4

understanding the LEGO MINDSTORMS NXT 2.0 pieces

Once you've begun creating your own robots with the NXT 2.0 set, you'll soon ask a simple but significant question: "How do I build great NXT robots?" Obviously, the NXT 2.0 set is capable of producing some impressive creations, but how do you utilize this potential? Is there a secret to constructing robust, functional, and remarkable robots? Not really. The key is simply to master the use of the LEGO pieces in the NXT 2.0 set.

In the last chapter, we focused specifically on the electronic pieces. In this chapter, we'll broaden our scope to include all the pieces in the NXT 2.0 set, addressing how to approach the entire system and then discussing the new pieces in detail. To acquire a real understanding of the pieces, we'll consider several basic questions: What types of pieces does the NXT 2.0 set include and in what quantities? What are the names of these pieces? What are their purposes?

We'll build upon this knowledge in the next two chapters that discuss construction techniques.

introduction to the pieces

If you haven't yet organized and observed the pieces in your NXT 2.0 set, briefly browse through Appendix A on page XX. You'll notice that there are dozens of different types of pieces in a variety of quantities and colors. Some of the pieces may look kind of strange, and you may have no idea how to use them. But every piece does have a purpose and was included for a specific reason.

NOTE **Pieces included in greater quantities are generally those that you'll use most often in your creations.**

It's natural to assume that all of the pieces in the NXT 2.0 set are MINDSTORMS pieces (i.e., pieces that are specific to the MINDSTORMS series), but besides the electronic pieces, most of them are actually LEGO *TECHNIC* pieces. Realizing this fact is important to understanding the nature of building with the NXT 2.0 set. Launched in 1977, the TECHNIC series—previously known as the *Technical Sets* and then the *Expert Builder* series—enables you to create mechanical (but not intelligent) LEGO inventions. Because TECHNIC creations employ movement, they use many pieces that deviate from the standard brick-and-plate design. Over the years, TECHNIC has proven to be a particularly versatile and powerful subset of LEGO building.

In a sense, MINDSTORMS is an offshoot of TECHNIC because it relies heavily on TECHNIC pieces and building techniques. MINDSTORMS is actually more capable, however, because it combines the ingenuity of TECHNIC pieces with the power of its own robotic components. When using such a powerful construction system, it's particularly important that we begin by considering three related tasks: classifying the pieces, naming the pieces, and measuring the pieces.

classifying the pieces

First, we should *classify* the pieces—not only to stay organized, but also to develop a more complete understanding of the pieces themselves. All of the pieces fit into five primary categories; you'll soon learn which categories include which pieces. The five main categories are as follows:

- Electronics
- Beams
- Connectors
- Gears
- Miscellaneous elements

naming the pieces

Second, we should *name* the individual pieces to facilitate communication. Without names, trying to describe the pieces would be a laborious (and sometimes humorous) task. Imagine that I asked you to grab the *long, thin, shaft-like piece that looks like a stick*. Using a term like *axle* instead is much easier, isn't it?

The LEGO Group doesn't give each of its thousands of pieces an official name, which is unfortunate but understandable. As a result, LEGO fans themselves have attached names to the pieces, resulting in more than a little confusion when the same piece goes by more than one name. Figure 4-1 illustrates this problem.

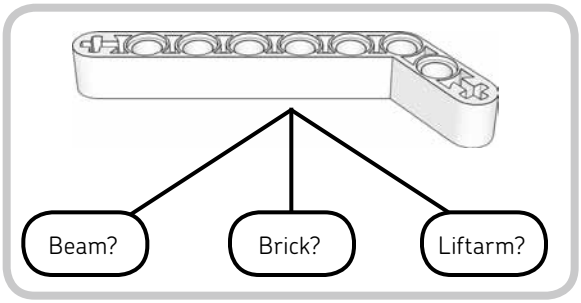

Figure 4-1: Should we call this piece a beam, *a* brick, *or a* liftarm*?*

I don't want to confuse you, so I have selected a unique name for each piece in the NXT 2.0 set and will *always* use these names. I'll introduce them in this chapter and use them consistently throughout the book. You should realize, however, that there isn't one naming standard that everyone follows, and you'll almost certainly hear people refer to pieces by names other than the ones I use in this book.

If you already have names with which you identify TECHNIC pieces, feel free to continue using them. On the other hand, you might consider adopting the naming standard used in this book. I selected or created these names after conducting considerable research, and I have attempted to choose the most concise and accurate names.

measuring the pieces

Third, we should *measure* some of the pieces. You might be thinking, "Why would I need to measure a LEGO piece? Isn't a name all I need to identify a piece?"

That's a good question with a good answer. Because many LEGO pieces are similar, it's sometimes necessary to specify a piece's name *and* a measurement in order to distinguish one piece from another. For example, imagine that you're helping someone build a LEGO robot, and the person extends part of the robot toward you and says, "Make sure you use five straight beams on this section."

While this person has given you a specific name (you'll learn about straight beams in a moment), you're also left wondering, "What kind of straight beams? Small ones? Medium ones? Large ones?" You wouldn't know and you *couldn't* know. Figure 4-2 illustrates this problem.

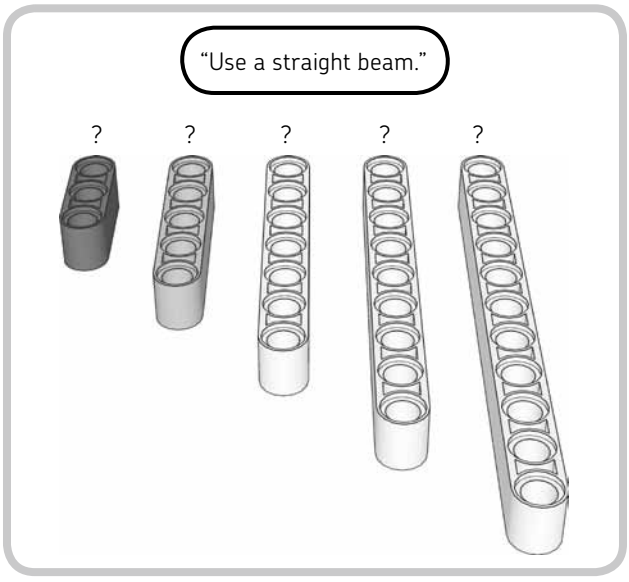

Figure 4-2: If you're told to use a straight beam, which kind of straight beam should you choose?

Using some simple measurements resolves this issue by allowing us to specify exactly which piece we're talking about. For the most part, we'll use the module as our unit of measure, but some pieces in the NXT 2.0 set use other units of measure. You'll learn the details of how and when to measure pieces throughout the rest of this chapter.

