introduction

The idea for this book was born in 2012 during a sandstorm in Saudi Arabia. I was locked in my hotel room waiting for the weather to improve and listening to Paul Dukas's symphonic poem *The Sorcerer's Apprentice*. At that time, I was involved in helping The LEGO Group in developing and testing the new LEGO MINDSTORMS EV3. I began drafting the story of a kid given the chance to become the apprentice of a scientist; I wanted this story to be the background of my next book about LEGO MINDSTORMS.

playing without a computer

The LEGO Group's idea for the EV3 set is that it should be fully usable if you have a computer with a fast Internet connection. Unlike previous versions, the EV3 Software is available only as a download. You also won't find a printed user guide, only a booklet with partial building instructions for the simplest official robot, TRACK3R, and a few hints about on-brick programming.

Even if you don't have a computer available, however, you'll still be able to enjoy playing with the robots in this book, thanks to the new EV3 on-brick programming. This is an effective (if limited) way to program the robots using the EV3 Brick menu. Chapters 1 through 4 and 8 through 10 offer numerous ways to play with your robots without a computer.

whom is this book for?

This book is for anyone with a passion for robots! No matter your age, this book can teach you how to build and program robots using the LEGO MINDSTORMS EV3 Retail set 31313.

Besides specific building and programming instructions, you'll learn general LEGO building techniques, as well as basic and advanced concepts of computer programming. Experts and more experienced robot makers will find sections scattered throughout the book that delve into topics a bit more deeply.

what do I need to use this book?

To use this book, you will need the LEGO MINDSTORMS EV3 Retail set 31313. You'll also need an Internet-connected computer to download and install the EV3 programming software, including the tutorials to build and program the five official models in the set. If you are a teacher or a student building with LEGO MINDSTORMS Education Core set 45544, see Appendix B for a list of the additional LEGO elements you'll need to make your set equivalent to the Retail set 31313.

You should find a USB cable in your set that will allow you to connect the EV3 Brick to your computer. To connect with a Bluetooth connection, your computer should have a built-in or external Bluetooth dongle. To connect the EV3 Brick to the computer using Wi-Fi, you must purchase a USB Wi-Fi dongle separately. As of this writing, the only dongle known to work with the EV3 Brick is the NETGEAR WNA1100.

the EV3 software

The EV3 Software was developed by National Instruments, creators of the LabVIEW development environment. The EV3 language is based on its visual dataflow programming language called G. National Instruments also developed the NXT-G

programming language for the previous LEGO MINDSTORMS NXT generation.

If you are an NXT user and you have programmed with NXT-G, you will find EV3 programming much clearer: Now all the blocks show all settings at once, and you don't have to select a block to see its settings in the Configuration Panel. The software allows you to zoom and pan through the programs to explore them more easily. You'll also find additional programming features.

the structure of this book

This book is both a manual and a workbook. It introduces new concepts as the story in the comics develops. (Look at the comics carefully, as they include hidden clues to downloading bonus material from the companion website, including AUDR3Y, the people-eating plant; the L3AVE-ME-ALONE box; and many more.) "Digging Deeper" sidebars explain some advanced topics in depth. If you're an expert, you may want to skip some of the more introductory chapters and go directly to Chapters 9 through 16, where you learn how to build and program the four main robots. The chapters also contain experiments to apply and deepen what your knowledge. Here's what you'll find in each chapter:

- Chapter 1: Contents of the 31313 set; identifying LEGO Technic elements.
- Chapters 2, 3, and 4: Build ROV3R, a wheeled robot that can be built quickly and programmed without a computer.
- Chapters 5, 6, and 7: Introduction to EV3 programming using the computer.
- Chapter 8: LEGO building techniques.
- Chapters 9 and 10: Build and program WATCHGOOZ3, a walking robot that can be programmed with or without a computer.
- Chapters 11 and 12: Build and program the SUP3R CAR, a steering car.
- Chapters 13 and 14: Build and program the SENTIN3L, a walking defense robot.
- Chapters 15 and 16: Build and program the T-R3X, a fearsome walking dinosaur.

the companion website

The companion website, **http://EV3L.com/**, contains the EV3 projects for the robots, errata, additional tips and tricks, and the bonus models for this book.

let's start already!

Welcome to the journey! Follow Dexter and Danny through their adventure and become an EV3L scientist's apprentice!

1

your LEGO MINDSTORMS EV3 set

Your LEGO MINDSTORMS EV3 31313 set includes a collection of LEGO elements, a printed manual (with instructions for building the official robot, TRACK3R, and some hints about how to get started with the EV3 Intelligent Brick), a USB-to-miniUSB cable to connect the EV3 Brick to your computer, and a paper test pad (just unroll the sleeve surrounding the box)—but no software. Where is the software? You can download it from the Downloads section of the LEGO MINDSTORMS EV3 official website (*http://LEGO.com/mindstorms/*). The LEGO Technic elements in the box are beams, pins, gears, and wheels as well as electronic components like motors, sensors, cables, and the EV3 Intelligent Brick itself.

the studless way of building

As you may already know, there are no classic LEGO bricks in the EV3 box, and the beams don't have any studs. So how do you connect them?

Since 2000, LEGO Technic sets have been composed mainly of "studless" parts. The good old sharp-edged Technic bricks with studs (called *studded*) have slowly been replaced by smooth, studless Technic beams, which give the models a sleeker look (Figure 1-1).

I remember when I first switched from studded to studless building: Despite years of experience with "classic" LEGO Technic, I suddenly felt as though I could not build even the simplest thing. I was so frustrated! But as I took a close look at the official LEGO Technic models, I became more and more familiar with the parts. Sure, I had to learn a completely different way of building, but it was worth the effort. Studless building produces models that are lightweight, solid, and beautiful. Once you get started with studless building, you'll wonder how you could have lived without it!

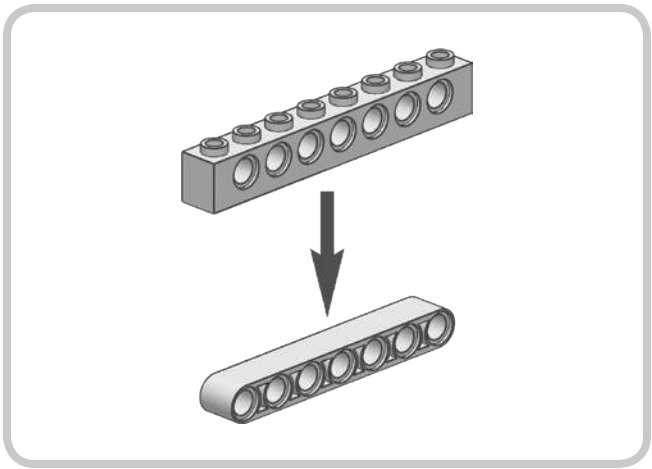


Figure 1-1: A classic 8M Technic brick compared to a 7M studless beam. Building with studless parts isn't always as intuitive as the classic way of building with LEGO by stacking bricks and plates from bottom to top. In fact, studless technique requires you to think three-dimensionally, from the inside out.

studless vs. studded: the structural differences

Technic bricks have an even number of studs and an odd number of holes (a two-stud brick has one hole, a six-stud brick has five holes, and so on), and you measure and name them by counting their studs. Technic beams are like a minimalist, studless version of Technic bricks. Measure them by counting their holes, as shown in Figure 1-1. Like the studs on a LEGO brick, Technic pins act as the "glue" for your LEGO creations, as you can see in Figure 1-2.

The round ends of Technic beams allow you to build structures and mechanisms that are more compact and lighter than the ones you might build with standard LEGO bricks. For example, in order for two studded bricks to rotate next to each other on pegs, the pegs need to have two empty holes between them (see Figure 1-3). In contrast, the studless beams' pegs can be right next to each other.

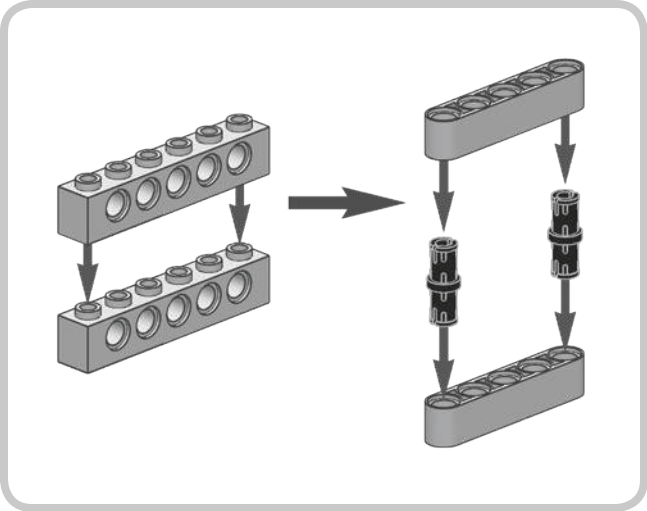


Figure 1-2: Like studs are for bricks, pins are the "glue" for studless beams.

