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LEGO® MINDSTORMS® NXT

Mars Base Command

FOUR ROBOT CHALLENGES TO TEST YOUR BUILDING AND PROGRAMMING SKILLS USING THE LEGO EDUCATION MINDSTORMS RESOURCE SET

James Floyd Kelly
and Christopher Smith

LEGO® MINDSTORMS® NXT

Mars Base Command

James Floyd Kelly
Christopher Smith

Apress®

LEGO® MINDSTORM® NXT: Mars Base Command

ISBN-13 (pbk): 978-1-4302-3804-1

ISBN-13 (electronic): 978-1-4302-3085-8

President and Publisher: Paul Manning
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Distributed to the book trade worldwide by Springer Science+Business Media New York, 233 Spring Street, 6th Floor, New York, NY 10013. Phone 1-800-SPRINGER, fax (201) 348-4505, e-mail `orders-ny@springer-sbm.com`, or visit `www.springeronline.com`.

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LEGO® MIND

For Decker and Sawyer – Life is fun, and you boys make mine even better.

–JFK

Contents at a Glance

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About the Authors

James Floyd Kelly is a writer from Atlanta, Georgia. He has degrees in English (University of West Florida, Pensacola, FL) and Industrial Engineering (Florida State University, Tallahassee, FL) and has found writing about technology to be the perfect job. James has written books on CNC machines and 3D printers, LEGO robotics, Open Source software, tablets, and much more. He also blogs for `www.GeekDad.com` and `www.Makezine.com` when he's not tinkering in his workshop. James is married to Ashley and has two great little boys who can't wait to get their hands on all the cool, shiny things in their dad's office.

Christopher R. Smith enjoys exploring life's mysteries. His tenure as Senior Quality Assurance Inspector in the Shuttle Avionics Integration Laboratory at NASA's Johnson Space Center in Houston, Texas furnished opportunities where his innovations were recognized by NASA with a prestigious Space Act Award. Toiling over LEGO elements, CAD'ing building instructions, and working for LEGO as a MINDSTORMS Community Partner and Developer, provides the creative exploration he enjoys the most. Chris believes that everything is possible and our world is what we make of it.

About the Technical Reviewer

James J. Trobaugh has a degree in Computer Science and has been working as a software architect for 19 years. He lives in the Atlanta, Georgia area with his family.

He has been involved with FIRST LEGO League since 2004 as a coach for Team Super Awesome, and as a technical judge at LEGO World Festival. He is also the FLL director of the Forsyth Alliance in Forsyth County Georgia.

James started out as a LEGO hobbyist by founding the North Georgia LEGO Train Club in 1998 and has found that LEGO robotics is a natural blending of his LEGO hobby and his day job as a software architect. The added bonus is the joy of getting to share his love of technology not only with his own children but with kids in general.

Acknowledgments

I've written many books on LEGO Mindstorms robotics, and every one of them has its own list of individuals who deserve credit for the book you're holding in your hands.

My two most favorite people at Apress, Jonathan Gennick and Kelly Moritz, deserve a big round of applause. This was a tough book to write, and an even tougher book to finish. Both of them were great with the encouragement and even better when it came to dealing with the slow and difficult process of getting their author to finish up chapters. Their patience and understanding is greatly appreciated.

My technical editor, James Trobaugh, deserves another round of applause. James had to read over my chapters, build the models, test the challenges, and give me feedback on what worked, what didn't work, and what was just plain confusing. He's a true LEGO expert, in every sense, and the book would not have been possible without his involvement.

Next, I have Christopher Smith, my good friend from Texas, to thank for creating the great CAD images used in the building instruction chapters. I submitted photos to Chris of my models and crossed my fingers that he could make sense of my designs. He never failed to impress me, and the quality and look of the building instructions are top notch and beyond anything I could have hoped to do myself.

Finally, I want to thank my wife, Ashley. She has always supported my writing career, and she always manages to deal with her stressed out husband when deadlines loom (or pass).

Other folks have had a hand in making this book a reality, and you can find a complete list of their names and duties a few pages earlier in the book. Thanks to all of the Apress team for their roles in getting this book done and in your hands.

James Floyd Kelly

Introduction

Mars.

It's the next place that man will set foot on for the first time, hopefully around 2030. For now, a manned mission is still far away. But we will get there. And when we do, I feel certain that joining those astronauts for the ride will be a number of robotic companions.

Countless science fiction stories and movies take place on Mars, and the book you're holding is no exception. In this book, you'll find that Mars is a busy place, full of bases and people with jobs to do. It's a busy place, and it's a dangerous place, with robots taking on many hazardous duties and making life a little safer for humans.

But there are many things that are beyond the control of humans and robots, and these are the challenges that the members of Mars Base Command will face during their tour of duty on the red planet. Life is unpredictable on Earth, on the Moon, and most definitely on Mars. That's why Mars Base Command is looking for the best, brightest, and most creative individuals – those people who can think on their feet, make quick and logical decisions and, above all else, solve problems.