NOTE **A third criterion for identifying a piece is color; for example, you might refer to a *light stone gray straight beam*. Since we're only using the NXT 2.0 set in this book, and most of the pieces only come in one color (I'll point out the exceptions later in the chapter), piece colors generally don't present a problem.**

examining the pieces

Armed with an understanding of the basic issues underlying the pieces in the NXT 2.0 set, we're prepared to begin examining the five categories of pieces presented earlier: electronics, beams, connectors, gears, and miscellaneous elements. This is a fundamental section of the book that you should read thoroughly (and even reread), but don't feel like you have to digest it all at once. At any point, move on to something else if you would like—you can always come back to this section later.

NOTE **Consult Appendix A for a summary of the attributes of each piece in the NXT 2.0 set.**

the electronics

This first category includes the NXT, the three servo motors, the four sensors, and the electrical cables. Because of these elements' complexity and capability, I devoted Chapter 3 to them and will not discuss them in further detail here.

the beams

The second category to consider is the beams category. The term *beam* encompasses a variety of pieces that compose the structures of creations. In other words, beams are to your LEGO creations what a foundation, walls, and a roof are to a house. Figure 4-3 offers a comprehensive view of the various types of beams in the NXT 2.0 set; match the number below a piece with its number in Table 4-1 for information about that piece.

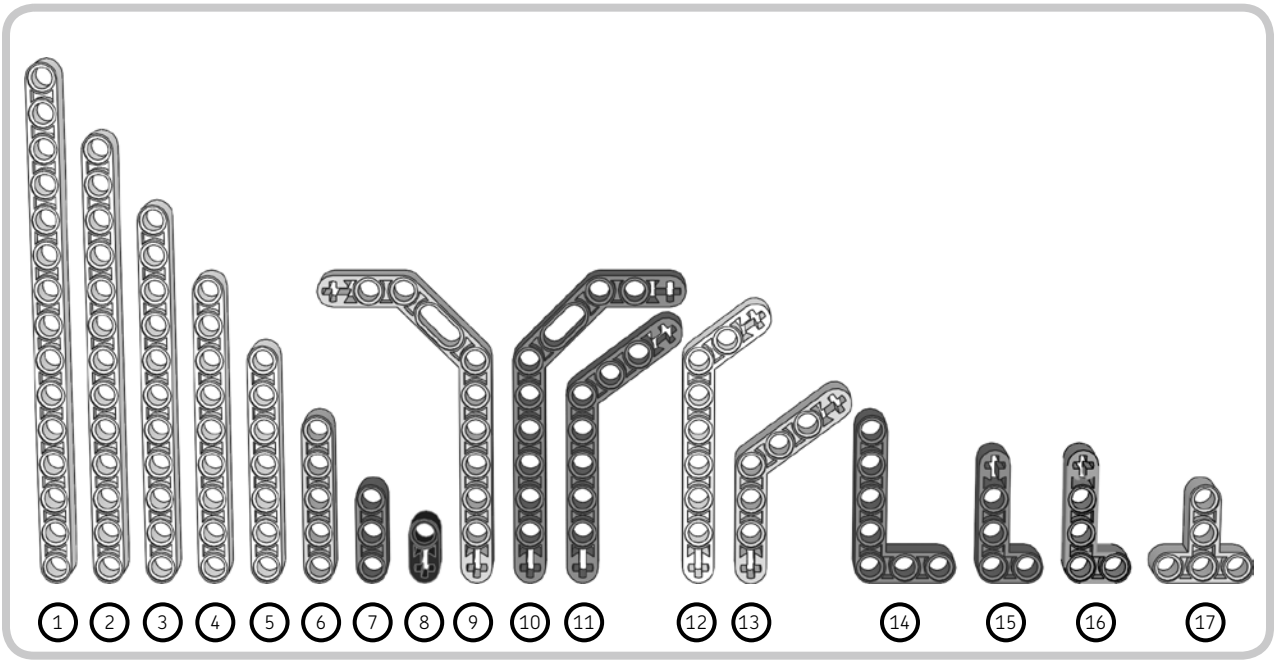

Figure 4-3: The beams in the NXT 2.0 set

We can break down these beams into three subcategories:

- Straight beams
- Right-angled beams
- Angled beams

table 4-1: the beams

number in figure 4-3	piece name	piece color
1	15M beam	Light stone gray
2	13M beam	Light stone gray
3	11M beam	Light stone gray
4	9M beam	Light stone gray
5	7M beam	Light stone gray
6	5M beam	Medium stone gray
7	3M beam	Dark stone gray
8	2M crossed beam	Black
9	11.5M angled beam	Medium stone gray
10	11.5M angled beam	Dark stone gray
11	9M (4 × 6) angled beam	Dark stone gray
12	9M (3 × 7) angled beam	Light stone gray
13	7M angled beam	Medium stone gray
14	7M right-angled beam	Dark stone gray
15	5M right-angled beam	Dark stone gray
16	5M right-angled beam	Orange
17	5M T Beam	Medium stone gray

the straight beam

The *straight beam* (Figure 4-4) is the most basic structural piece, which means that you'll use it often. It has a smooth exterior, rounded ends, and an odd number of holes called *round-holes* that run along the middle. These round-holes are chiefly used to connect the beam to other pieces with TECHNIC connectors (which we'll discuss later in this chapter). In the NXT 2.0 set, the 2M crossed beam is the only straight beam with a round-hole *and* a cross-hole; we'll discuss the cross-hole in the "Angled Beams" section on page 35.

If you observe Figure 4-3 again, you'll notice eight different types of straight beams in the NXT 2.0 set. To distinguish one straight beam from another, we measure their lengths in modules, a basic TECHNIC unit that is abbreviated *M*. Between two adjacent round-holes on a straight beam is an hourglass-shaped depression. A *module* is the distance from the center of one of these depressions to the center of an adjacent depression, and it measures approximately 8 mm. Figure 4-5 shows exactly what a module is, and Figure 4-6 shows how to use the module to measure a straight beam. In "The Connectors" on page 36, we'll also use the module to measure other types of pieces.

