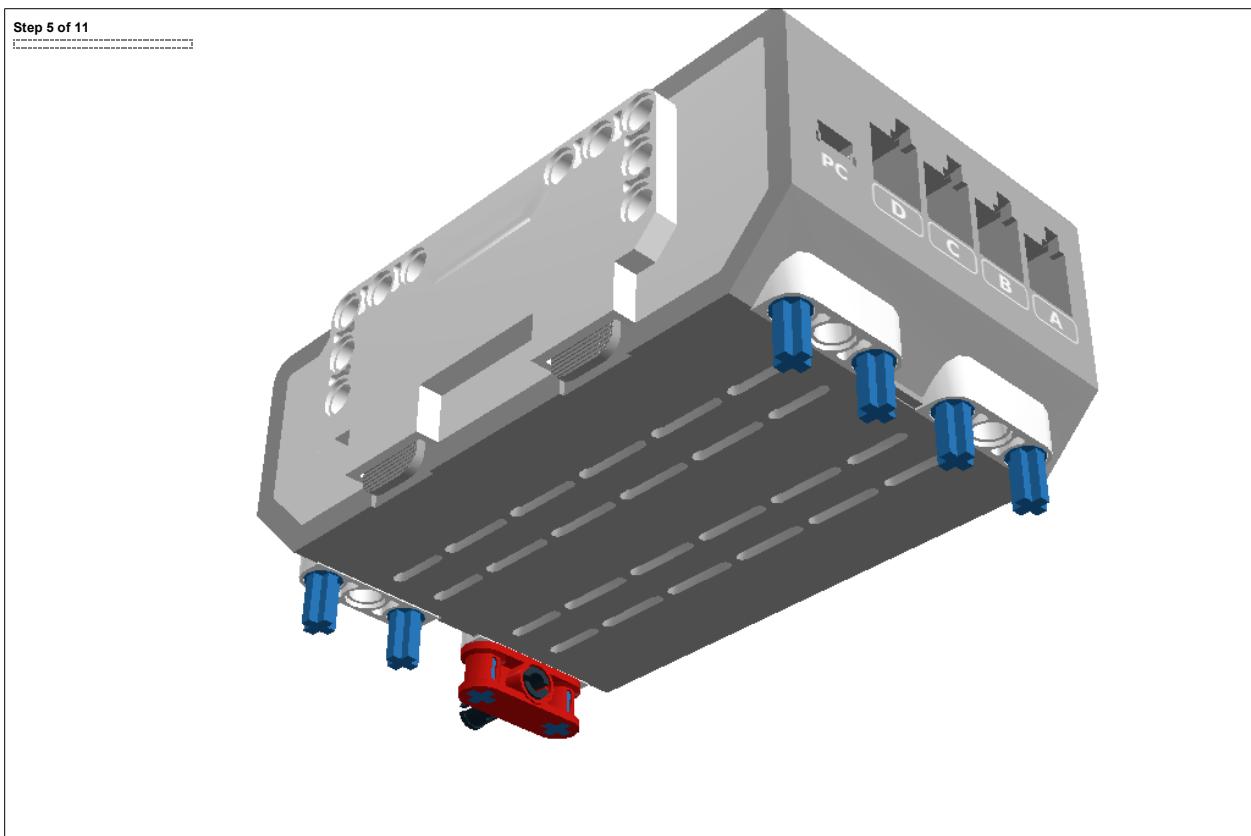


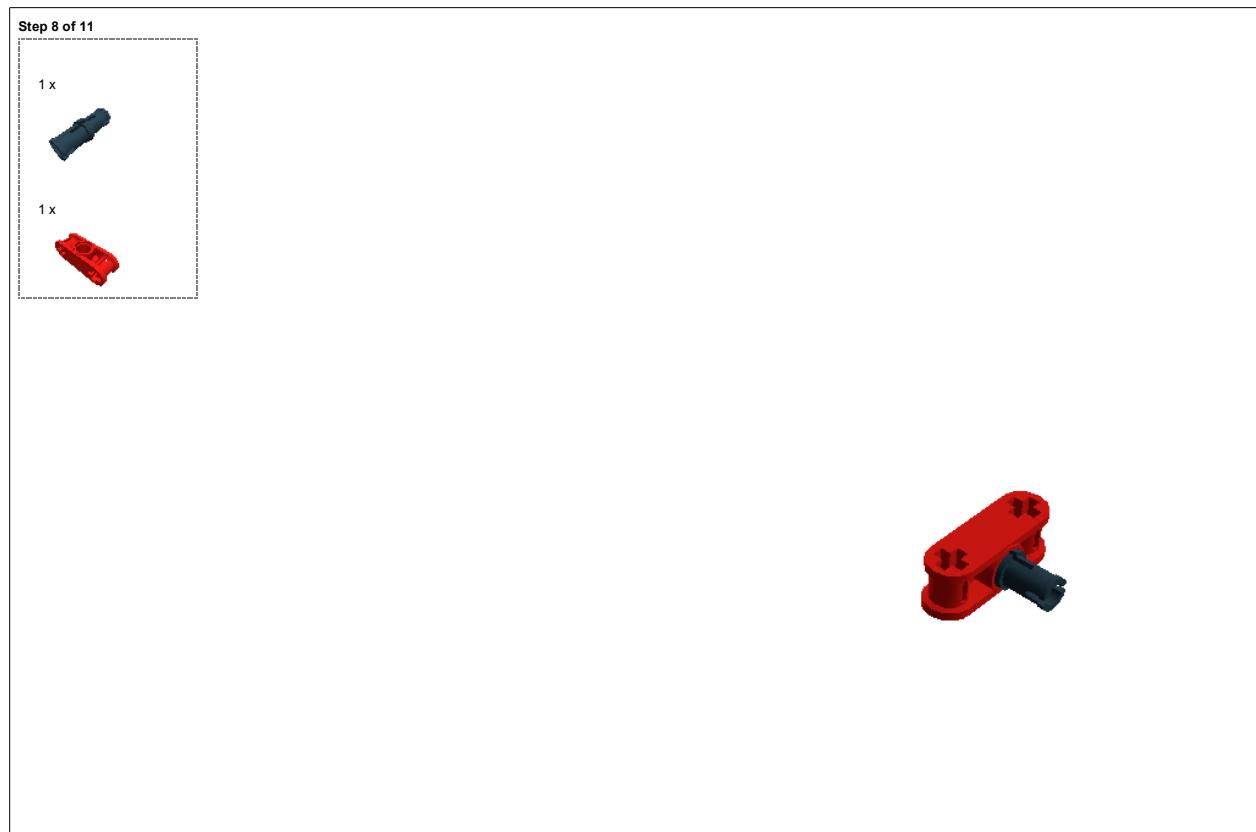
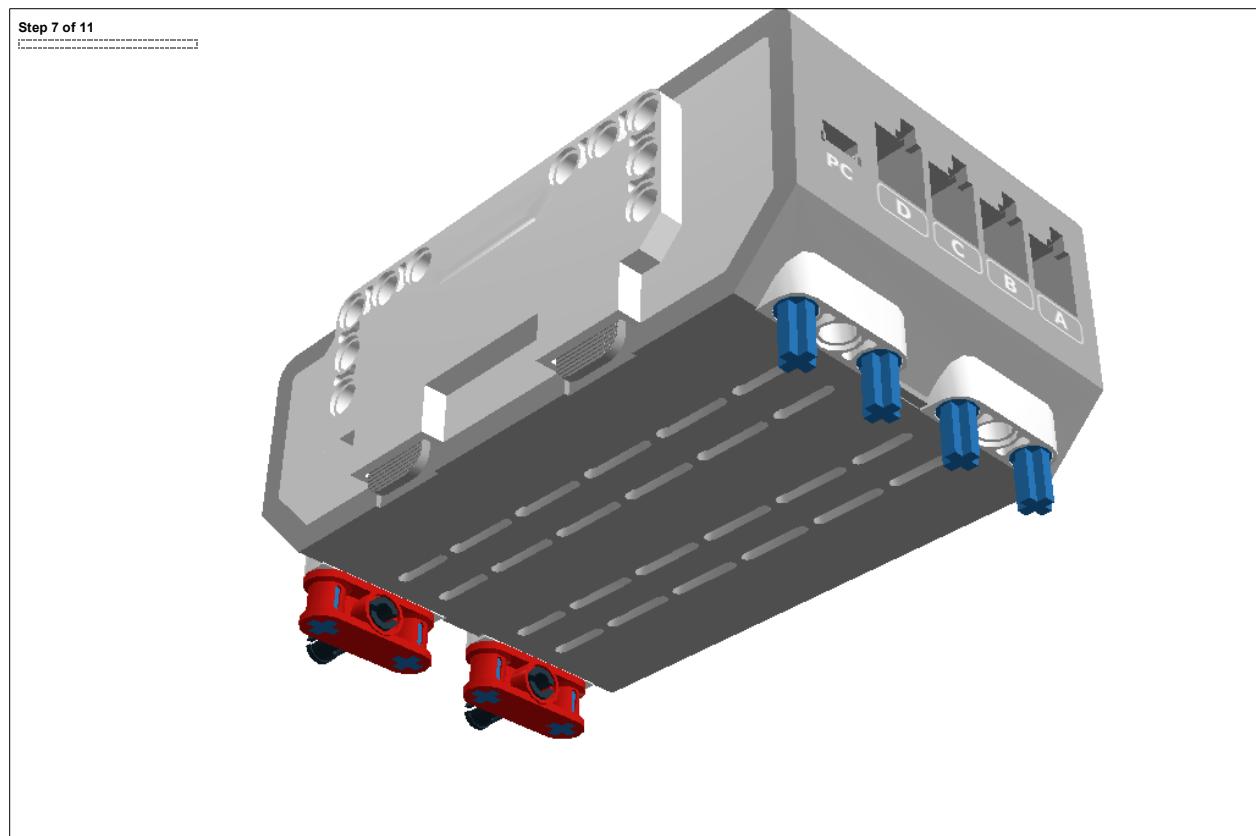