Are you up to the challenges that Mars will put before you? Are you willing to dive in, explore, and find the answers necessary to keep the bases on Mars functioning smoothly? Can you work together with your fellow specialists to examine, build, test, program, diagnose, and repair any challenge that comes your way?

Glad to hear it.

Welcome to Mars Base Command, Specialist. I've got a few special jobs in store for you.

Commander James Floyd Kelly
Mars Base Command

Who This Book Is For

This is a book of challenges. More specifically, these are challenges for a LEGO Mindstorms robot. The four challenges use parts found in a LEGO Educaiton Resource Set (Set # 9648). These challenges were designed using this Resource Set so as to avoid using parts from a LEGO Mindstorms robotics kit. Teams or individuals will build the various models used in the challenges and then build and program a robot to interact with the models.

While the book was written to address specific requests from teachers for challenges that would use the Resource Set and provide classroom activities, the challenges aren't just for the classroom. Individuals, after-school programs, and other organizations (such as scouting or home-school networks) will also find a number of activities here to engage kids of all ages with hours of hands-on opportunities.

How This Book Is Structured

The four challenges are broken up into small groupings of chapters.

The first chapter of each challenge is a fictional short story. This story introduces a problem that the Mars base personnel have encountered and provides clues or suggestions for how a robot might be used to solve the problem.

Additional chapters after each fiction story will provide the building instructions for the various models used to simulate the challenge encountered. Two to three chapters ared used to break up the building instructions into smaller, more manageable components. Readers will also find these chapters offer up suggestions for how to build and test robots to interact with the models.

The final chapter for each challenge will provide the rules and the suggested placement of the models for simulating the challenge. A point system is provided for scoring a competition and providing feedback to individuals or teams related to the success (or failure) of solving a particular challenge.

This pattern of short story, building instructions, rules and challenge setup continues throughout the book for four separate challenges.

Prerequisites

Experience with a LEGO Mindstorms robotics kit is definitely preferable, but these challenges can also be used as incentive to encourage students to dive deeper into the building and programming of LEGO robots.

Building and programming solutions for the challenges are not provided, so it’s up to the individual or team members to increase their knowledge of the LEGO Mindstorms robotics kit in order to successfully complete the challenges.

CHAPTER 1

Plan B

We Fix It

Mars Base Alpha, Section D, Control Center
August 20, 2062 at 10:26 PM (Greenwich Mean Time)

"Would someone please turn off that alarm?" asked Lieutenant Raleigh. "I can't concentrate!"

The red flashing security lights on the ceiling were annoying, but it was the up-and-down wail of the alarm that was truly overwhelming. Base Alpha was on full alert, but only two of the five individuals seated in Section D were aware of the true extent of the danger facing the facility. Commander Evans was away for two days on an inspection of Mars Base Beta, which left Lieutenant Raleigh in command.

Sitting at her console, Kristie Raleigh was attempting to decipher the data scrolling down the flexi-screens. *These numbers just aren't making sense*, she thought. *According to these readings, the backup generators haven't kicked in yet.*

Four feet to Kristie's left, at another console, Engineering Specialist Brian Platt leaned over and quickly typed a command on his laser-projected virtual keyboard. The alarm in the room stopped, but Kristie could still hear it echoing from other parts of the base.

"Thank you," she said. "What's the status of the power consumption for Sections A through E?"

Emergency lighting in the room was running, a definite sign that the batteries were still operational.

But for how long? Kristie wondered. Twenty-five minutes earlier, a small meteor shower had brightened the sky. Meteor showers were nothing unusual, but today, a few larger fragments that didn't burn up entering the Martian atmosphere impacted with the power conduits connecting the fusion energy facility to Alpha. For the last fifteen minutes, her five-person team had struggled to reconnect the control systems that would give access to the fusion power station over 300 kilometers from Alpha.

With the base's primary power out, backup generators would normally kick in. But not today. Something was wrong, and the power supply figures were simply dwindling too fast.

"Power consumption is at 10 gigawatts per hour," replied Brian. He typed another command and leaned back in his chair, shaking his head. "We've got less than two hours of reserve battery power, Kristie."

Kristie paused and counted to five. It was an old stress-relief trick she learned in college, but back then, she would count to ten. Right now, she could only spare five seconds.

"OK, we've got to figure out why we're not generating backup power. Once we figure that out, we fix it. It's as simple as that," she replied.

"Video systems should still be operational, even on backup power, but they're not. I can only guess that those systems may have been damaged, too. There were numerous impacts between the fusion plant and here," said Brian.

"Someone's got to do a visual inspection," Kristie responded. "Who do we have over in PLS?"

Brian entered a quick command and scanned the screen. "The duty roster shows Davis and Rhodes as the response team for Power and Life Support."

"Get them on the radio," replied Kristie. "Let's just hope it's not as bad as the numbers are telling us."

It's Bad

Mars Base Alpha, Section E, Power and Life Support
August 20, 2062 at 10:42 PM (Greenwich Mean Time)

Kristie watched the clock on her console and tapped her fingers nervously. "Five minutes. They should have been able to get a visual for us by now," she said. "We've got to…"

The radio squawked, startling her. "Kristie, are you there?" It was the voice of Ian Davis, one of Alpha's power system engineers.