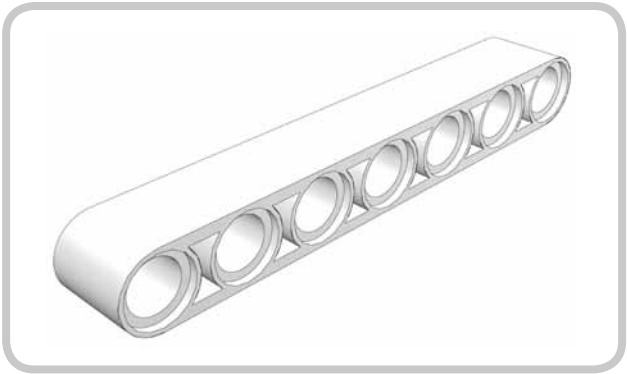

Figure 4-4: The 7M beam is an example of a straight beam.

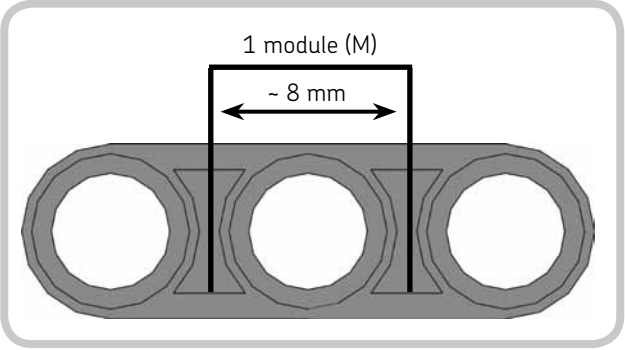

Figure 4-5: A module (M) is about 8 mm, the distance from the center of one hourglass-shaped depression to the center of the adjacent depression.

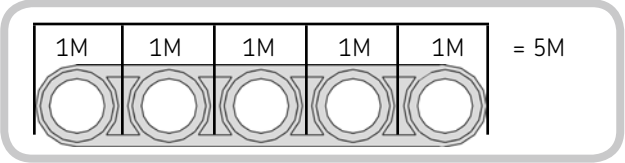

Figure 4-6: For this beam, adding up the number of modules equals a total measurement of 5M.

NOTE The number of round-holes in a straight beam corresponds to its module measurement, which means you can count round-holes as a measuring shortcut. For example, as you can see in Figure 4-6, a straight beam with five round-holes has a module measurement of 5M.

To properly describe a straight beam, you must give both its module measurement and its name. However, when we give a straight beam's module measurement, we drop the word *straight* from the name. For example, a straight beam measuring 3M (three modules) would be called a *3M beam*, a straight beam measuring 5M (five modules) would be called a *5M beam*, and so on. When only the module measurement and the word *beam* are given, it's understood that the piece in question is a straight beam.

Straight beams exist in sizes ranging from 2M to 15M, and the different sizes are designed to accommodate different situations. In one case, you may want to use a long straight beam; in another situation, you may want to use a short straight beam.

the angled beam

The *angled beam* (Figure 4-7) is primarily different from the straight beam in that one or more sections of the beam are angled. Sometimes this type of beam simply makes a creation more interesting, while other times it can play important structural roles (e.g., some angled beams work well as "fingers" on grabbing mechanisms). Looking back at Figure 4-3 once again, you'll notice that five types of beams in the NXT 2.0 set fall into the angled beam subcategory, ranging in sizes from 7M to 11.5M.* The 11.5M angled beams come in two colors, dark stone gray and medium stone gray, meaning that there are actually four unique types (sizes) of angled beams.

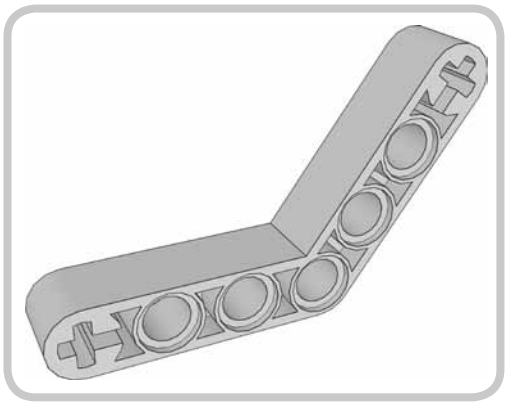

Figure 4-7: The 7M angled beam is an example of an angled beam.

Most of the angled beams have another important but less noticeable characteristic: cross-holes. Figure 4-8 shows the same beam as in Figure 4-7 but points out its two cross-holes. A *cross-hole* is specifically used with connectors known as *cross-axles* or simply *axles*, which you'll learn about in "The Connectors" on page 36. When measuring an angled beam, proceed exactly as you would when measuring a straight beam (Figure 4-9). Having a combination of both round-holes and cross-holes makes no difference in how you measure a beam.

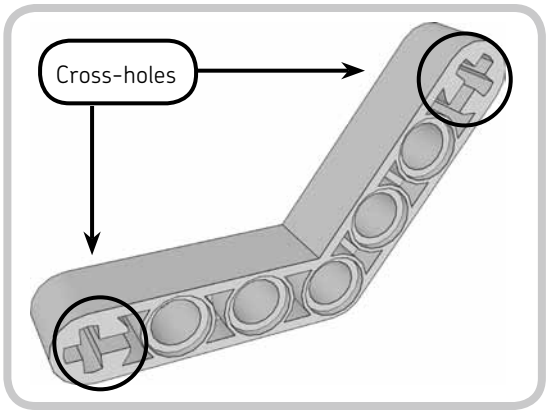

Figure 4-8: Some angled beams, such as the 7M angled beam, have cross-holes.

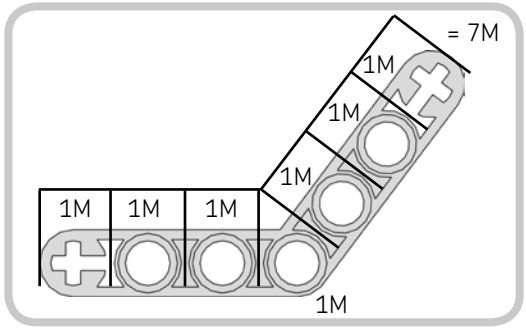

Figure 4-9: Measure an angled beam just as you would measure a straight beam.