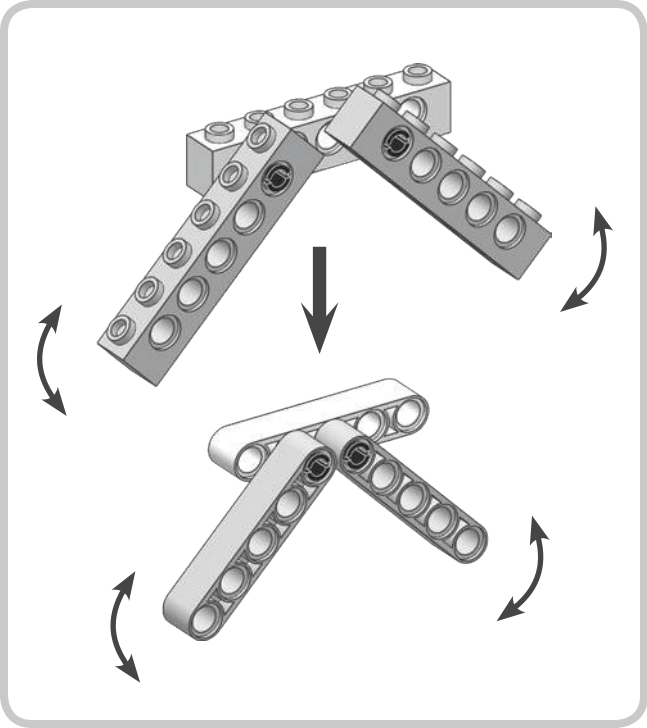


Figure 1-3: Technic beams occupy less space than bricks, allowing you to build more compact structures.

On the other hand, you can make sturdier, more rigid structures using standard bricks and plates. Depending on what you want to make, you might use studded, studless, or a combination of both techniques.

naming the pieces

Imagine that we're building a LEGO robot together and you find that you're missing a LEGO part. You ask me if I have one, but all you can muster is "Danny, would you pass me that . . . something, thingamajig, whatchamacallit, doodad, a habba whatsa?" and I don't understand what you need! Or worse, if you need to buy parts online (from a site like BrickLink; *http://www.bricklink.com/*) and you don't know how to refer to the parts, you'll be at a loss and unable to finish your robot.

Names are important. It's much easier to master LEGO building techniques if you know how to classify, name, and measure LEGO parts. You can't write a novel if you don't know grammar and vocabulary, and the same holds true for LEGO. You've got to know the parts.

The pieces in the EV3 31313 set can be divided into these categories:

beams straight beams, angular beams, frames, thin beams, and links
connectors pins, axles and bushes, axle and pin connectors, and cross blocks
gears spur gears, bevel gears, and worm gears
wheels and treads wheels, treads, and tires
decorative pieces panels, teeth, swords, and so on
miscellaneous pieces balls, ball magazine, ball shooter, rubber band
electronic pieces the EV3 Intelligent Brick, motors, sensors, and cables

NOTE For these categories, I've chosen to use the names that I think are the easiest to remember. For the official LEGO names, see Appendix A.

I'll describe the categories briefly, with a minimum of boring chatter.

beams

As mentioned earlier, *beams* are the studless equivalent of Technic bricks. This category includes straight beams, angular beams, and frames. We'll include thin beams and links in this category too. Beams can have round holes, which can fit pins, or cross holes, which can fit axles or axle pins. Links have ball sockets that fit pins with towballs.

straight beams

Figure 1-4 shows the straight beams; their names are listed in Table 1-1. The beams are measured by counting their holes. For example, a straight beam with three holes is a *3M beam* (and you can omit the adjective "straight"). The number of holes in a beam corresponds to the length of the beam as expressed in *Fundamental LEGO Units*, or *modules* (1M = about 8 mm). In all LEGO building instructions, you'll see a box for each building step that lists the parts needed in that step. The length of a beam is noted at its top-right corner.

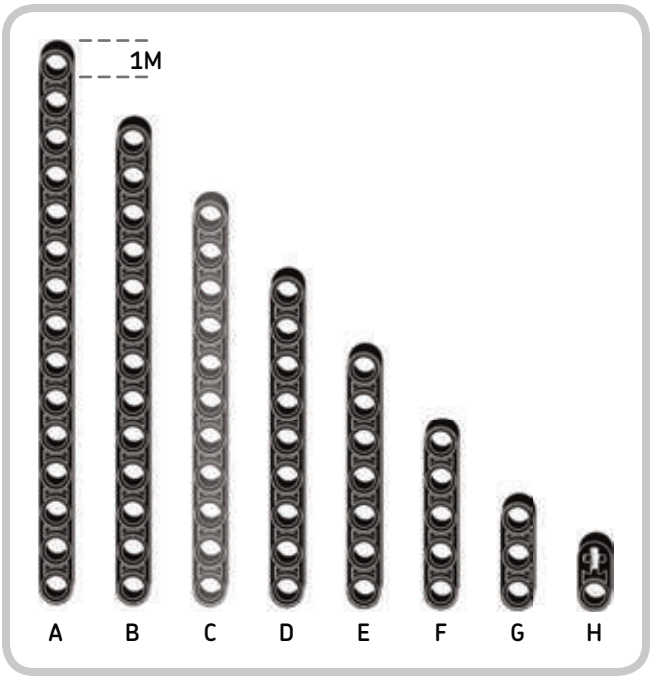


Figure 1-4: The straight beams

table 1-1: the straight beams

Label in Figure 1-4	Name	Color
A	15M beam	Black
B	13M beam	Black
C	11M beam	Red
D	9M beam	Black
E	7M beam	Black
F	5M beam	Black
G	3M beam	Black
H	2M beam with cross hole	Black

angular beams

Figure 1-5 and Table 1-2 show the angular beams and their names. An angular beam with three holes before and seven holes after the bend is a *3×7 angular beam*. The same naming pattern is used for the other angular beams. Notice that some angular beams have cross holes at their ends.

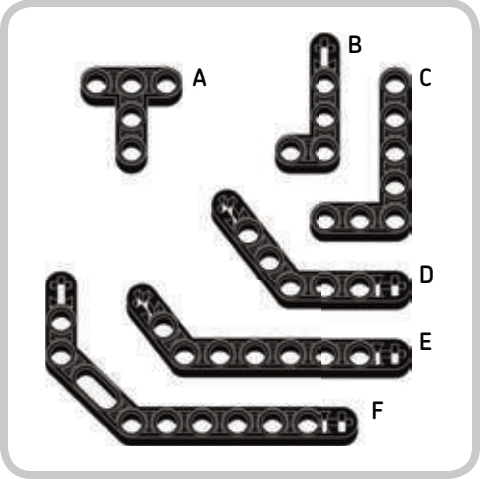


Figure 1-5: The angular beams

table 1-2: the angular beams

Label in Figure 1-5	Name	Color
A	T beam	Black
B	2×4 angular beam	Black
C	3×5 angular beam	Black
D	4×4 angular beam	Black
E	3×7 angular beam	Black
F	Double angular beam	Black

The angular beams labeled A, B, and C have right angles, while F has two 45-degree bends. But what about the others? What kind of strange angle is that, and how do you use it to build? You'll learn the secrets of working with the various angular beams in Chapter 8.

frames

We also have special beams called *frames*, as shown in Figure 1-6. We refer to these based on their shapes as *O-frames* (or simply *frames*) and *H-frames*. Once you know how to work with them, you'll find that they allow you to build rock-solid structures that will not come apart!

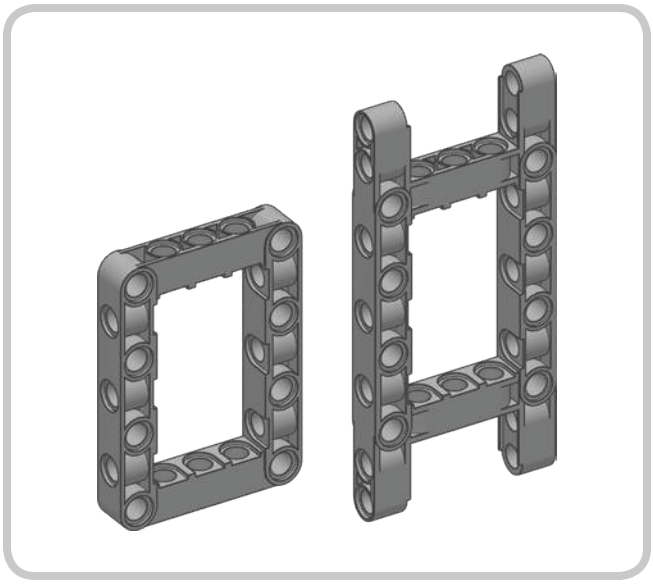


Figure 1-6: The O-frame and the H-frame

thin beams and links

The *thin beams* and *links* are shown in Figure 1-7 and Table 1-3. Thin beams have cross holes at each end, and they are one half-module thick. Think of the 6M and 9M links as beams with ball sockets at their ends. These fit pins with towballs (items D and H in Figure 1-8). Ball joints allow for a wide range of motion and rotation, similar to your shoulder or hip joints.