Kristie pressed the Send button on her console. "I'm here, Ian. Tell me something good," she said, releasing the button.

Another squawk issued from the speakers. "No can do, Kristie. It's bad. The computer systems regulating the backup generators took a direct hit. The systems are automated, so no one was in there, but it's going to take a day or more to get them back online."

Kristie heard Brian take a deep breath at the news. He rolled his chair closer to Kristie and pressed the Send button. "Ian, all we need are two, maybe three, generators back online—just enough to provide steady power for repairs. Any chance to get a few of them operational?"

"Sorry. The generators aren't designed to be run without the power redirect the systems provide. It was a bad design, and we'll fix it, but not today."

"Okay, Ian," replied Kristie. "Do what you can. And try to reduce power consumption for Section E. We'll get back to you. Out."

Kristie stood, closed her eyes, and took a deep breath.

"Any ideas?" asked Brian.

"Well, I had an old engineering professor who always said, 'Whenever possible, have a backup plan'," said Kristie.

Brian raised his eyebrows. "I thought our backup generators were our backup plan."

Kristie shook her head. "No. The generators are part of the standard emergency procedures when power is lost. We're going to have to deviate from those procedures a bit, I think."

"And that would involve…?" asked Brian.

"We go to Plan B," replied Kristie. "Let's move."

Will That Thing Even Work?

Mars Base Alpha, Section B, Storage and External Access
August 20, 2062 at 10:58 PM (Greenwich Mean Time)

"You have got to be kidding," said Brian. "That thing hasn't been used in over five years."

Kristie pulled back the tarp and threw it behind her. "I started out in Environmental Maintenance and Control. I learned how to program on a model just like this one. It's got voice control and level-five sensor capabilities and can withstand the temperature out there," she replied.

"But will that thing even work?" asked Brian. "And even if it does, what's the plan?"

Kristie reconnected the internal batteries and flipped the power switch. A small whine was heard from within as processors and cooling fans began to boot up, and within a few seconds, external system lights were all green.

Kristie looked at Brian and smiled. “So far, so good,” she said. “Let’s try a few commands. E-M-3, status report please.”

The large robot gave a small lurch to the side. “Environmental Maintenance Bot 3 ready,” the robot responded in a pleasant voice that reminded Kristie of her old archaeology professor, Dr. Hicks.

“OK, it works,” said Brian. “Now what? If Ian can’t fix the generators, this robot certainly isn’t going to do it.”

“Forget about the generators for now. The situation has changed,” said Kristie. She dropped to one knee and looked directly into the robot’s visual processor. “E-M-3, I’ve got a job for you.”

Now, We Wait

Mars Base Alpha, Section D, Control Center
August 20, 2062 at 11:18 PM (Greenwich mean time)

From the safety of the control center, Kristie and Brian watched E-M-3 through the small window ports as it exited the cargo bay and disappeared around the corner of Section E. Because video systems were still down, they would be unable to verify all of the robot’s movements. Kristie had done the best job she could in programming the robot with the details of its destination and the job it needed to perform, but there were always going to be unknown elements. Kristie just hoped that the robot would be able to manage.

As E-M-3 rolled across the Mars landscape, Kristie spoke into the microphone on a nearby console. “E-M-3, can you hear me?”

“Affirmative,” the robot responded over the speakers.

“Good. When you’ve reached the junction at Collector A-1, stop and report in,” said Kristie.

“Affirmative.”

“How long will it take to reach the first collector?” asked Brian. “We’ve only got about 70 minutes or so of backup power.”

“By my estimates, it’ll take about ten minutes. But each collector after that will only take a minute or two. How many do we need rerouted to gain a stable power level?” asked Kristie.

Brian did some quick calculations on a terminal. “Well, all of the sections have reduced their power consumption like we asked,” he responded. “If we can get six of the collectors feeding power to the base systems, we should be OK. But, since the robot is out there, we might as well have it bring all 40 collectors online.”

“Agreed. Now, we wait.”

Kristie sat down in her chair and rocked nervously. Four years ago, the base had rerouted power from the solar cell farms. Solar Collectors A-1 through A-10 were now feeding power to five remote monitoring stations a few kilometers from Alpha, and the 20 collectors from Farm B and Farm C were providing extra power to the heaters at the hydroponics facility just to the south of the base. Farm D, with its ten collectors, was dedicated to providing power to the garage’s seven rovers. *No one will be going for a drive today*, thought Kristie.

The plan was simple, but they were relying on a robot to complete it. The danger was simply too high for a human to attempt the re-routing of the collectors’ power.

Each solar collector was matched to a power interrupt device and a power redirect. First, E-M-3 would need to take a collector offline by shutting down its power interrupt device. But each PID maintained a large electrical charge that was slow to dissipate. If E-M-3 made contact with the top of the charged PID, the robot’s circuits would be damaged beyond repair.