Also, you might have noticed that two types of angled beams have a measurement of 9M but have slightly different angles. How do we distinguish between these two beams? On one of the 9M angled beams, the shorter angled section is three holes long, while the longer straight section is seven holes long. So we add a 3 × 7 in parentheses after the 9M like this: a 9M (3 × 7) angled beam. On the other 9M angled beam, the shorter angled section is four holes long, while the

* The 11.5M angled beam has a half module in its measurement because of a 1.5M gap between two round-holes.

longer straight section is six holes long. So we add a 4 × 6 in parentheses after the 9M like this: a 9M (4 × 6) angled beam.

the right-angled beam

The *right-angled beam* (Figure 4-10) is simply an angled beam with a right angle (i.e., an angle of 90 degrees). This kind of beam is quite useful, as there are many cases in which a right-angled beam can help you to properly position and brace pieces. Looking back at Figure 4-3 one more time, you'll notice that four types of beams in the NXT 2.0 set fall into the right-angled beam subcategory, ranging in sizes from 5M to 7M. The 5M right-angled beams come in two colors—dark stone gray and orange—meaning that there are actually three unique types (sizes) of right-angled beams. Also, the 5M T beam is a new piece—both for the NXT 2.0 set and as a LEGO element itself—and is very useful in certain situations. You only have two of them, though, so use them wisely. Finally, the right-angled beams have only round-holes except for the 5M right-angled beams, which have one cross-hole.

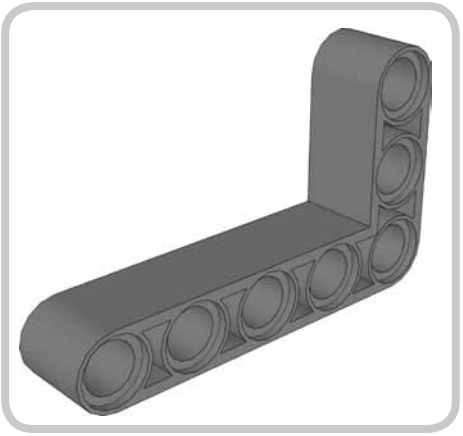

Figure 4-10: The 7M right-angled beam is an example of a right-angled beam.

the connectors

We can now transition to the connectors category, which is the largest category in terms of both types and quantities of pieces. *Connector* is a general term which encompasses a variety of pieces that provide connectivity. In essence, TECHNIC connectors are like nails, staples, screws, bolts, and other similar items that hold a structure together. Figure 4-11 presents the various connectors in the NXT 2.0

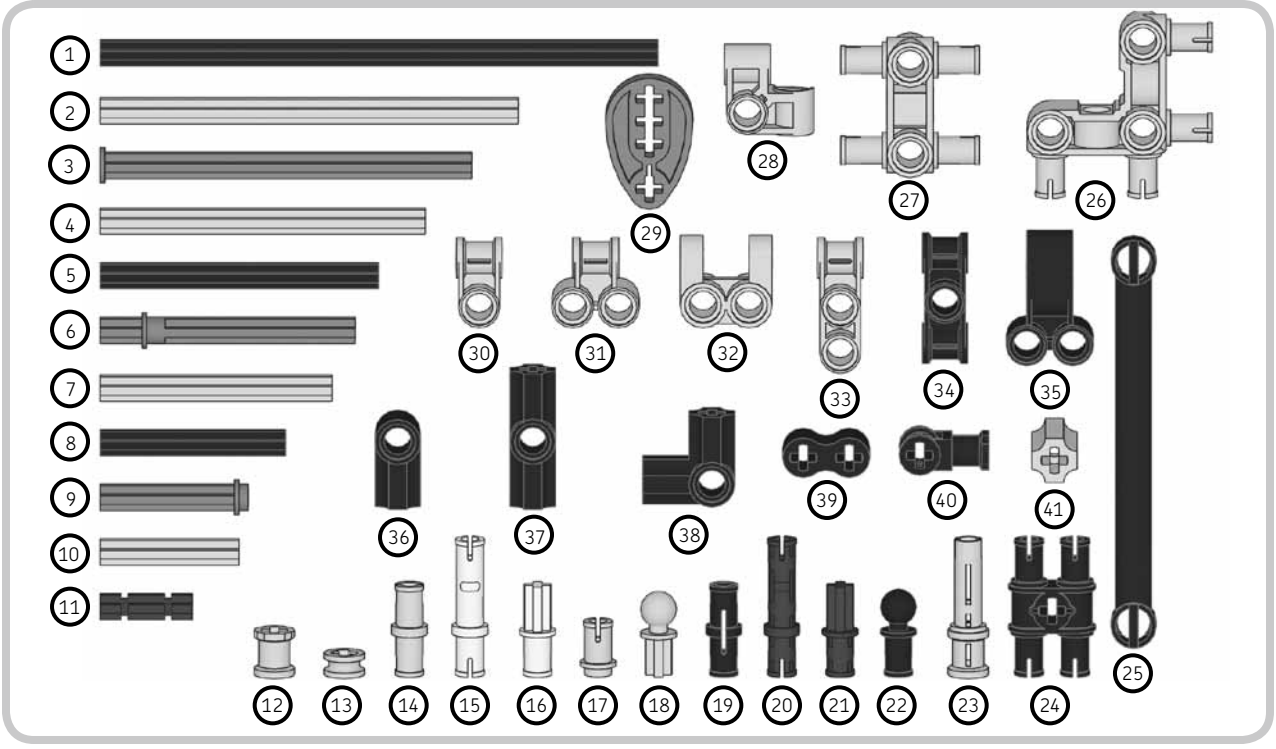

Figure 4-11: The connectors in the NXT 2.0 set

table 4-2: the connectors

number in figure 4-11	piece name	piece color
1	12M axle	Black
2	9M axle	Medium stone gray
3	8M stopped axle	Dark stone gray
4	7M axle	Medium stone gray
5	6M axle	Black
6	5.5M stopped axle	Dark stone gray
7	5M axle	Medium stone gray
8	4M axle	Black
9	3M studded axle	Dark stone gray
10	3M axle	Medium stone gray
11	2M notched axle	Red
12	Bushing	Medium stone gray
13	Half-bushing	Medium stone gray
14	Smooth peg	Medium stone gray
15	3M smooth peg	Tan
16	Smooth axle peg	Tan
17	Studded peg	Medium stone gray
18	Axle ball peg	Medium stone gray
19	Friction peg	Black
20	3M friction peg	Blue
21	Friction axle peg	Blue
22	Friction ball peg	Black
23	Bushed friction peg	Medium stone gray
24	Double friction peg	Black
25	9M steering link	Black
26	Right-angled block	Medium stone gray
27	3M block	Medium stone gray
28	Cornered peg joiner	Medium stone gray
29	Cam	Dark stone gray
30	Cross block	Medium stone gray
31	Double cross block	Medium stone gray
32	Split cross block	Medium stone gray
33	Extended cross block	Medium stone gray
34	Inverted cross block	Black
35	Double peg joiner	Black
36	#1 angle connector	Black
37	#2 angle connector	Black
38	#6 angle connector	Black
39	Flexible axle joiner	Black
40	Catch	Black
41	Axle extender	Medium stone gray

set; match the number by a piece with its number in Table 4-2 for information about that piece.

