4

understanding the LEGO MINDSTORMS NXT pieces

Once you've begun creating your own robots with the NXT set, you'll soon ask a simple but significant question: "How do I build great NXT robots?" Obviously, the NXT 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 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 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 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

Since we'll be encountering dozens of different types of pieces in a variety of quantities, our first task should be to quickly get an overview of them. Figure 4-1 shows each type of piece included in the NXT set, followed by an *x* and a number, which specify the number of those pieces that are included.* Briefly look over it to gain a basic understanding of the building elements.

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 set are MINDSTORMS pieces (i.e., pieces that are specific to MINDSTORMS), but besides the electronic pieces, most of them are actually LEGO *TECHNIC* pieces. Realizing this fact is important to understanding the nature of MINDSTORMS NXT construction. 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.

* The exact count of pieces in your NXT set may slightly differ. A LEGO set usually includes a few extra of some of its smaller pieces.

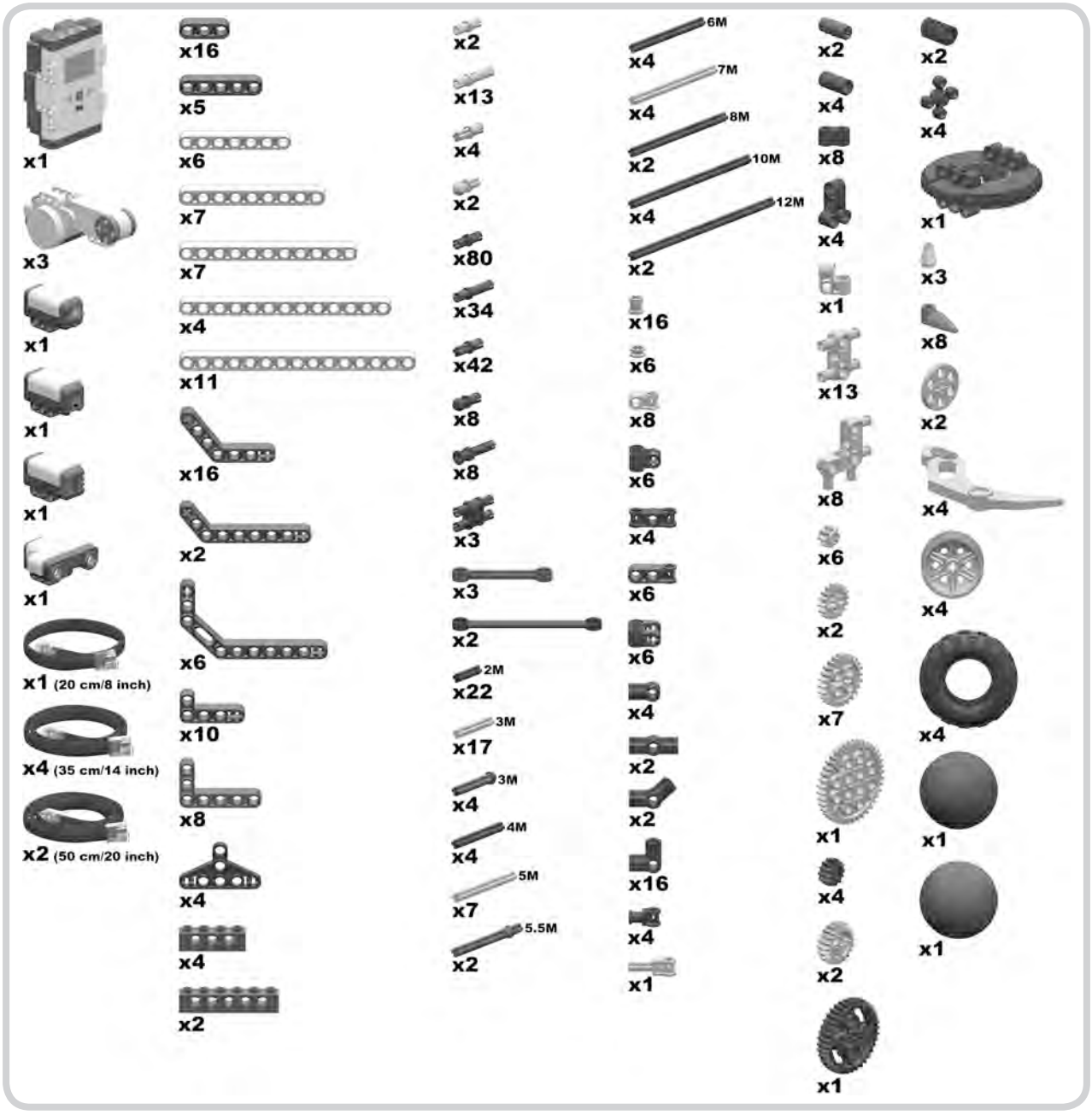

Figure 4-1: The types and quantities of pieces in the NXT set

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
- Connectors
- Miscellaneous elements
- Beams
- Gears