Once the PID was offline, E-M-3 would then proceed to the power redirect, a simple switch for rerouting the power to the base.

Next, E-M-3 would manually rotate the collector back to its original bearing; a drawback to taking the PID offline was that the collector would rotate away from the Sun to protect the solar cells when not collecting energy.

After reorienting the collector, E-M-3 would then reengage the PID for power flow. If everything was done correctly, E-M-3's actions would redirect the energy gathered by the collector to Mars Base Alpha. Of course, E-M-3 would need to successfully redirect power from five more collectors.

"E-M-3 status: Arrival at Collector A-1 confirmed," came the voice from the speakers.

Proceed

Mars Base Alpha, Section D, Control Center
August 20, 2062 at11:29 PM (Greenwich mean time)

Kristie rolled her chair over to the communications console and spoke into the microphone. "E-M-3, confirm your exact position."

"E-M-3 status: North facing at coordinates 19.40 degrees north, 33.12 degrees west," replied the robot.

Brian consulted the map on the screen in front of him. The robot was indeed at the entrance to the power conduit switch for the collector. He nodded to Kristie. "In position."

"Okay, E-M-3. Please confirm your objectives," Kristie said.

"E-M-3 objectives: Disengage PID. Configure power redirect for Alpha supply. Reorient collector to optimum bearing. Reengage PID," replied E-M-3.

"And after completing Collector A-1, where will you proceed, E-M-3?" asked Kristie.

"E-M-3 objective: Proceed with identical process on Collectors A-2 through A-10, Collectors B-1 through B-10, Collectors C-1 through C-10, Collectors D-1 through D-10," replied E-M-3.

Kristie nodded at Brian. "Does that sound right to you?" she asked.

"Sure does. Let's get moving; six collectors need to be rerouted in 58 minutes."

Kristie nodded and spoke into the microphone. "E-M-3, proceed with your objectives."

"Affirmative."

And the radio went silent.

Operational

Mars Base Alpha, Solar Farm A, Collector A-1
August 20, 2062 at 11:32 PM (Greenwich Mean Time)

```
> System Status: Idle. . .
> Initializing Program Collector1. . .
> Run Program Collector1. . .
> System Status: Operational. . .
```

Environmental Maintenance Bot 3 did not hesitate in its duties, and the robot began moving into the electrical conduit cage for Collector A-1.

Your Turn

Mars Base Alpha, Solar Farm A, Collector A-1
August 20, 2062

Was E-M-3 successful? It's time to find out. You're in charge now, and the fate of Mars Base Alpha is in your hands. Continue on with Chapters 2, 3, and 4 to build the simulation environment for your own Environmental Maintenance Bot. You'll build a power interrupt device, a power redirect, and a solar collector. After building these three devices, you'll next need to construct and program a robot to successfully complete a set of missions that are described in Chapter 5.

Good luck!

CHAPTER 2

Creating the Power Interrupt Device

To successfully complete the Mars Base Alpha challenge, you will be required to construct a robot that will interact with three models. These models are built using parts from the LEGO Education Resource Set.

The first model you must prepare is called the power interrupt device (PID), and you will find complete building instructions for the PID in this chapter. Figure 2-1 shows what the completed PID will look like.

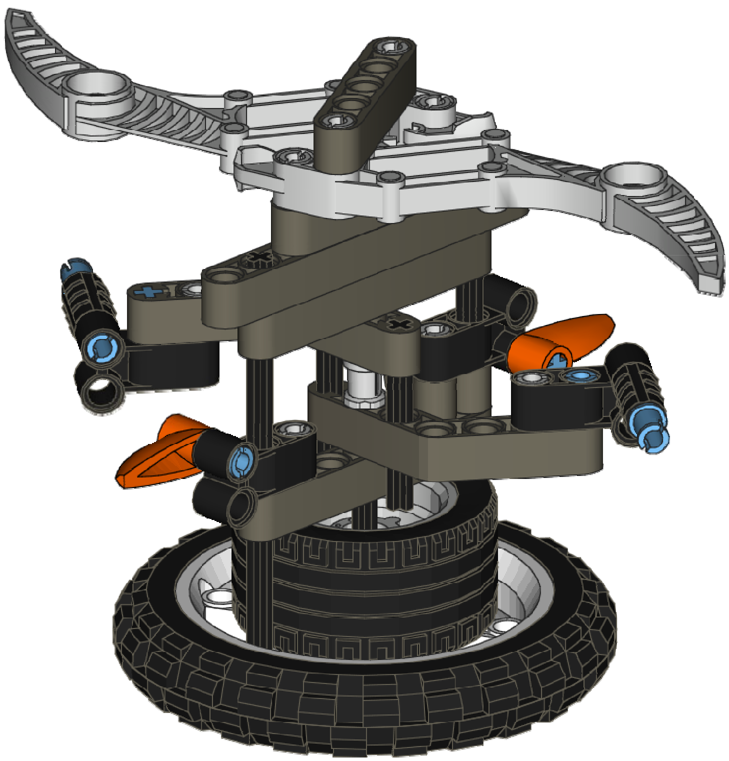


Figure 2-1. *The power interrupt device (PID) fully assembled*

The PID has a few moving parts. On top, you'll find two spinning claws that your robot must avoid at all costs. Below the claws is a swiveling mechanism; when the PID is engaged, the ends of the swiveling arms are touching the two orange pieces. When it's disengaged, the ends of the swiveling arms are not touching the two orange pieces.