Figure 1-7: The thin beams and links

table 1-3: the thin beams and links

Label in Figure 1-7	Name	Color
A	Cam	Black
B	3M thin beam	Grey
C	6M link	Black
D	9M link	Black

connectors

Most parts in the EV3 set are connectors. When building with wood or metal, we use nails, glue, staples, screws, bolts, washers, and so on to connect the various pieces. In the wonderful world of LEGO Technic, we use pins, axles and bushes, axle connectors, and various cross blocks.

pins and axle pins

Pins hold beams together when fitted inside the beams' round holes. Pins are divided into two groups: pins with friction and pins without friction (also called *smooth pins*). Figure 1-8 and Table 1-4 show 2M and 3M pins, axle pins, pins with towballs, and a special 3M pin with a stop bush (also called a *bushing*).

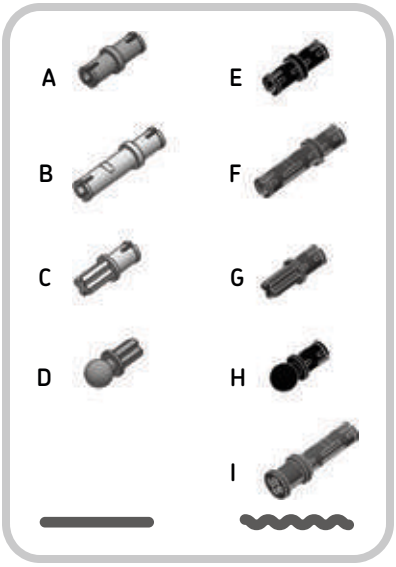


Figure 1-8: The renowned Technic pins. The straight line signifies the pins without friction (A–C); the wavy line indicates pins with friction (E–I). The axle pin with towball (D), while not technically a smooth pin, is listed here for comparison with the pin with towball (H).

table 1-4: the pins and axle pins

Label in Figure 1-8	Name	Color
A	Pin without friction	Grey
B	3M pin without friction	Tan
C	Axle pin without friction	Tan
D	Axle pin with towball	Grey
E	Pin with friction	Black
F	3M pin with friction	Blue
G	Axle pin with friction	Blue
H	Pin with towball	Black
I	3M pin with stop bush	Red

Pins without friction (labeled A, B, and C in Figure 1-8) turn smoothly and freely in the Technic holes. They are color coded: 2M pins are always grey, while 3M pins and axle pins are tan. Pins without friction are mainly used to connect moving beams.

NOTE The EV3 set has no axle pins without friction, labeled C in Figure 1-8, but I've included it here for the sake of completeness. Axle pins without friction can be used to hold a gear so that it can turn freely.

The *pins with friction* (labeled E, F, G, H, and I) have ridges that increase friction and make it harder for them to turn in the Technic holes. The ridges also prevent the pins from rattling. 2M pins with friction are always black, and 3M pins with friction and axle pins with friction are blue. 3M pins with stop bush come in many colors, but they're red in the EV3 set. The pins are color coded to help you identify their function at first sight.

Pins with friction are great for building stable structures because they hold beams together better than pins without friction. In the following chapters, you'll learn many ways to use pins and axle pins.

axles and bushes

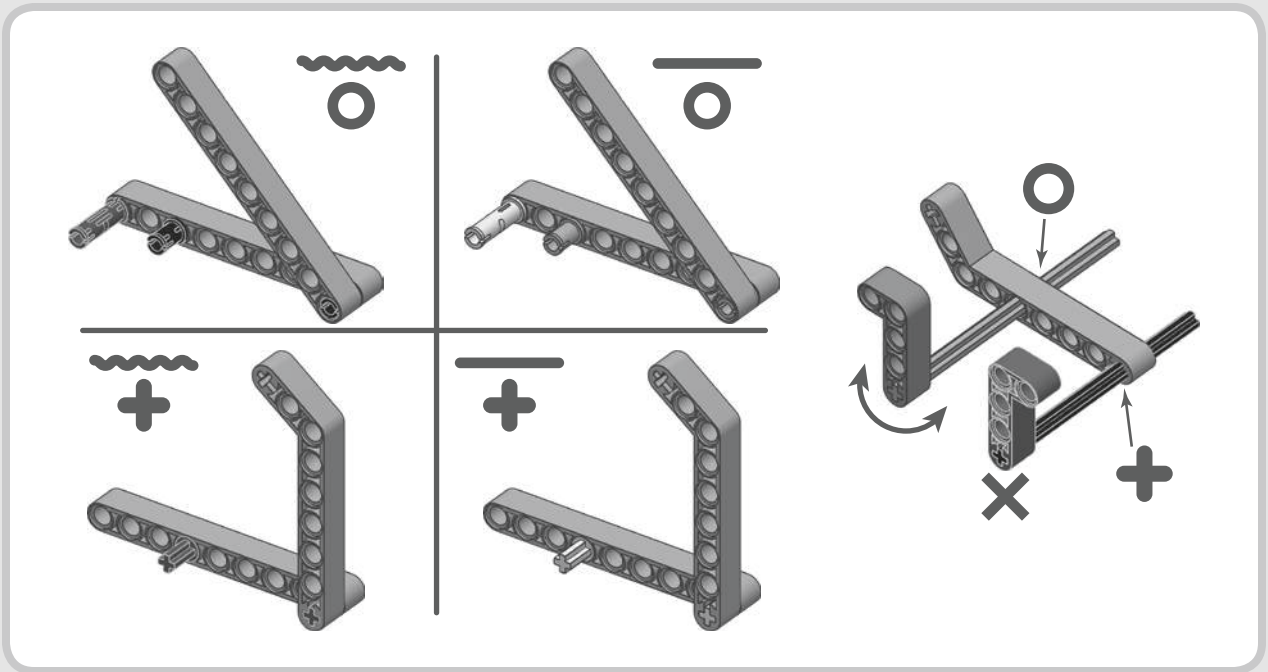
Axles are designed to transfer rotational movement, for example from a motor shaft to a wheel. Axles can also be used to hold structures together. Their cross section looks like a cross (their complete name is actually *cross axle*), and they fit perfectly into parts that have cross holes, such as gears, angular beams, and cross blocks.

Like beams, axles come in many lengths. You can measure them by putting them next to a beam and counting the holes in the beam. Once you get used to working with them, you will be able to sort them by size at a glance, even without measuring them. This superpower really amazes people!

CROSSES AND HOLES

Build the following assemblies. Each one has a symbol to help you pick the right pieces. Wavy lines indicate a pin with friction (black or blue) and straight lines indicate smooth pins (grey or tan). A plus (+) indicates axle pins and a circle indicates round pins.

- Once you've built the assemblies, hold them and try to make the inclined beam swing. What happens in each case?
- In the rightmost assembly, which 2×4 angular beam is the easiest to turn?



Like pins, axles are color coded, as shown in Figure 1-9: The 2M axle is red, odd-length axles are light grey (3M, 5M, 7M, 9M), and larger even-length axles are black (4M, 6M, 8M, 10M, 12M). The EV3 set doesn't have normal 4M and 8M axles; it includes a tan axle with a cylindrical stop in the middle (4c), as well as some axles with a stop at one end (3s, 4s, and 8s). Unlike the 4M and 8M axles with stop (4s and 8s), the 3M axle with stop (3s) has a protruding stud. In the 3s, 4s, and 8s axles, the stop looks like a built-in bush, and it *stops* the axle from passing through a hole or a cross hole. In the 4c axle, the stop in the middle stops the axle from passing completely through a cross hole.

Figure 1-9 also shows two bushes, labeled B1 (yellow, one half-module thick) and B2 (red, one module thick). You'll usually fit these bushes over axles to prevent the axles from coming out of holes, or you'll use them to keep space between two or more elements of a structure. Because the bushes are mainly used with axles, I've listed them together.

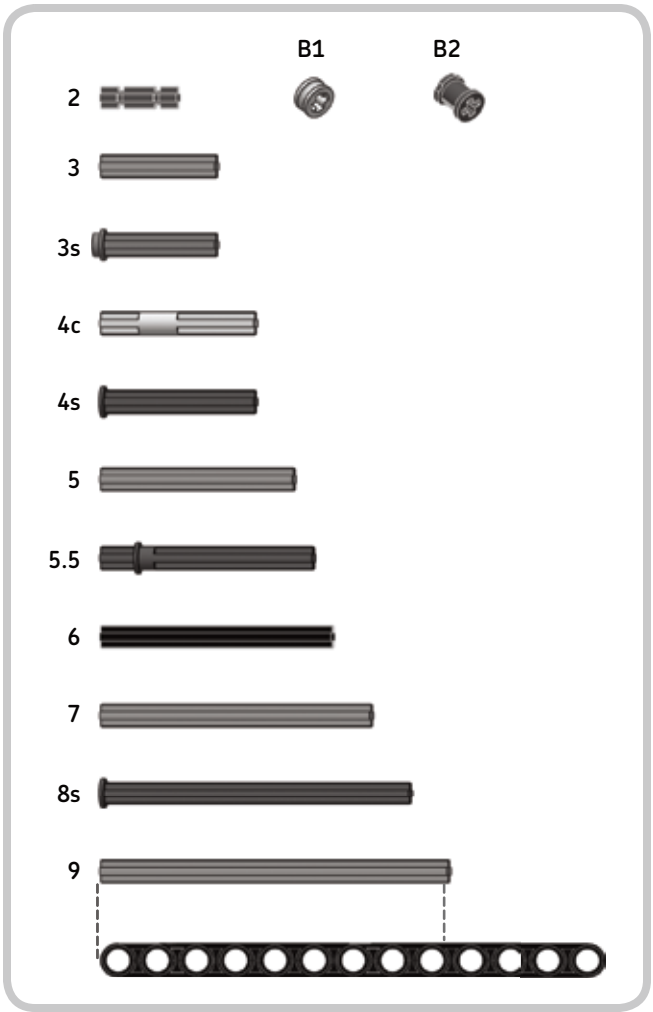


Figure 1-9: The axles and bushes (with 13M beam shown for comparison)

axle, pin, and angle connectors

Figure 1-10 shows the axle, pin, and angle connectors, and Table 1-5 lists their names. Each angle connector (those labeled E, F, G, and H) is identified by a number embossed on its body.