We can break down these connectors into three subcategories:

* Axles
* Pegs
* Connector blocks

the axles

The *axle* is one of the most vital connectors, but it's nothing more than a cross-shaped shaft (Figure 4-12). Although its full name is the *cross-axle*, it's more commonly known simply as the *axle*, which is how I'll refer to it. The NXT 2.0 set includes 61 axles of 11 different types, which signals that the axle is indeed an important piece.

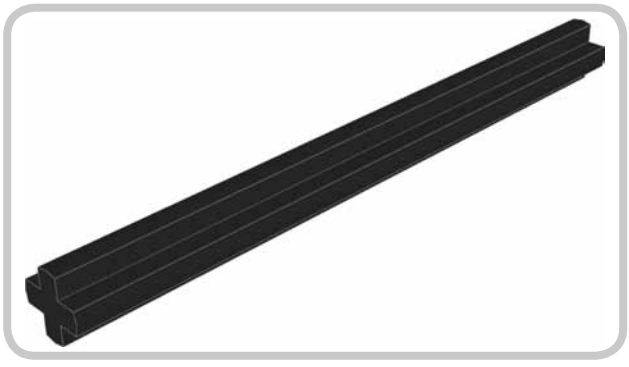

Figure 4-12: The 8M axle is an example of an axle.

I mentioned earlier that the cross-holes in beams (and other pieces) specifically accommodate axles, so you might think that you only use axles in situations involving cross-holes. Using an axle with one or more cross-holes does create a very rigid connection, as the leftmost part of Figure 4-13 demonstrates. However, using an axle with one or more round-holes allows the axle to spin freely, as the rightmost part of Figure 4-13 demonstrates. (Note that we would normally keep the axle in place with other pieces.) Powered by motors, rotating axles are the basis of nearly all forms of movement in NXT robots. By attaching one or more pieces to rotating axles, we can develop various forms of movement, such as driving or walking. You'll learn more about this concept in "The Gears" on page XX and in Chapter 6.

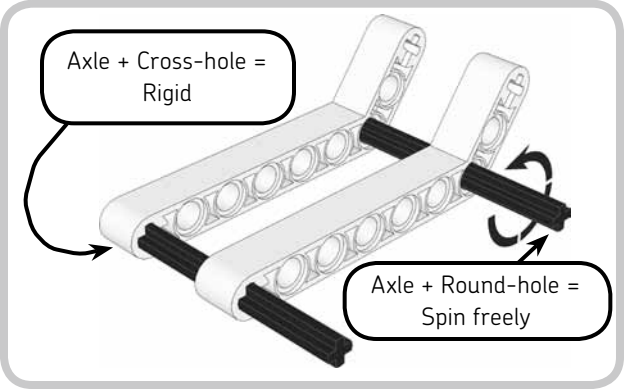

Figure 4-13: Using an axle in cross-holes creates a very rigid connection, while using an axle in round-holes allows the axle to spin freely.

Since a variety of axles exist—mainly in different lengths—it's imperative that we measure them. The module is the unit of measure for axles, but it's more difficult to measure axles in modules because axles don't have round-holes or cross-holes. Fortunately, in the NXT 2.0 set and other more recent LEGO sets, the axles are color-coded: Axles with an even module measurement (such as 4M and 6M) are black, while axles with an odd module measurement (such as 3M and 5M) are medium stone gray. This means that with some practice you can successfully deduce an axle's module measurement just by its color and relative length. If you're ever unsure of an axle's size, you can also compare it against the axles pictured on the back cover of your LEGO MINDSTORMS user guide.

NOTE The 2M notched axle is red, not black like other axles with an even module measurement. Since the 2M axle is quite small, its color helps you to see it amidst a pile of other black axles.

Three axles are neither black nor medium stone gray. The 8M stopped axle, 5.5M stopped axle, and 3M studded axle are dark stone gray. This difference in color merely signifies that these are specialized axles: Each one has some sort of "stop" along the axle that prevents pieces from moving all the way down the axle. This feature is useful for keeping pieces in place and functions like a permanent bushing (discussed next).

Finally, I must mention two important pieces that we call *axle accessories*: the bushing and half-bushing (Figure 4-14). These two parts, which are essentially cross-holes in piece form, rigidly hold their place anywhere along an axle. They generally function as separators when positioned between pieces on an axle and as fasteners when used to prevent an axle from falling out of a round-hole or a piece from falling off an axle. You'll always want to keep some of these pieces close at hand when working with axles.

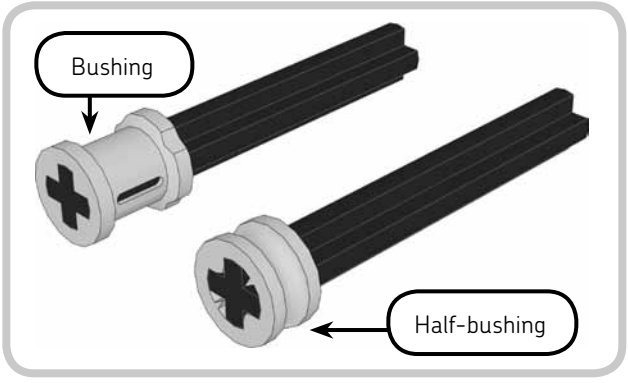

Figure 4-14: The bushing and half-bushing are assistants to the axle.

the pegs

Though quite small, pegs are also vital components of TECHNIC construction (Figure 4-15).* They can be used to easily yet firmly connect two or more pieces. The NXT 2.0 set includes over 200 pegs of 11 different types—that's about 35 percent of its entire collection of pieces! Depending on the type of peg, it may snap into a round-hole, a cross-hole, or both. The peg shown in Figure 4-15 is the most basic peg—in fact, it's commonly called *the peg*—and when pushed into a round-hole, it goes as far as its *stop ridge*, which circles the middle of the peg. Hence, it can connect two pieces, one on each side of its stop ridge. However, we often use two or more pegs together, as Figure 4-16 illustrates.

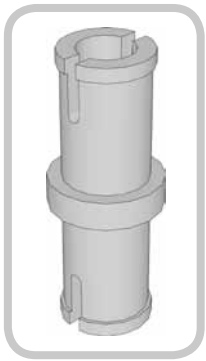

Figure 4-15: The smooth peg is an example of a peg.