D. Readying the EV3

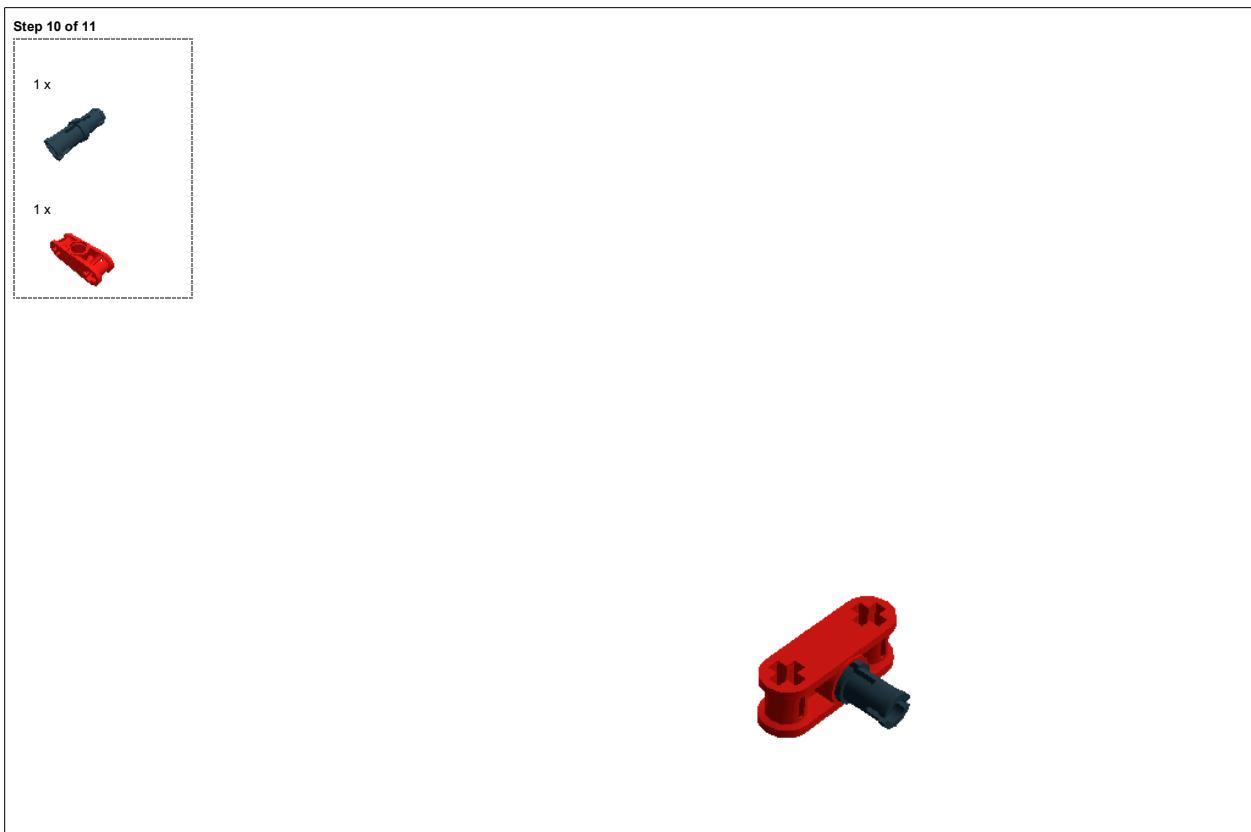
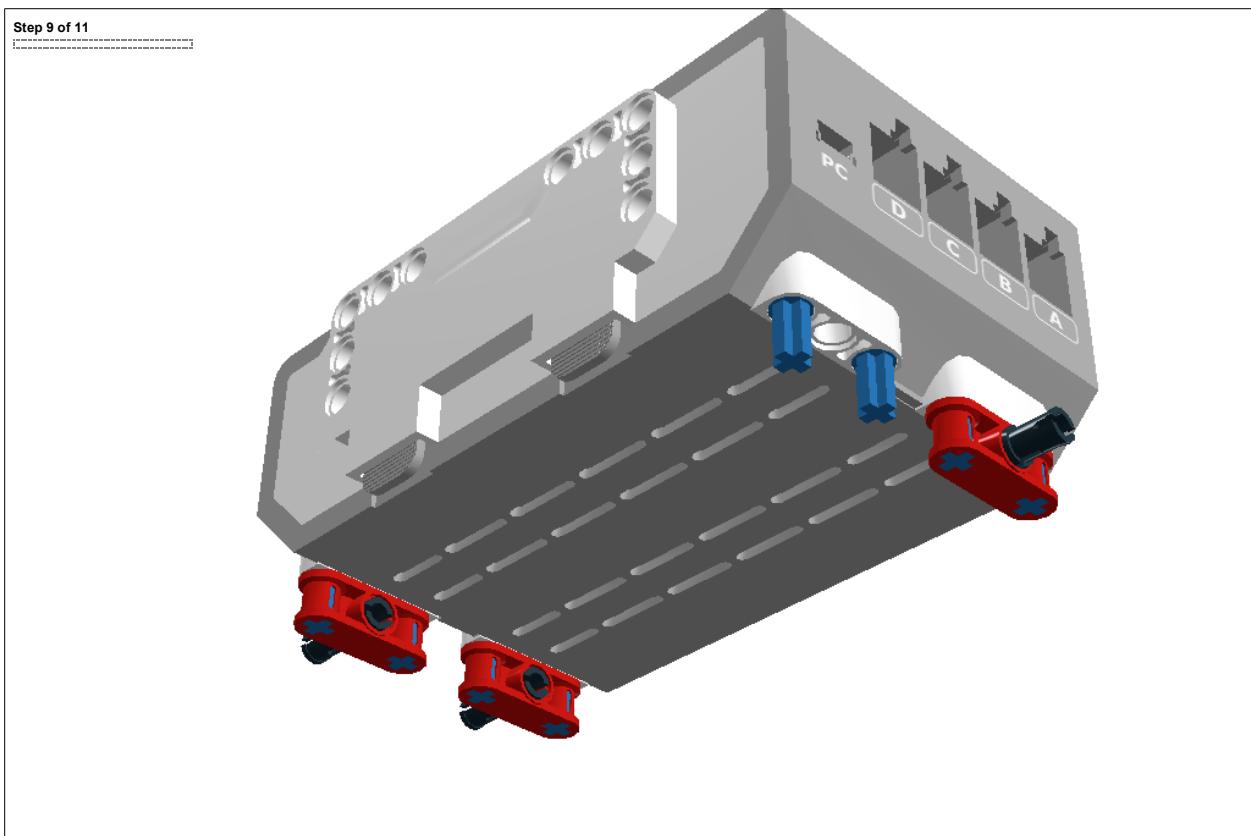


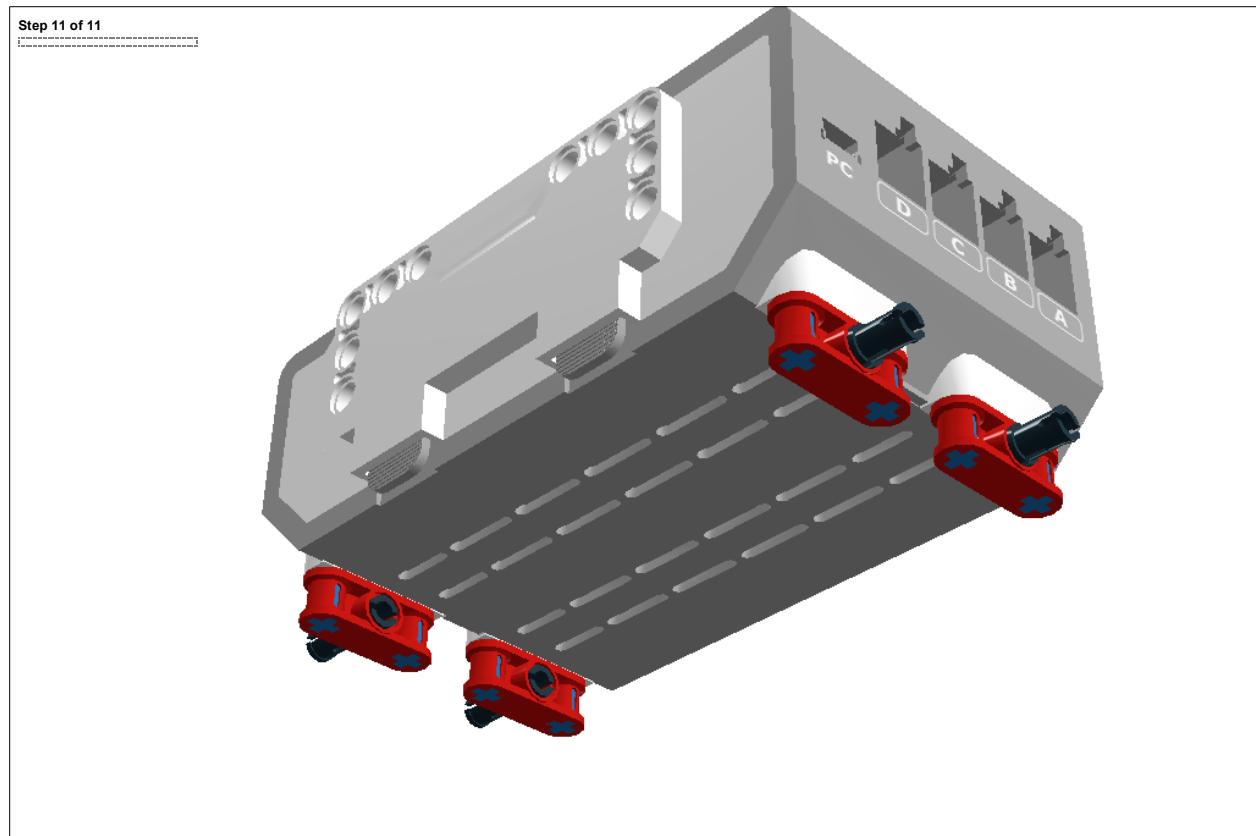












GLOSSARY

EV3

As of 2014 the Lego Mindstorms EV3 is the latest Mindstorms robot building kit manufactured by Lego.

REFERENCES

- [1] Zoltek, *What is Carbon Fiber?* [Online]. Available: <http://www.zoltek.com/carbonfiber/>
- [2] Ayman El-Fatatty, *Inertial Measurement Units – IMU* [Online]. Available: <http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA425327>