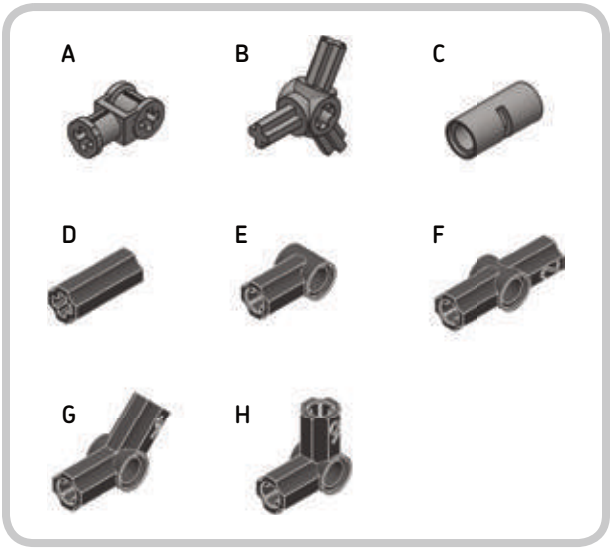


Figure 1-10: The axle, pin, and angle connectors

table 1-5: the axle, pin, and angle connectors

Label in Figure 1-10	Name	Color
A	Connector with axle holes	Grey
B	Connector hub with 3 axles	Grey
C	Pin connector	Grey
D	Axle connector	Red
E	Angle connector #1	Red
F	Angle connector #2	Red
G	Angle connector #4	Red
H	Angle connector #6	Red

cross blocks

Here comes the fun! Cross blocks are essential to studless building because they allow you to build—and think—in three dimensions. Remember, studless building isn't about simply stacking bricks; we're adding parts from all sides, as shown in Figure 1-11.

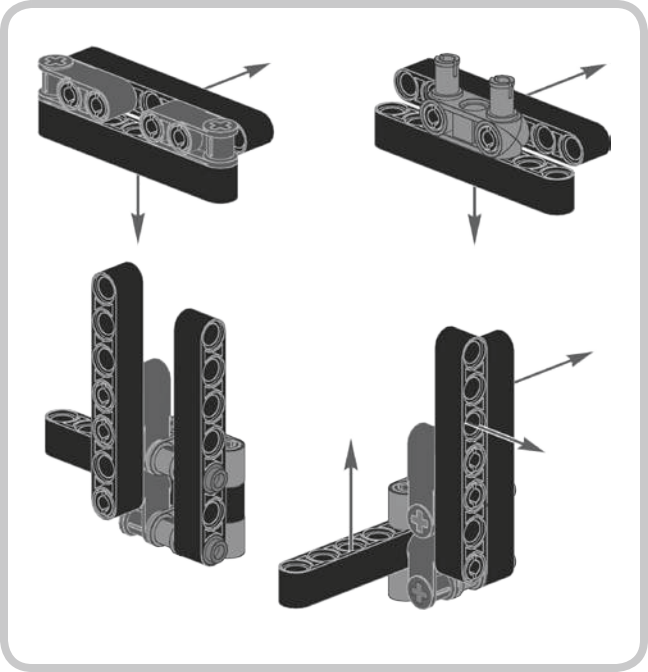


Figure 1-11: With cross blocks, you can build in any direction, not just from bottom to top.

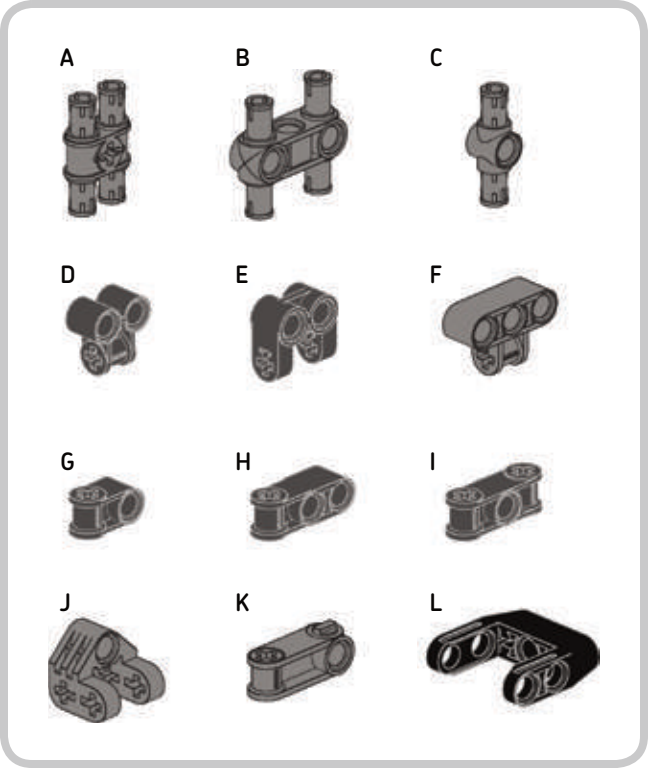


Figure 1-12: The cross blocks

Figure 1-12 shows the cross blocks in the EV3 set, and Table 1-6 lists their names. Some entries also list a nickname for the piece; for example, "Mickey" and "Minnie" are funny names for parts D and E, respectively. (Thanks to LEGO MINDSTORMS Education designer Lee Magpili for these nicknames.) The part labeled L can be used as a gearbox to hold 90-degree-coupled 12z and 20z bevel gears (for example, see "Medium Motor with Gearbox" on page 126).

It would be nearly impossible to show you all of the combinations you can build with cross blocks. The best way to learn how to use them is to draw your inspiration from the projects in this book and from the many Technic models in the wild.

gears

When people think of complicated machines, gears often pop into their minds, even if the machine is a computer with few moving parts! And when a machine stops working, people often blame its (sometimes imaginary) gears.

Gears are rotating wheels with teeth that mesh with other toothed parts (like gears, gear racks, and worm gears) to transmit movement. Figure 1-13 shows the gears included in the EV3 set, with their corresponding names in Table 1-7. LEGO gears are identified by number of teeth, as indicated in their name followed by *z*; for example, a 24-tooth gear is called a *24z gear*.

table 1-6: the cross blocks

Label in Figure 1-12	Name	Color
A	2M beam with 4 pins	Grey
B	3M beam with 4 pins	Grey
C	3M pin with hole	Grey
D	2×1 cross block ("Mickey")	Red
E	2×2 fork cross block ("Minnie")	Red
F	3×2 cross block	Grey
G	2M cross block	Red
H	3M cross block	Red
I	Double cross block	Red
J	2×2×2 fork cross block	Grey
K	3M cross block, steering	Grey
L	Gearbox cross block	Black

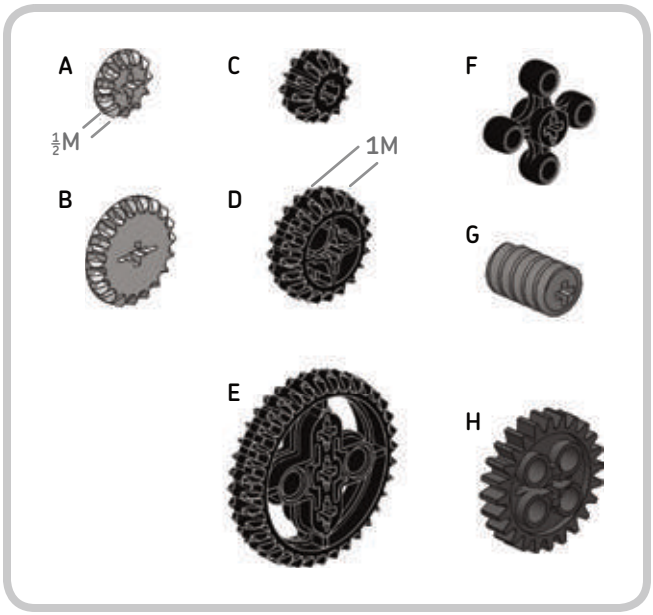


Figure 1-13: The gears

table 1-7: the gears

Label in Figure 1-13	Name	Color
A	12z bevel gear	Tan
B	20z bevel gear	Tan
C	12z double-bevel gear	Black
D	20z double-bevel gear	Black
E	36z double-bevel gear	Black
F	4z knob wheel	Black
G	Worm gear (1z)	Grey
H	24z gear	Dark Grey

Most gears are 1M thick, with the exception of the 12z and 20z bevel gears, which are both one half-module thick. The 24z gear (labeled H) is a spur gear, but "spur" can be omitted from the name (8z, 16z, and 40z spur gears also exist in the LEGO system). The worm gear is a particularly tough gear. You'll learn more about it and how to combine gears in Chapter 8 and while building the robots in this book.

wheels, tires, and treads

The simplest and most efficient way for your robots to move is on wheels. The EV3 set contains four large wheels with tires, three medium wheels with tires, four small wheels with two small tires, and two rubber treads. Figure 1-14 shows the various types of wheels, tires, and treads in the set, and Table 1-8 lists their names.