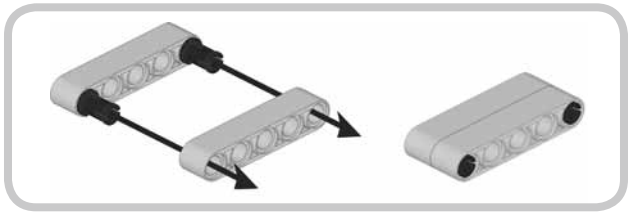

Figure 4-16: Two friction pegs connecting two 5M beams

There are two main types of pegs: smooth pegs and friction pegs. *Smooth pegs* can swivel freely in place; *friction pegs* cannot. Friction pegs stiffly keep their position, but not so stiffly as to be immovable. The NXT 2.0 set includes five different types of smooth pegs (numbered 14 through 18 in Figure 4-11) and six different types of friction pegs (numbered 19 through 24 in Figure 4-11). In terms of quantity, the NXT 2.0 set includes mostly friction pegs, since you'll use these most often. If you build the example shown in Figure 4-17—using a 5M beam, a smooth peg, and a friction peg—you'll better understand the concept of smooth pegs and friction pegs. Just twist the pegs with your fingers.

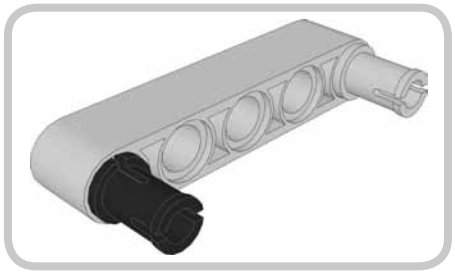

Figure 4-17: Twist each peg to feel the difference between a friction peg and a smooth peg.

NOTE Many people drop the word *smooth* when referring to any kind of smooth peg. However, for the sake of clarity in this book, I will always include the word *smooth* when referring to any smooth peg.

Do we measure pegs? In most cases, no. We can correctly identify most pegs by their names alone. However, the two most basic pegs—the smooth peg and the friction peg—each have a slightly longer counterpart that we'll designate the 3M smooth peg and the 3M friction peg, respectively. Do you remember what the actual length of a module is? It's about 8 mm. Not by accident, the smooth peg and friction peg are 16 mm long, which corresponds to two modules (2M). The longer smooth peg and longer friction peg are each just 8 mm longer, for a total of 24 mm (3M). Also, the studded peg—a new piece in the NXT 2.0 set—is about half the size of a regular smooth or friction peg.

NOTE In the NXT 2.0 set and other more recent LEGO sets, pegs are color-coded to help you distinguish between smooth pegs and friction pegs. The smooth pegs are tan or medium stone gray, and the friction pegs are black or blue. As usual, there's an exception: The bushed friction peg in the NXT 2.0 set is medium stone gray, not black or blue.

Finally, the NXT 2.0 set also includes a *peg accessory*: the 9M steering link (Figure 4-18). (If you compare the black 9M steering link to a 9M beam, you can prove to yourself

* Pegs are also commonly known as *pins*.

that they are the same length.) This piece is a complement to the axle ball peg and the friction ball peg and offers very flexible forms of movement. If you want to better understand the flexibility of steering links, build the example pictured in Figure 4-18. Incidentally, the famous Alpha Rex robot that appears on the front cover of the NXT 2.0 set uses steering links.

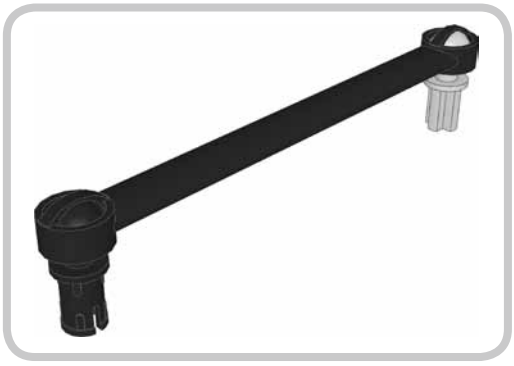

Figure 4-18: Steering links and ball pegs work together to provide flexible forms of movement.

the connector blocks

Connector blocks are unique in that they are connectors in every sense and rightfully belong in the connectors category, but they usually require that you use them with pegs, axles, or both—which are connectors themselves! If you briefly glance back at Figure 4-11 and the pieces numbered 26 through 41, you'll get a sense for the diversity of this subcategory. Measuring is unnecessary for most of these pieces. Figure 4-19 shows the *cross block*, a very common and useful connector block, which has both a round-hole and a cross-hole.

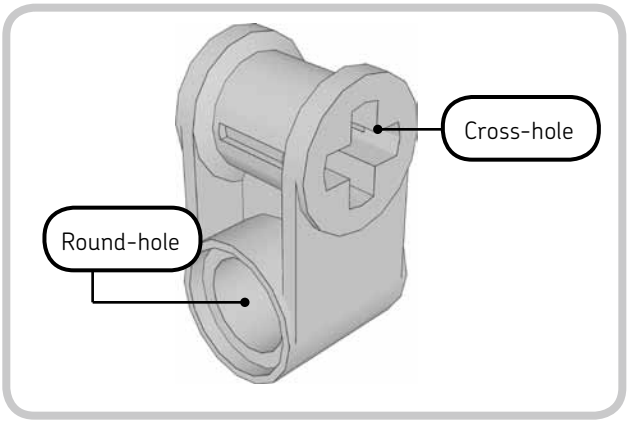

Figure 4-19: The cross block is an example of a connector block.

The purpose of the cross block or any other connector block is to enhance your construction abilities. Although you *could* create robots entirely out of beams, pegs, and axles, connector blocks help you build more interesting and complex structures and mechanisms. For example, Figure 4-20 shows how two cross blocks—in combination with an axle, a bushing, and friction pegs—can position a beam in a manner that would be difficult to achieve using just beams with pegs or axles. The projects in Part IV will show you many ways to creatively and effectively employ connector blocks.