Chapter 5 will provide details on the placement and operation of the PID in the challenge. You will also find information related to the challenge area; this can be quickly put together with nothing but the three assembled models for the Mars Base Alpha challenge and some tape to define the boundaries. You will also find details on a mat that can be downloaded (for free) and printed out in color or black and white and used as the challenge area.

Tackling the PID Challenge

After assembling the power interrupt device, you'll want to spend some time examining it. I suggest that you place it on a solid surface and take some measurements that will help you when it comes time to build a robot to solve the challenge.

Notice that the PID's most dangerous part is at the very top—a set of spinning claws (blades) that would easily damage a real robot if they were real. You'll want to make certain that any part of your robot that approaches the PID does not touch the blades, as the challenge rules will either disqualify the robot or result in penalty points (depending on the level of complexity of the challenge you wish to run).

Below the blades is the part of the model that will award you points. The swiveling arms start out touching the small orange pieces, indicating that the PID is engaged. You must build and program a robot that can safely disengage the PID by moving the swiveling arm in such a way that the ends are not touching the orange pieces. And remember, your robot must do this while not touching the spinning claws on top.

Keep in mind that the swiveling arms are extremely sensitive and easy to move; it won't take much for your robot to move them away from the orange pieces (and thus disengage the PID). This means you are not likely to need the use of a motor or any other complex device. A simple arm device mounted on the robot can easily disengage the PID and keep the robot's main body safely away from the claws.

The most difficult tasks in disengaging the PID will be having your robot identify it and orient itself in such a way that it does not go out of the challenge area boundaries. How can you do this?

It will involve taking measurements and programming your robot to move and turn properly to place itself where it can safely disengage the PID. If you choose to print and use the mat provided in Chapter 5, you could provide some visual cues for your robot, such as the colors or lines on the mat. Using a Light or Color sensor, you can program your robot to start, stop, and turn at various times depending on lines and colors the sensor detects on the mat or ground.

Taking One Challenge at a Time

After you've successfully built the power interrupt device, you may consider building a small robot or using the standard tribot (instructions are included with the NXT-G software) to try to solve just the PID challenge.

Rather than building all three models used in the Mars Base Alpha challenge, consider breaking the challenge into parts and attempting to work out the design and programming requirements needed to interact with only one model at a time.

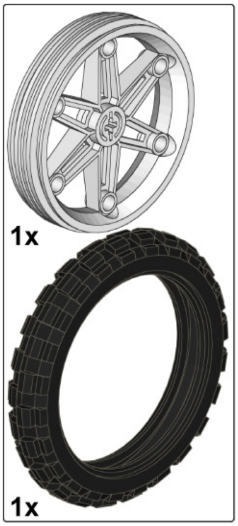
In this instance, your goal would be to find a way to get the robot to find and locate the PID in the challenge area and then disengage the device. Once you have a robot that can successfully complete that challenge, move on to the next model, the power redirect (PR) covered in Chapter 3.

Don't get frustrated. Keep in mind the single goal here—move the swiveling arms in such a way that they are not touching the orange pieces. Don't overcomplicate your robot design here. Just get the robot from the starting position (see Chapter 5) to a suitable location on the mat to interact with the PID. Do that one task correctly, and you'll be able to do it again no matter the final design of your challenge robot.

Building the Power Interrupt Device

In this section, you will find the building instructions for the power interrupt device. Each image shows the pieces you will need to locate in the LEGO Education Resource Set and their quantities. You will also see where these pieces are to be placed.

If you are uncertain about the placement of a piece in a figure, jump ahead to the next image or even go back to a previous image to make certain you've built the model correctly so far. Examine the figures carefully, and you should be able to correctly identify the pieces and their final location on the model.



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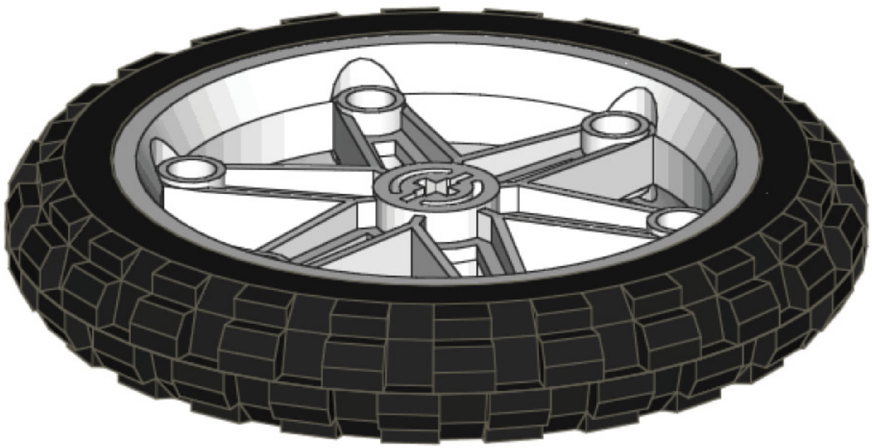