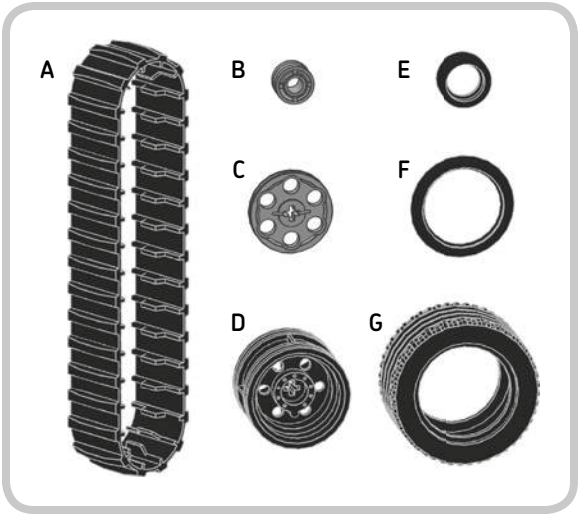


Figure 1-14: The wheels, tires, and treads

table 1-8: the wheels, tires, and treads

Label in Figure 1-14	Name	Color
A	Rubber tread	Black
B	Small wheel	Grey
C	Medium wheel	Grey
D	Large wheel	Black
E	Small tire	Black
F	Medium tire	Black
G	Large tire	Black

The large tires have their dimensions printed on their edge; for example, *43.2×22 ZR*. These measurements are in millimeters: In this example, 43.2 mm is the tire diameter and 22 mm is the width of the tire. The medium tire has a 30 mm diameter and is about 3 mm wide. The small tire has a 14 mm diameter and is 6 mm wide.

decorative pieces

The EV3 set contains several decorative pieces. In addition to the teeth with axle holes, there are many white panels, blades, and swords, as you can see in Figure 1-15. Their names are given in Table 1-9. The panels come in mirrored pairs and are identified by a number embossed on the concave side. Because these panels have many connection holes, you can even use them as large cross blocks when building.

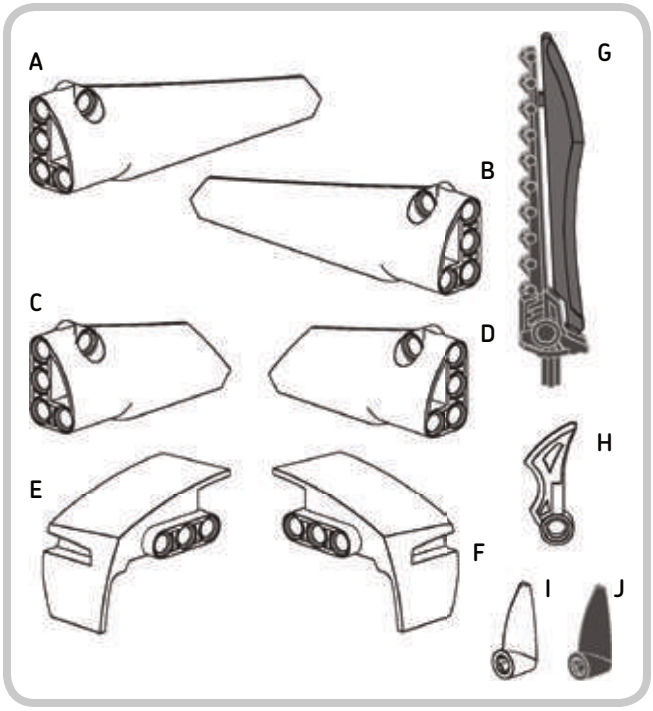


Figure 1-15: The decorative pieces

table 1-9: the decorative pieces

Label in Figure 1-15	Name	Color
A	Long panel #5	White
B	Long panel #6	White
C	Medium panel #3	White
D	Medium panel #4	White
E	Right mudguard	White
F	Left mudguard	White
G	Sword	Red/Grey
H	Curved blade	White
I	Tooth	White
J	Tooth	Red

miscellaneous pieces

The miscellaneous pieces are special elements: a ball magazine, a ball shooter, three balls, and a rubber band. LEGO rubber bands are color coded; the red one included in the EV3 set has a 24 mm diameter. These parts are shown in Figure 1-16 and listed in Table 1-10.

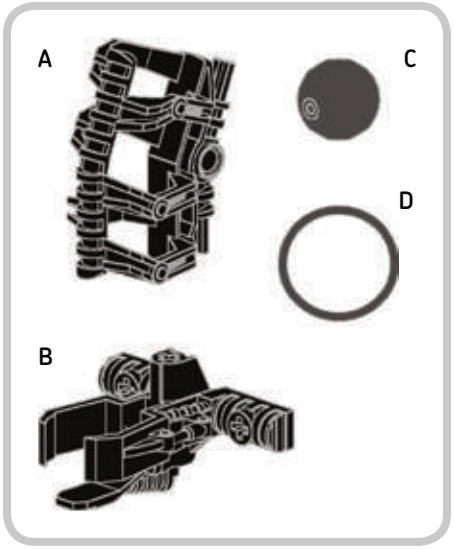


Figure 1-16: The miscellaneous pieces

table 1-10: the miscellaneous pieces

Label in Figure 1-16	Name	Color
A	Ball magazine	Black
B	Ball shooter	Black
C	Ball	Red
D	Rubber band	Red

electronic pieces

Finally, here's what makes a MINDSTORMS set a real robotics tool kit: the electronic pieces! These pieces are shown in Figure 1-17 and their names are listed in Table 1-11. The 31313 set contains two Large Servo Motors and seven cables: four 25 cm (10 in) cables, two 35 cm (14 in) cables, and one 50 cm (20 in) cable.

The EV3 Intelligent Brick is a microcomputer that acts as the brain for your robotic creations. It features the Linux operating system running on a 300 MHz ARM9 controller. It has 64MB of RAM and 16MB of flash memory, expandable with a microSD card up to 32GB! The screen resolution is 178×128 pixels (black and white).

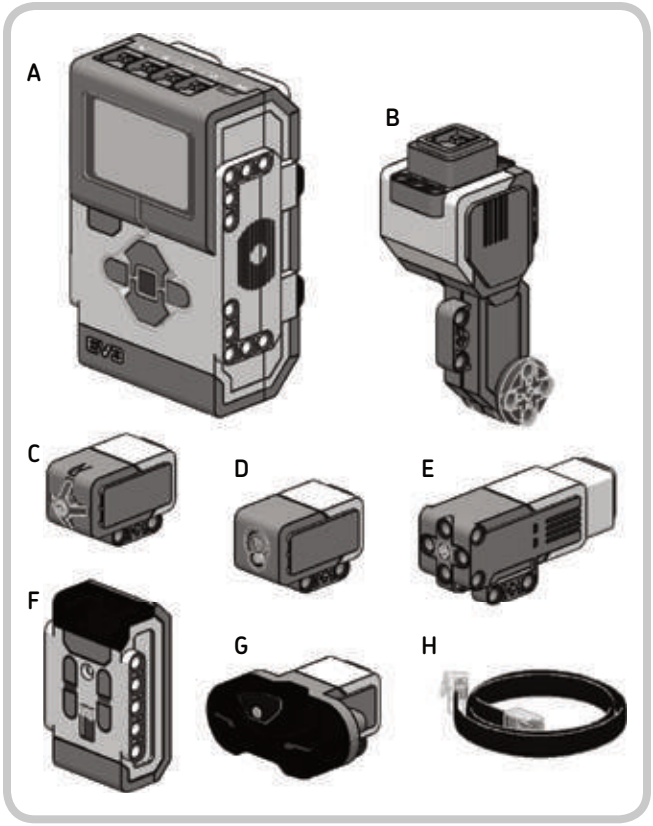


Figure 1-17: The electronic pieces

table 1-11: the electronic pieces

Label in Figure 1-17	Name
A	EV3 Intelligent Brick
B	Large Servo Motor
C	Touch Sensor
D	Color Sensor
E	Medium Servo Motor
F	Remote IR Beacon
G	IR Sensor
H	Connector cable

You can connect the EV3 Brick to a computer with a mini-USB 2.0 port, and you can connect other devices (daisy-chained EV3 Bricks or a Wi-Fi Dongle) to the USB 1.1 host port on its side. You can also connect up to four motors and four sensors to the Brick. The EV3 Brick can recognize which motor or sensor is attached to its ports, thanks to the Auto-ID feature. You can use 6 AA batteries to power it (LEGO Education sells a rechargeable battery; see Appendix B for details).