Figure 4-20: Connector blocks help you to create more interesting and complex structures and mechanisms.

the gears

Except for the electronic elements, LEGO gears are probably the most fascinating pieces in the NXT 2.0 set. The term *gear* encompasses a variety of pieces that transmit motion. Since a gear generally fits the description of a wheel with teeth, it's sometimes called a *gearwheel*. Figure 4-21 presents the various gears included in the NXT 2.0 set; match the number above a piece with its number in Table 4-3 for information about that piece.

table 4-3: the NXT gears

number in figure 4-21	piece name	piece color
1	12t bevel gear	Tan
2	12t double bevel gear	Black
3	20t double bevel gear	Black
4	36t double bevel gear	Black
5	Knob wheel	Black

How do LEGO gears transmit motion? They accomplish this task through their teeth, as Figure 4-22 demonstrates. When the teeth of two gears *engage* or *mesh*, the rotation of any one gear causes the other gear to rotate. Notice that the gears are mounted on axles by means of their cross-holes, and the axles are mounted in round-holes so that they can rotate freely. We set up most LEGO gears in this manner. As you learned earlier, motion originates with the axles, and gears generally transmit motion between axles. Watching LEGO gears in action is exciting, but so is building with them—especially when you learn to utilize the underlying properties that govern their operation. We'll cover gearing techniques in Chapter 6. Also, it's worth noting that since the NXT 2.0 set does not include many gears (especially in comparison to the original version of the NXT set), you'll often attach pieces directly to the motor shaft heads rather than using gears to transmit motion from the motors to other parts of your robot.

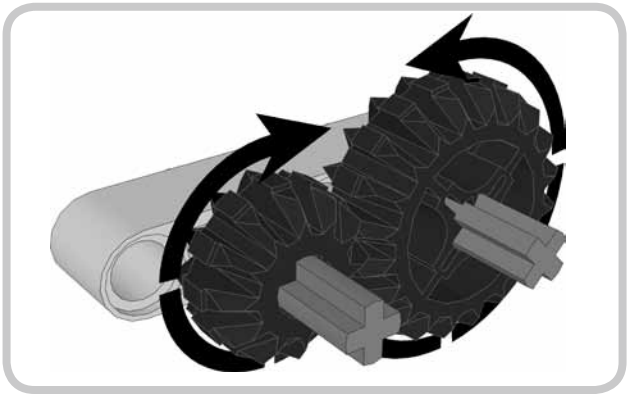

Figure 4-22: When two gears mesh, motion can transfer between the gears and, subsequently, their axles.

At this point you might be wondering, "How do we measure gears?" The answer is simple: We count teeth! With most gears we can simply count the number of their teeth and then abbreviate *teeth* with the letter *t*. For example, a gear with 12 teeth would have a measurement of *12t*. In Figure 4-22, the smaller gear has 12 teeth (12t) and the larger gear has 20 teeth (20t).

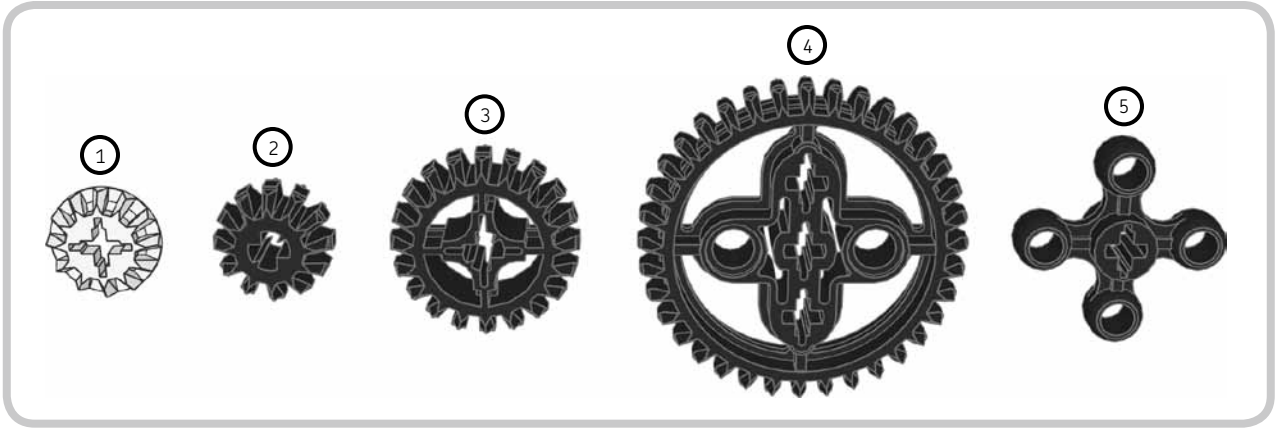

Figure 4-21: The gears in the NXT 2.0 set

The LEGO Group has introduced a variety of gears over the years, but there are just three subcategories of gears in the NXT 2.0 set. You can combine a gear's subcategory name with its measurement to get its complete name. Let's observe these three subcategories:

* Bevel gears
* Double bevel gears
* Other gears

bevel gears

A *bevel gear* (Figure 4-23) has teeth on one side that can only mesh with teeth on other bevel or double bevel gears positioned on perpendicular axles. In other words, the bevel gear transmits motion at a right angle, as shown in Figure 4-24. The NXT 2.0 set includes one bevel gear: the 12t bevel gear. You'll find this small gear useful when you want to transmit motion at a right angle but don't have much room. Unless you have other bevel gears in your LEGO collection, you'll need to use the bevel gear with a double bevel gear, since the NXT 2.0 set has only one bevel gear.

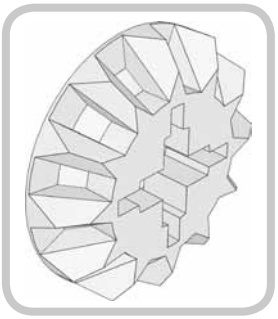

Figure 4-23: The 12t bevel gear is an example of a bevel gear.

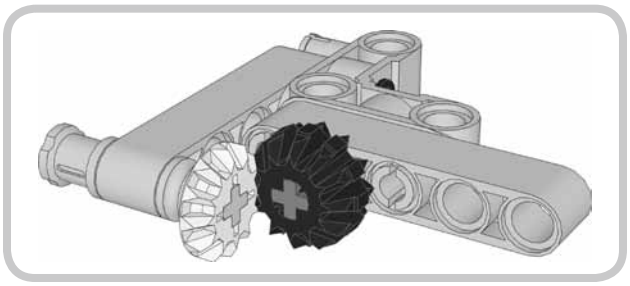

Figure 4-24: Bevel gears transmit motion at a right angle.

double bevel gears

A *double bevel gear* (Figure 4-25) is a truly unique piece. Its uniqueness lies in the fact that it can use its specially-shaped teeth to act like two different types of gears. First, like bevel gears, double bevel gears can mesh when positioned on axles that are *not* parallel (*skewed*), usually engaging at right angles. Second, double bevel gears can mesh when positioned on axles that *are* parallel, as shown in Figure 4-22. The NXT 2.0 set contains three kinds of double bevel gears: the 12t, 20t, and 36t.