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 4-2 illustrates this problem.

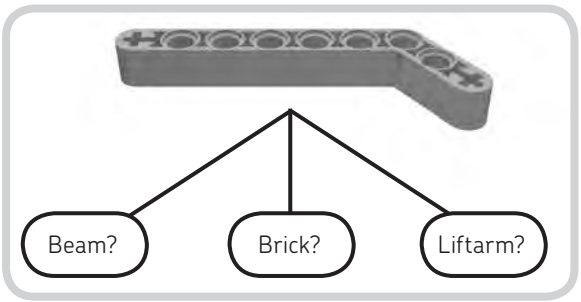

Figure 4-2: Should we call this piece a beam, *a* brick, *or a* liftarm*?*

I don't want to confuse you, so I have selected a unique name for each piece in the NXT 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 creation, and the person extends part of the creation 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 4-3 illustrates this problem.

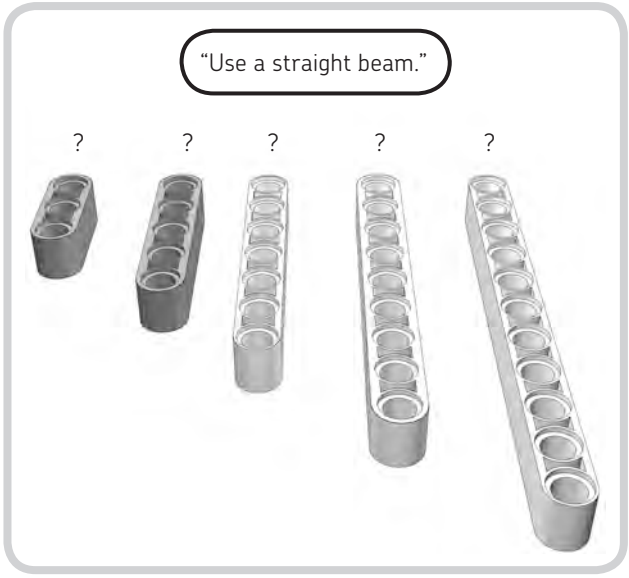

Figure 4-3: If you're told to use a straight beam, which kind of straight beam should you choose?

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 a few pieces in the NXT set use the LEGO Unit. In addition, gears are often measured in their own way. 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 set in this book, and each type of piece in the NXT set only comes in one color (with the exception of the plastic balls), 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 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 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 4-4 offers a comprehensive view of the various types of beams in the NXT set; match up the numbers above each of the pieces with the numbers in Table 4-1 for information about each piece.

We can break down these beams into four subcategories:

- Straight beams
- Half-beams
- Angled beams
- TECHNIC bricks

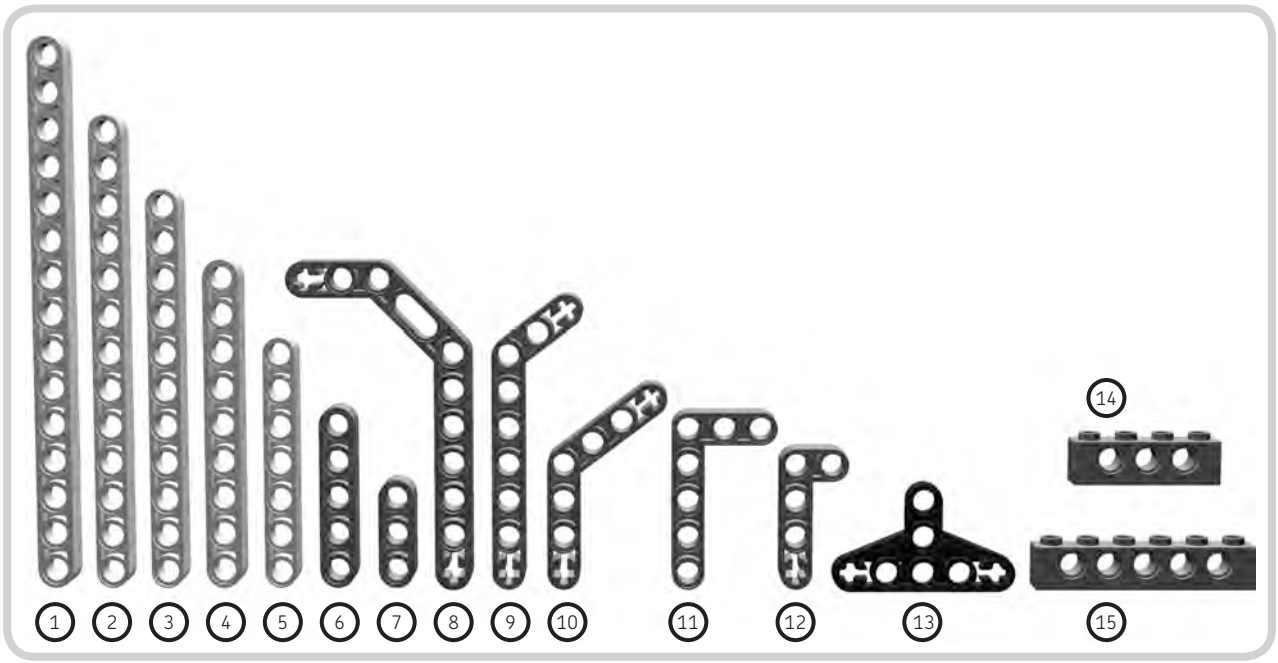

Figure 4-4: The beams in the NXT set

table 4-1: the NXT beams

number in figure 4-4	piece name	piece color (in NXT set)
1	15M (straight) beam	Light stone gray
2	13M (straight) beam	Light stone gray
3	11M (straight) beam	Light stone gray
4	9M (straight) beam	Light stone gray
5	7M (straight) beam	Light stone gray
6	5M (straight) beam	Dark stone gray
7	3M (straight) beam	Dark stone gray
8	11.5M angled beam	Dark stone gray
9	9M angled beam	Dark stone gray
10	7M angled beam	Dark stone gray
11	7M perpendicular angled beam	Dark stone gray
12	5M perpendicular angled beam	Dark stone gray
13	Triangular half-beam	Black
14	1 × 4 TECHNIC brick	Dark stone gray
15	1 × 6 TECHNIC brick	Dark stone gray

the straight beam

The *straight beam* (Figure 4-5) 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).

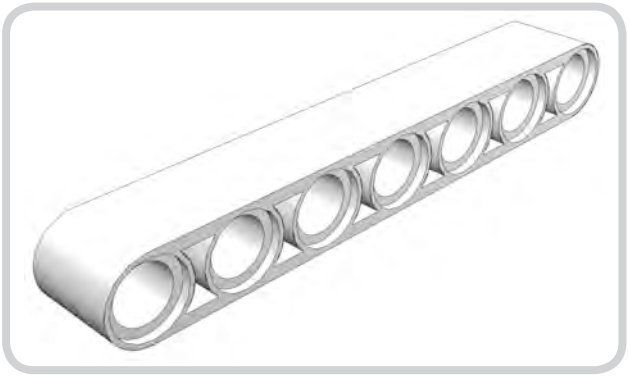

Figure 4-5: The 7M (straight) beam

If you observe Figure 4-4 again, you'll notice seven different types of straight beams in the NXT 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 4-6 shows exactly what a module is, and Figure 4-7 shows how to use the module to measure a straight beam. In "The Connectors" on page 37, we'll also use the module to measure other types of pieces.

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, a straight beam with five round-holes has a module measurement of 5M.

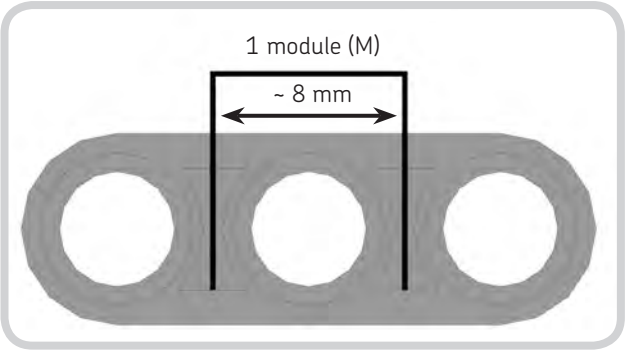

Figure 4-6: A module (M) is about 8 mm, the distance from the center of one hourglass-shaped depression to the center of the adjacent depression.