The EV3 Servo Motors are not plain LEGO motors: They have a built-in rotation sensor (1 degree resolution) to allow precise motion control. The Large Servo Motor runs at 160 to 170 rpm, with a running torque of 20 N·cm and a stall torque of 40 N·cm. The Large Servo Motor is slower but stronger than the Medium Servo Motor, which runs at 240 to 250 rpm with a running torque of 8 N·cm and a stall torque of 12 N·cm.

A motor is in stall (or is *stalled*) when it is commanded to turn but the shaft is blocked by some mechanical stop and is unable to move. This consumes a lot of battery power, and you should avoid this situation by, for example, turning the motor off before it gets stuck or removing the block that's preventing the shaft from turning freely.

The sensors give your robots the ability to touch and see. The Touch Sensor is basically a switch that your robot can use to detect contact with objects. The Color Sensor can measure ambient light, measure the amount of light reflected by objects, and recognize the color of objects. The IR Sensor can measure distance, detect the distance and the bearing to the Remote IR Beacon, and receive remote commands from the Remote IR Beacon. I'll describe the various sensors in detail later in the book.

the differences between the EV3 retail and education sets

The EV3 set comes in two versions: Retail set 31313 (the set used in this book) and Education Core set 45544. The sets have different assortments of parts, and they also differ in which EV3 sensors they include. While in the Retail version you have a Touch Sensor, an IR sensor with a Remote IR Beacon, and a Color Sensor, in the Education set you have two Touch Sensors, a Color Sensor, an Ultrasonic Sensor, and a Gyroscopic Sensor. The differences between the two sets are listed in detail in Appendix B.

conclusion

This chapter has provided an overview of the contents of the LEGO MINDSTORMS EV3 31313 set. You learned how to identify the various elements in the set. You've also been introduced to the unique aspects of studless Technic parts: round and cross holes, connection blocks, pins with and without friction, and so on. In Chapter 2, you'll build a simple mobile robot to start exploring the world of robotics with LEGO MINDSTORMS EV3.

2

building ROV3R

Now that you're familiar with the pieces that come in the EV3 set, it's time to build your first robot: ROV3R, a mobile robot that is built with just a few parts. Thanks to its modular design, reconfiguring it for various missions is a snap. In this chapter, I'll show you how to combine the wheeled version of ROV3R with different sensors and tools (see Figures 2-1 and 2-2), but you can easily swap out ROV3R's wheels for treads. In the chapters that follow, you'll learn how the added sensors and tools work and then program these ROV3Rs to accomplish various tasks.

Along with the building instructions that follow, you'll find many tips and tricks. As you read through the instructions, you'll learn various building techniques, tips for making good design choices, and some rules of thumb for building robots with studless LEGO Technic pieces.

Although this book is printed in grayscale, the contrast and readability of the images have been maximized. Almost all of the parts in the 31313 set are white, black, or red. When knowing the color of a certain element is important—for example, to distinguish pins with friction from pins without friction (or axle pins)—I've added labels to indicate the color (see Table 2-1).

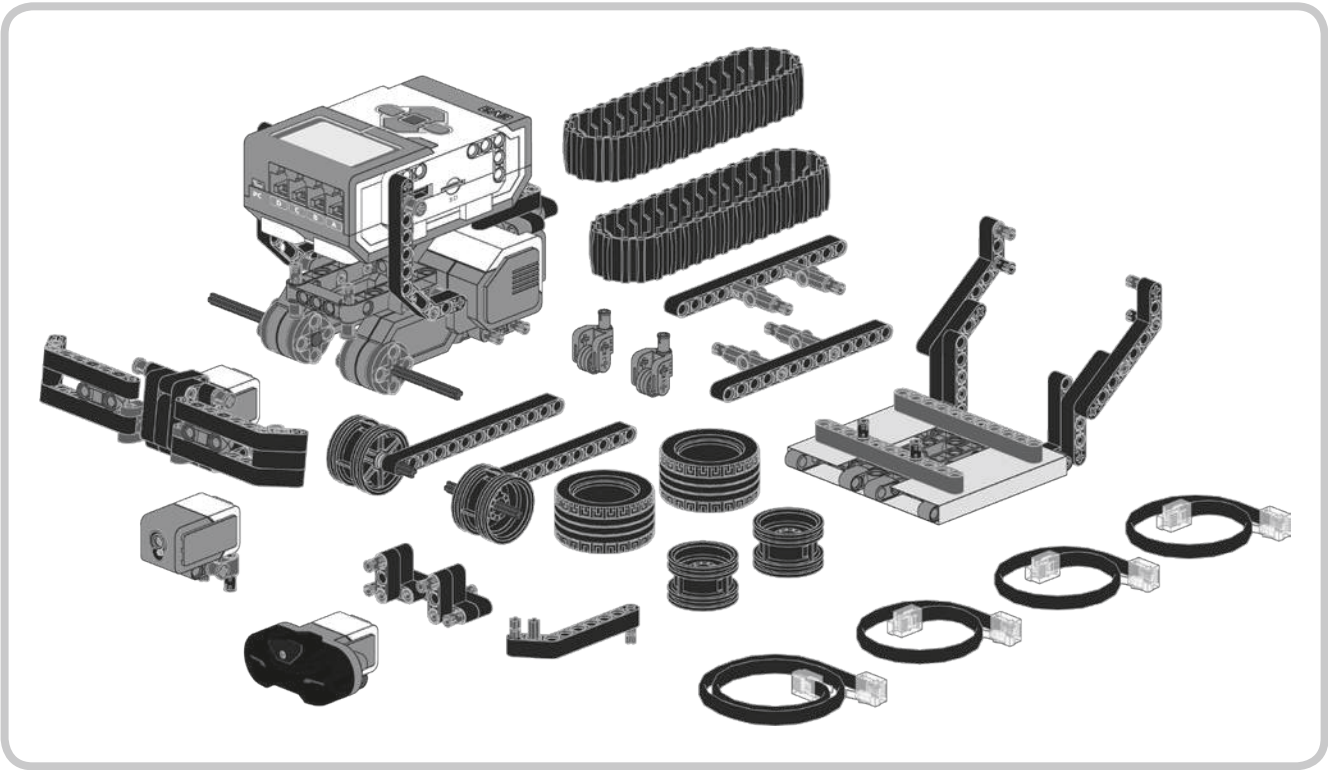


Figure 2-1: An overview of ROV3R's modules

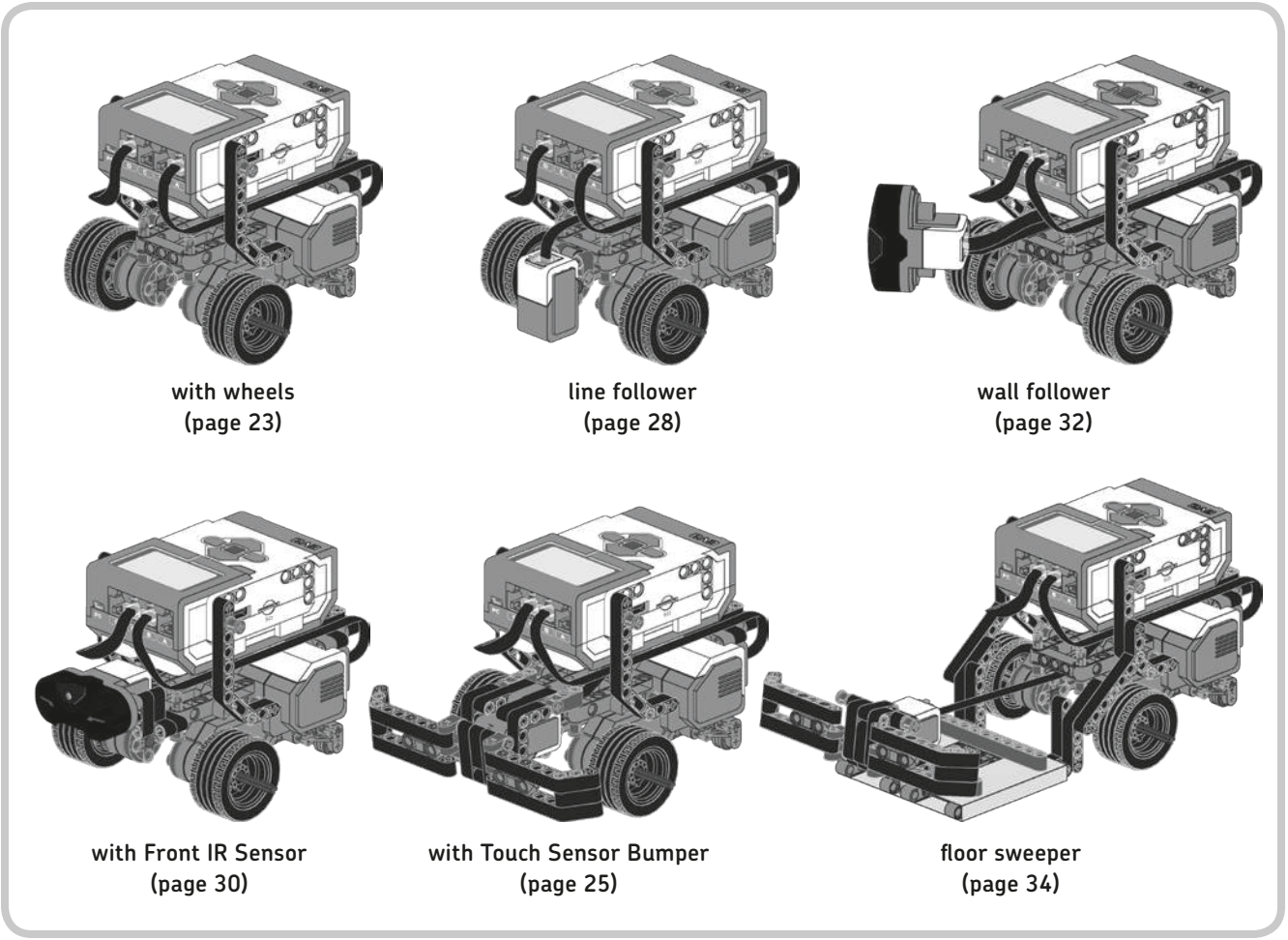


Figure 2-2: ROV3R can be reconfigured in many ways, thanks to its modular design. These are just a few of the possible combinations.