Figure 4-25: The 20t double bevel gear.

other gears

The knob wheel (Figure 4-26) is the only gear from the NXT 2.0 set in this subcategory. While classifying the knob wheel as a gear is a bit of a stretch, I've done so because it functions as a gear: It transmits motion from one axle to another. This piece, however, has the limitation of only working with another knob wheel. In other words, the knobs on two knob wheels "mesh," causing the same rotary motion produced by the meshing of toothed gears. On the other hand, an advantage of knob wheels is that they mesh equally well when positioned on parallel and skewed axles. In fact, the knob wheel performs particularly well when transmitting motion at a right angle.

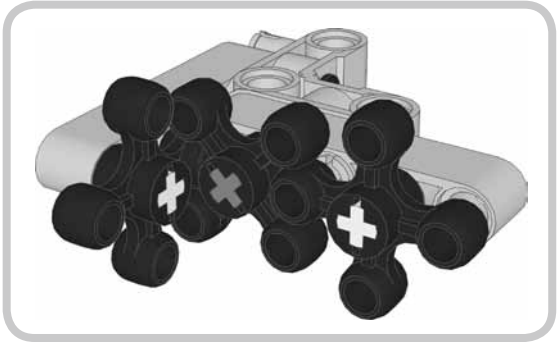

Figure 4-26: The knob wheel acts just like a gear with teeth.

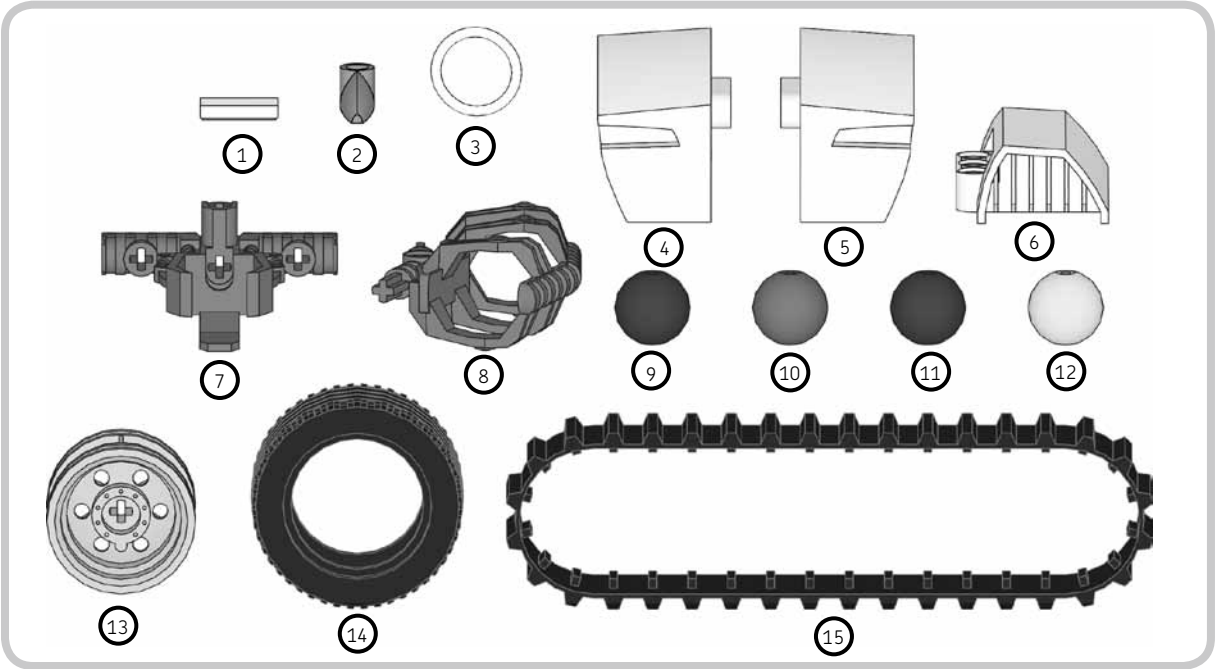

Figure 4-27: The miscellaneous elements in the NXT 2.0 set

the miscellaneous elements

We have reached the fifth and final category of pieces, the miscellaneous elements. Defining these pieces is rather simple: A miscellaneous element is a piece that does not fit into any of the previous four categories. Figure 4-27 presents all of these miscellaneous pieces; match the number below each piece with its number in Table 4-4 for information about that piece. Even though some of these elements do have their own units of measure—you'll notice, for example, that the tire is marked 43.2 × 22—we can just use a name to identify each piece because there are not many pieces in this subcategory, and each piece is quite unique. For instance, there's only one type of tire in the NXT 2.0 set, so we'll simply call it *the tire*.

The applications of these pieces are as varied as the pieces themselves. The tile and TECHNIC tooth may be great decorative pieces, but they can also serve important functions: The tile allows pieces to smoothly slide or roll across it, and the tooth can be especially useful in grabbing mechanisms. The rubber band has countless uses and is especially common in bumpers (touch-sensing mechanisms). The three fairing elements are definitely great as decorative parts, but even these can have unconventional uses: One of the challenges for the official Color Sorter robot uses the

table 4-4: the miscellaneous elements

number in figure 4-27	piece name	piece color
1	Tile	White
2	TECHNIC tooth	Orange
3	Rubber band	White
4	Right fairing	Light stone gray
5	Left fairing	Light stone gray
6	Intake fairing	Light stone gray
7	Ball shooter	Pearl light gray
8	Ball magazine	Pearl light gray
9	Ball	Red
10	Ball	Green
11	Ball	Blue
12	Ball	Yellow
13	Wheel	Medium stone gray
14	Tire	Black
15	Tread	Black

intake fairing to hold balls for a catapult. The ball shooter, ball magazine, and collection of different colored balls make up an exciting system with which you can rapidly shoot balls—but again, you can do things with balls other than just shoot them. The tires, wheels, and treads usually give mobility to vehicles. In Part IV you'll see some of the many ways these miscellaneous pieces can be put to use. You'll realize quickly that although some of these pieces may not seem especially useful, they can be indispensible in some of your projects.

conclusion

Exploring the topic of LEGO MINDSTORMS NXT 2.0 construction is incredibly fun, and the magnitude of the subject is astonishing. As you learned in this chapter, one of the first steps is to acquire a solid understanding of the LEGO pieces in the NXT 2.0 set. We began by discussing some basic concepts related to the pieces, and then we proceeded to examine each of the five categories of pieces in the NXT 2.0 set: electronics, beams, connectors, gears, and miscellaneous elements. In the following chapter, you'll learn practical techniques for building effective structures for NXT robots.