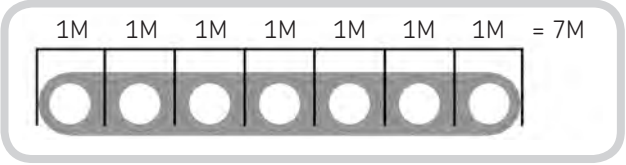

Figure 4-7: Add up the number of modules to get a total measurement of 7M.

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, but the seven types of straight beams in the NXT set range in sizes from 3M to 15M. Of course, 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 4-8) 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 4-4 once again, you'll notice that five types of beams in the NXT set fall into the angled beam subcategory, ranging in sizes from 5M to 11.5M.* Included among these are two types of *perpendicular angled beams*, which are beams angled at exactly 90 degrees.

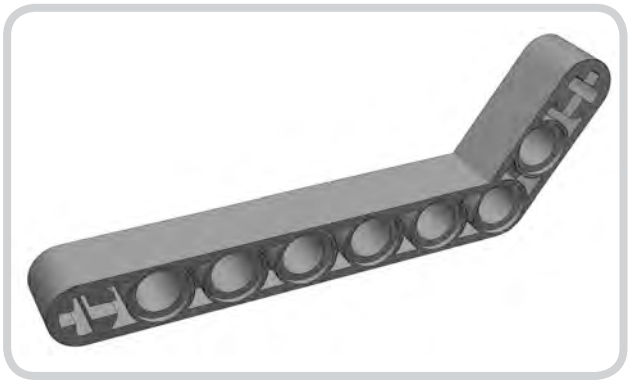

Figure 4-8: The 9M angled beam

In the NXT set, most of the angled beams have another important but less noticeable characteristic: cross-holes. Figure 4-9 shows the same beam as in Figure 4-8 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 the next page. When measuring an angled beam with or without cross-holes, proceed exactly as you would when measuring a straight beam (Figure 4-10).

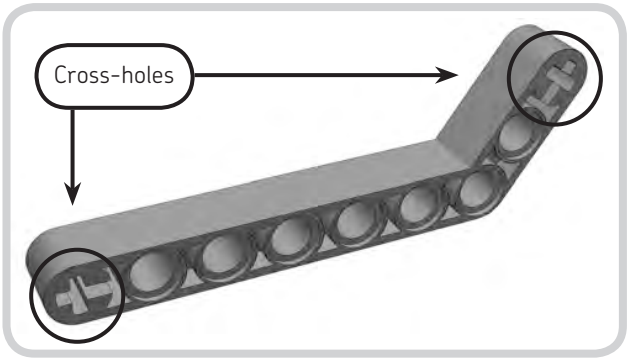

Figure 4-9: Some angled beams, such as this 9M angled beam, have cross-holes.

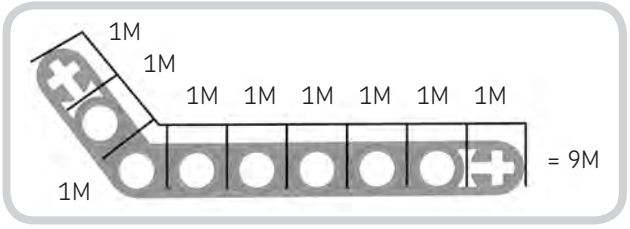

Figure 4-10: Measure an angled beam just as you would measure a straight beam.

the half-beam

A *half-beam* is simply a beam that is half the width (4 mm) of a regular beam (8 mm). A variety of these half-beams exist, but the NXT set contains only one kind: the triangular half-beam (Figure 4-11). Uniquely shaped and possessing both round-holes and cross-holes, the *triangular half-beam* enables you to solve structural and mechanical problems in unconventional ways. We don't measure the triangular half-beam.