When not otherwise specified, pins are black pins with friction, axle pins are blue axle pins with friction, and 3M pins are long blue pins with friction. And remember that odd-length axles (3M, 5M, 7M, 9M) are light grey.

NOTE This color legend applies to all elements throughout this book.

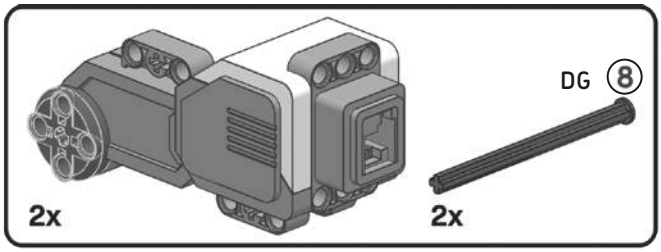
table 2-1: labels used to designate colors in the building instructions

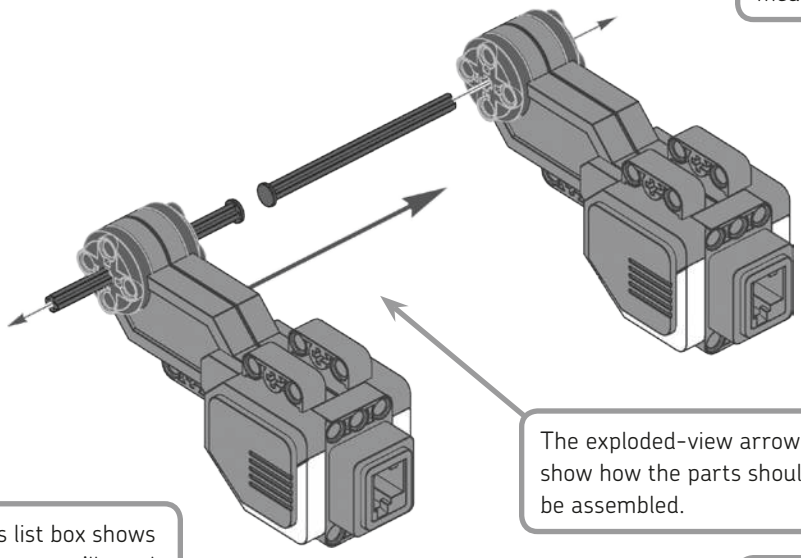
Color	Label
White	W
Grey	G
Dark grey	DG
Yellow	Y
Red	R
Blue	B
Tan	T

base module

First you'll need to build the Base Module, which can be used with wheels (see "ROV3R with Wheels" on page 23) or treads (see "ROV3R with Treads" on page 40).

At the top of an axle, you will see a number indicating its length. To determine the length of an axle, first place it next to a long beam and then count the holes in the beam that lie alongside the axle. You can also use these real-scale pictures to measure axles.

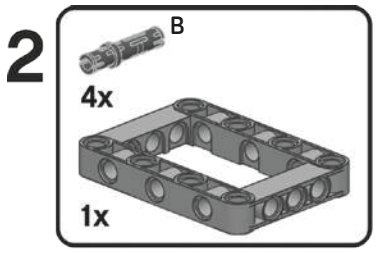


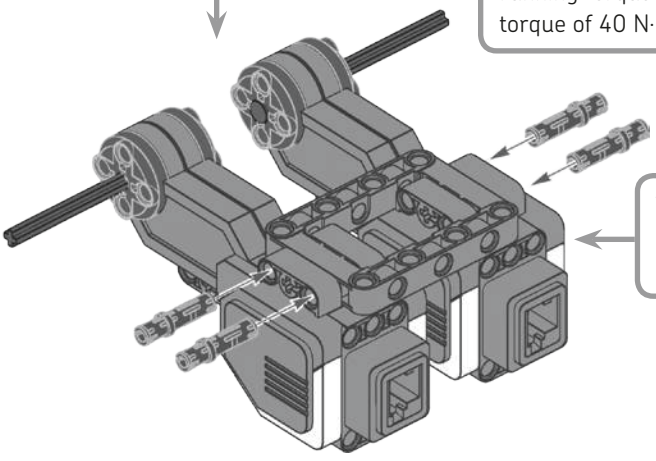


The exploded-view arrows show how the parts should be assembled.

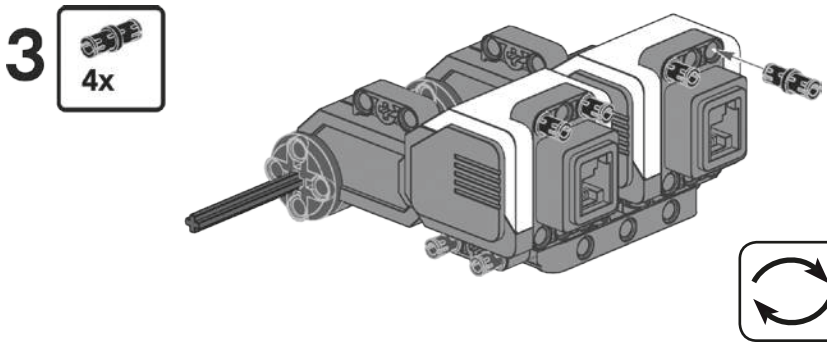
The parts list box shows the elements you'll need for that particular step.

The EV3 Large Servo Motor is internally geared down, with a built-in one-degree-resolution rotation sensor. The Large Motor runs at 160 to 170 rpm, with a running torque of 20 N·cm and a stall torque of 40 N·cm.

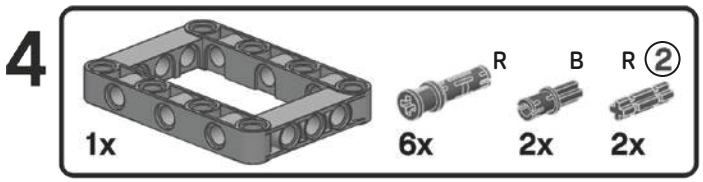


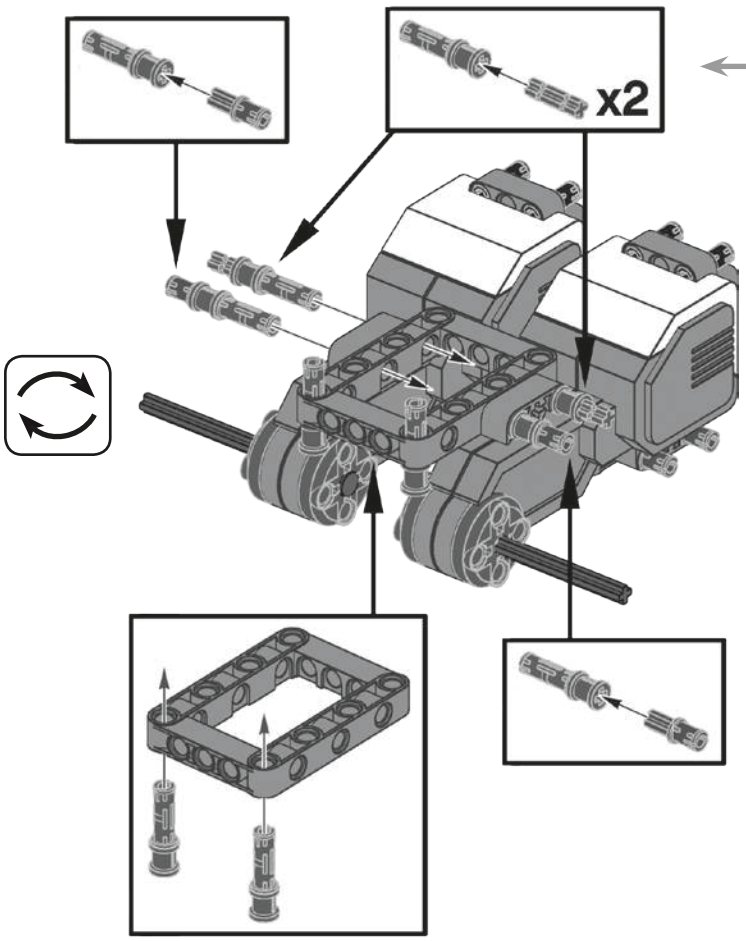


The O-frame holds the motors together. This technique is called *bracing*.