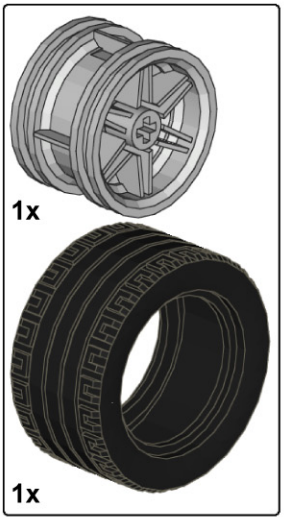

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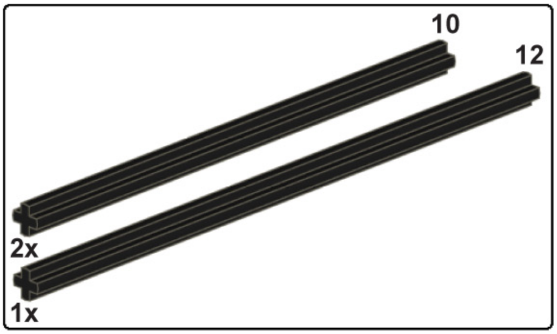

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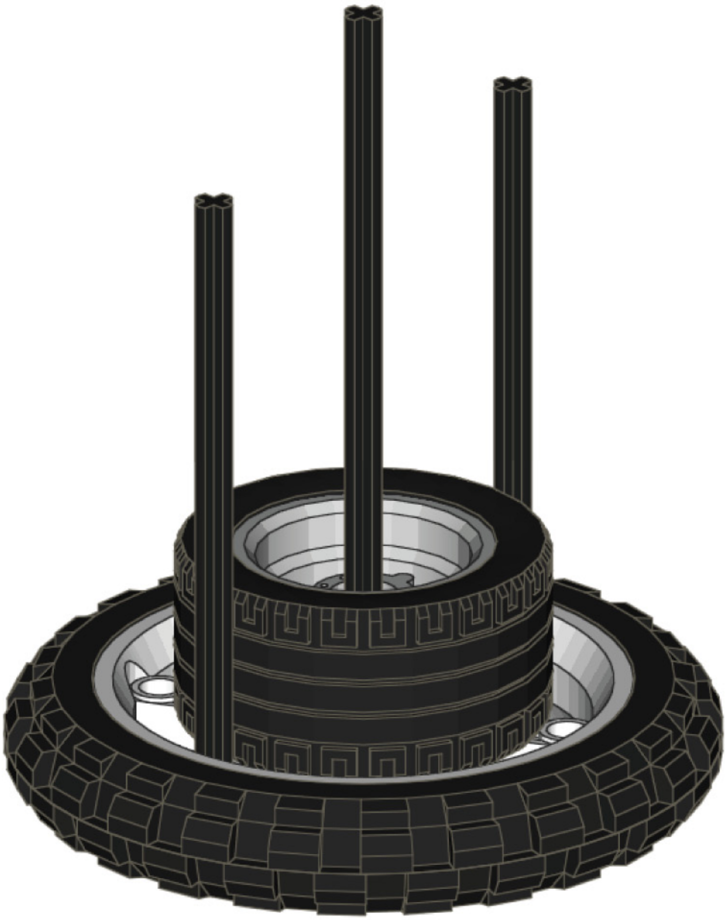