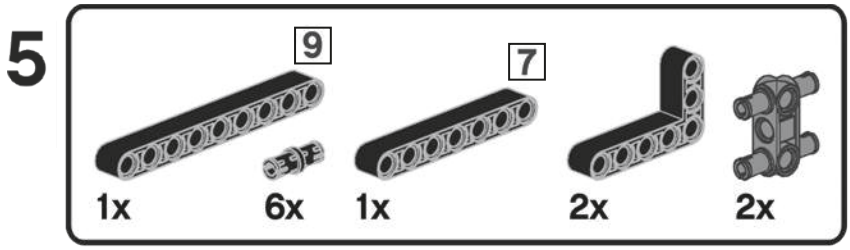
When you see this symbol, rotate the model to look like the picture.

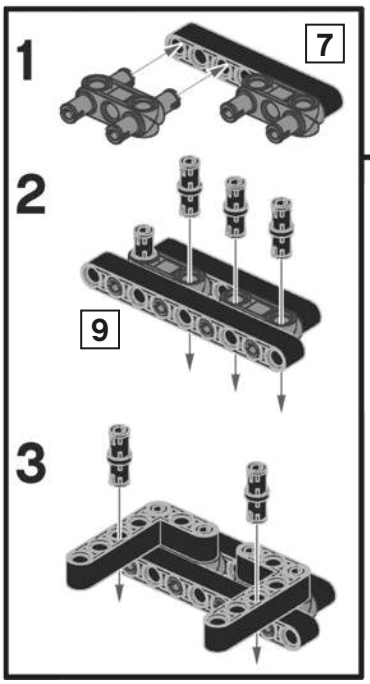


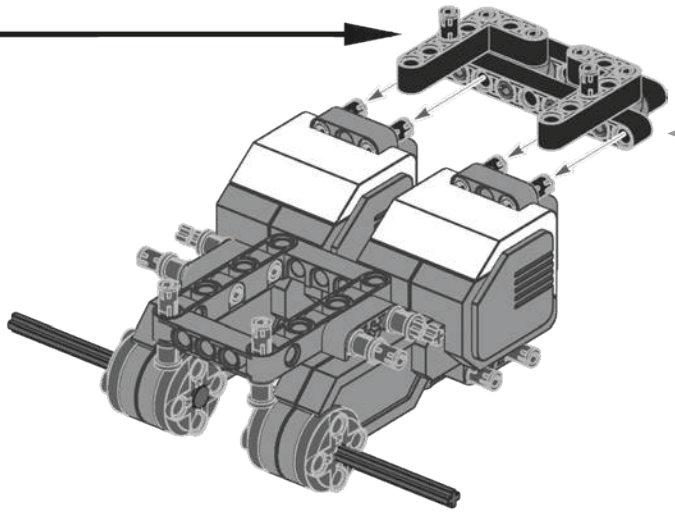


Always build the subassemblies shown in the callouts first. Then add them to the main model.

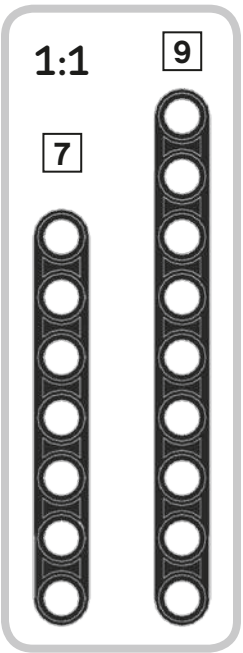
Inserting an axle pin into the cross hole of a 3M pin with stop bush gives you a sort of four-module-long pin.

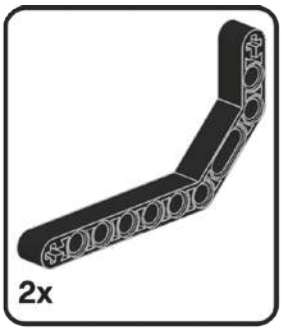


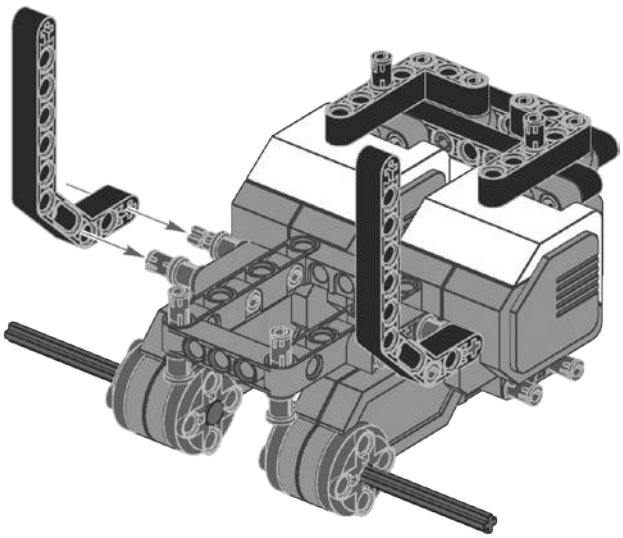




The 9M beam braces the motors so that you can no longer pull them apart. This is another example of bracing.

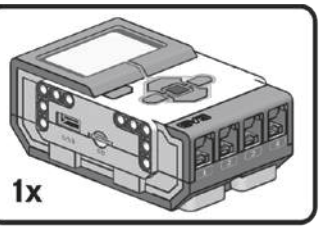


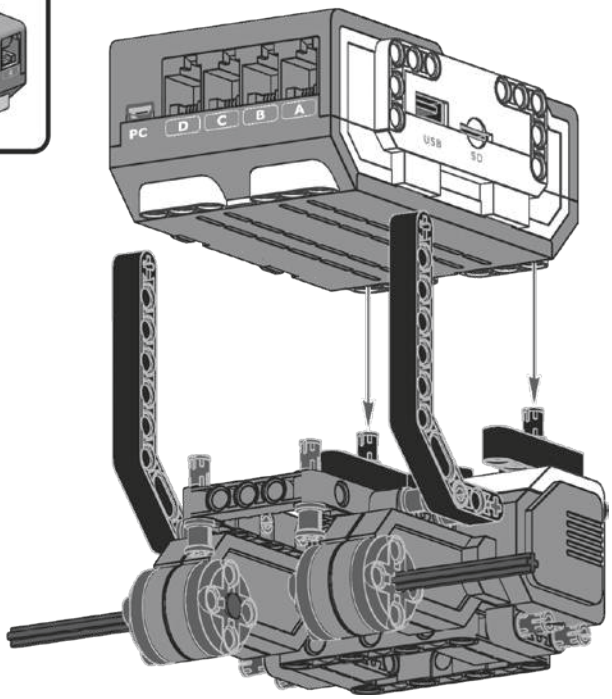




The double angular beam's ends form a right angle, since each bend is 45 degrees.

7





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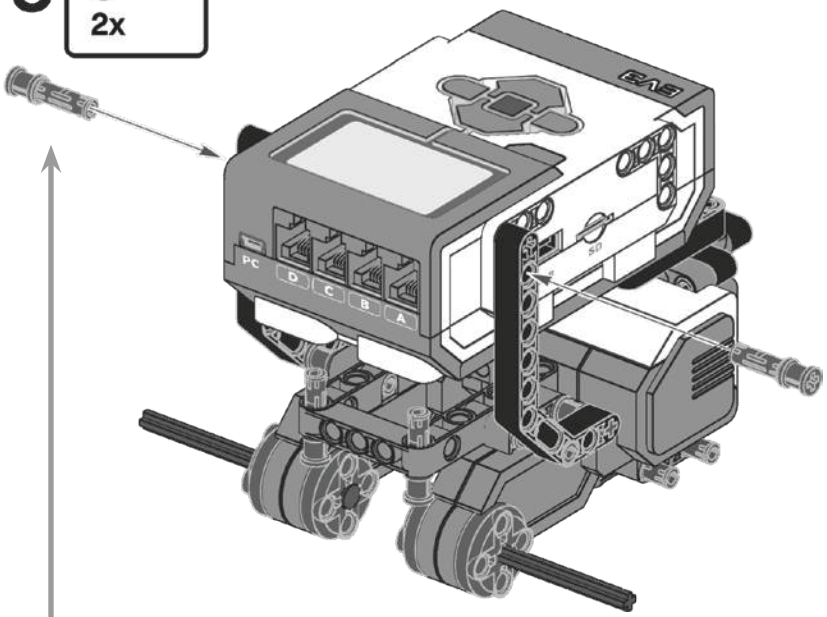

The Base Module is complete.

Lock the EV3 Brick with the 3M pins with stop bush. Thanks to the bush, these pins can be easily grabbed and pulled out with little force.