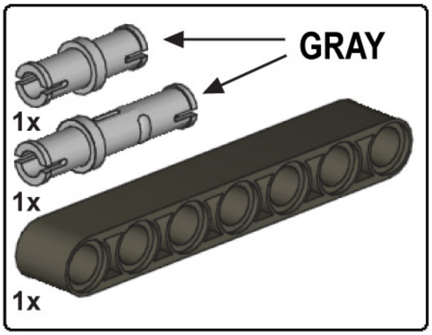

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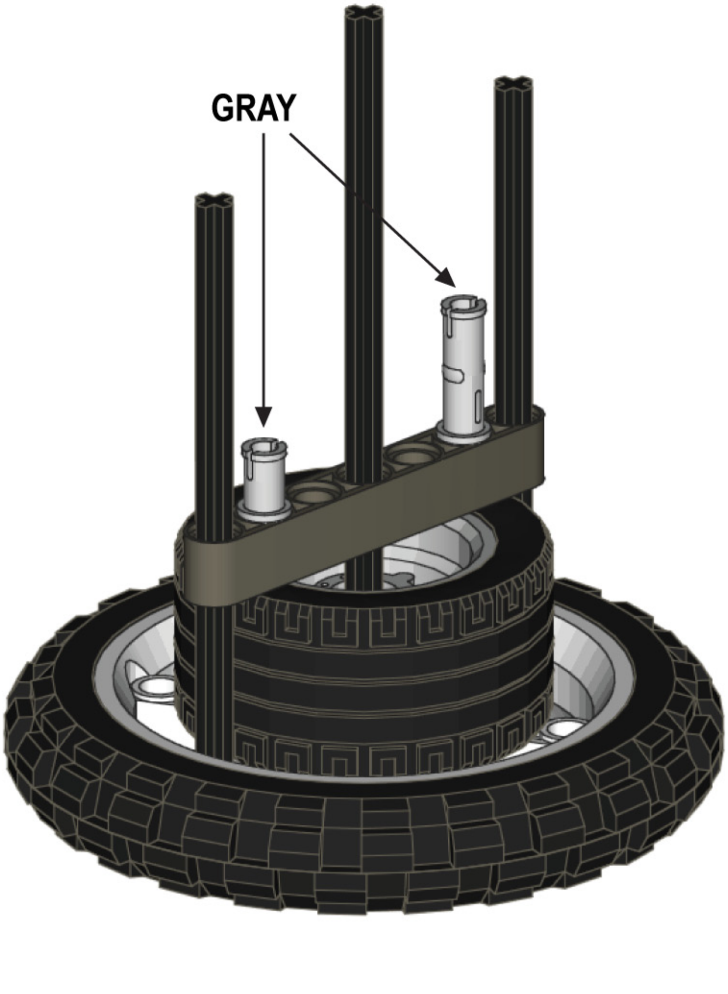

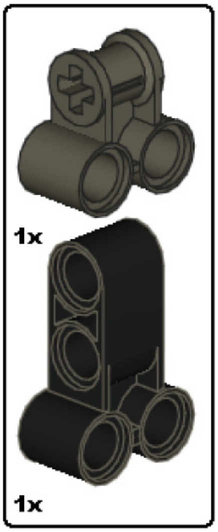

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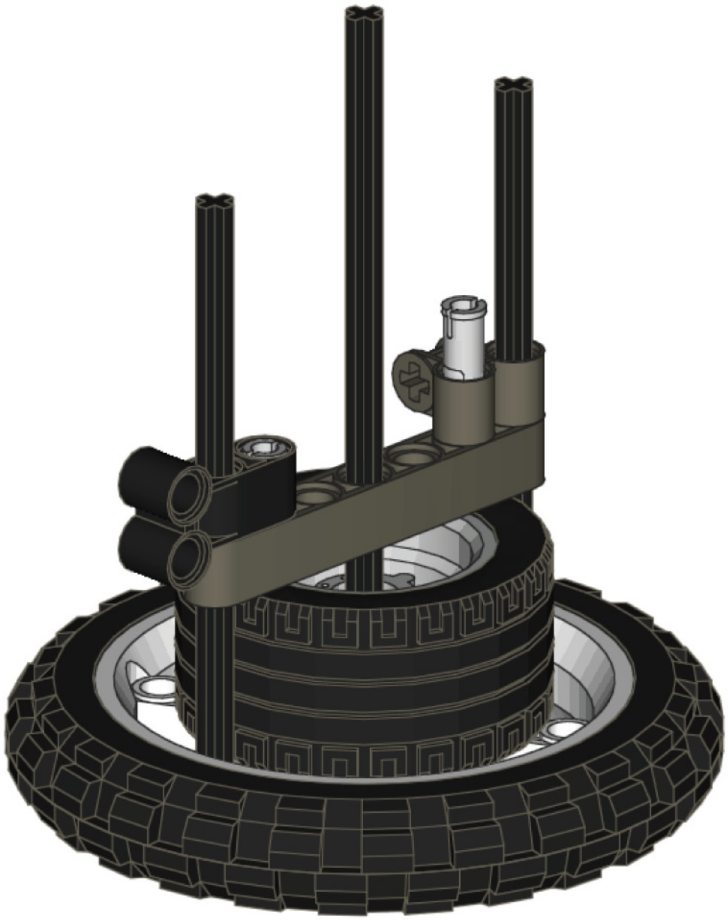

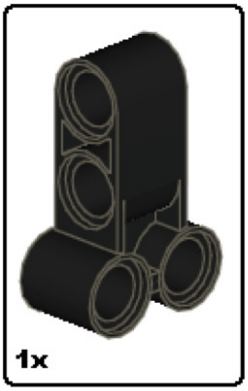

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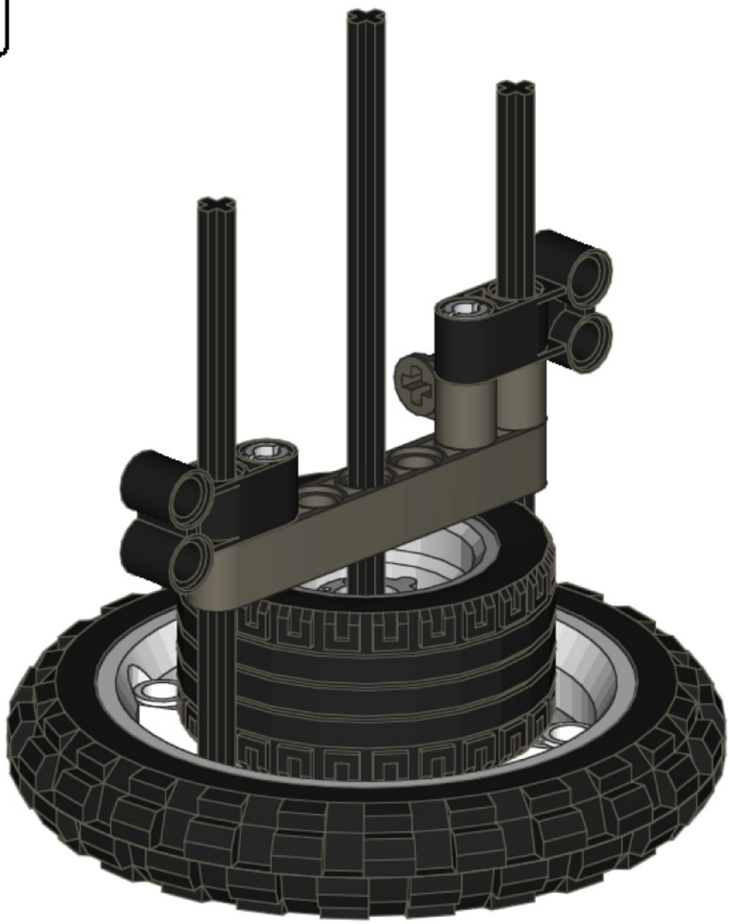

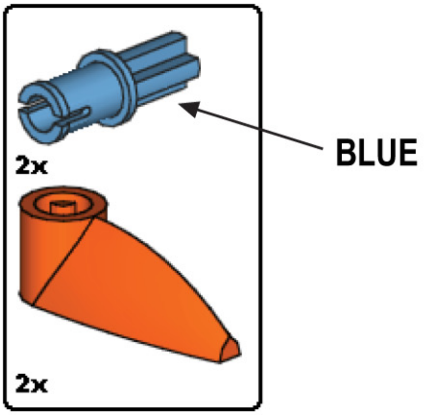

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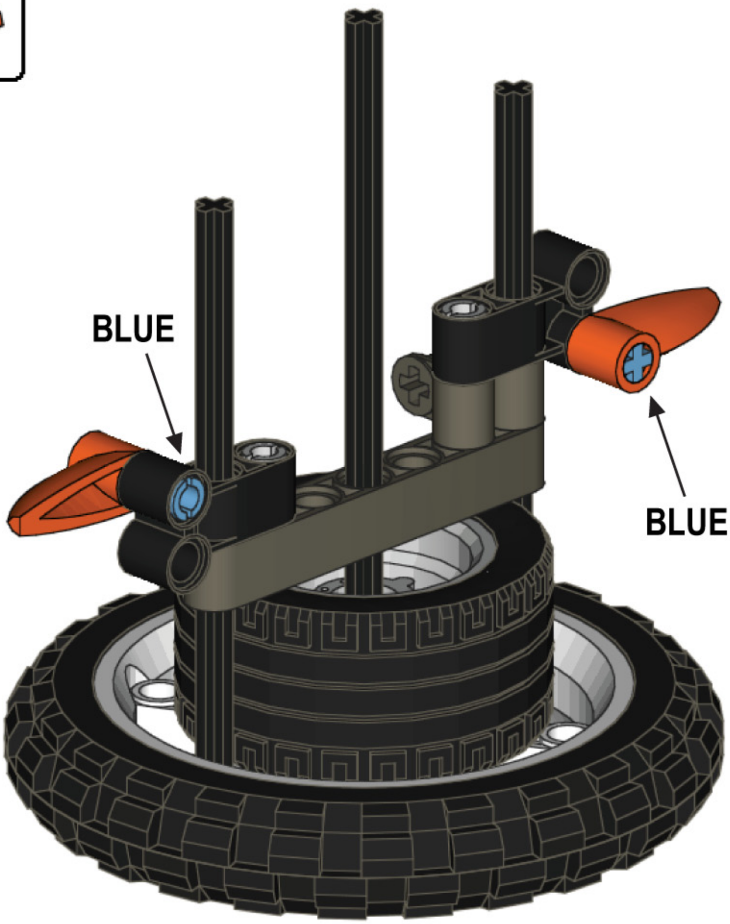

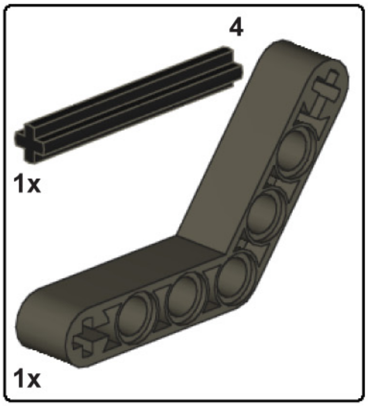

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