Figure 4-11: The triangular half-beam

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

the TECHNIC brick

The last type of beam is the TECHNIC brick (Figure 4-12).* Because it has round-holes like the other beams, the *TECHNIC brick* can interact with other TECHNIC pieces by means of connectors. On the other hand, because it has studs, the TECHNIC brick can interact with other studded LEGO pieces, such as bricks. *Studs* are small cylindrical "bumps" on top of certain LEGO pieces that can snap into the bottom of other studded pieces—a connection system known as the *stud-and-tube coupling system*. There are only a handful of TECHNIC bricks in the NXT set, so they do not play a large role in NXT construction. Nevertheless, there are some situations in which you'll find them very useful.

Figure 4-12: The 1 × 4 TECHNIC brick has four studs.

We don't measure TECHNIC bricks with the module but rather with the LEGO Unit, which is also used to measure bricks and plates. In simplified terms, the *LEGO Unit* measures width and length by counting studs. How many studs wide is the TECHNIC brick in Figure 4-12? It's one stud wide. How many studs long is it? It's four studs long. Take the two measurements, combine them, put the width before the length, and you get what's called a 1 × 4 TECHNIC brick. (Note that 1 × 4 is pronounced *one by four*.) As this example demonstrates, using the LEGO Unit is very intuitive.

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 4-13 presents the various connectors in the NXT set; match up the numbers by the pieces with the numbers in Table 4-2 for information about each piece.

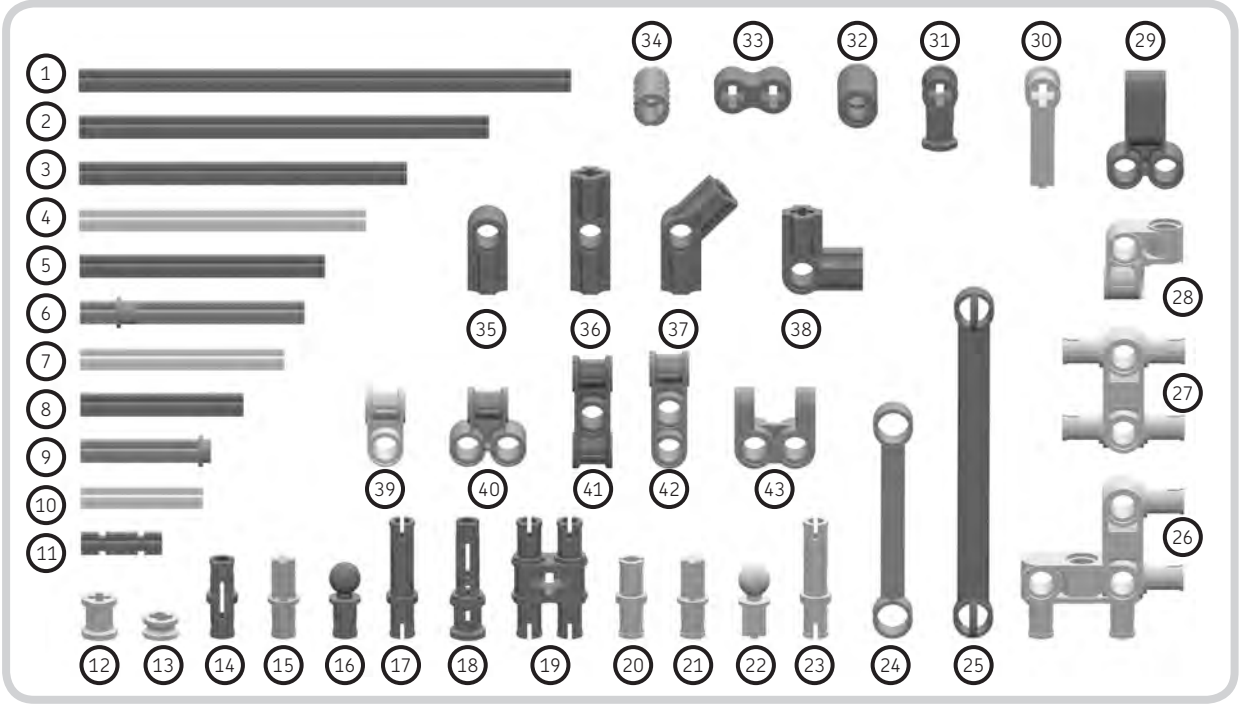

Figure 4-13: The connectors in the NXT set

* It's sometimes also known as the *studded beam*, but the name *TECHNIC brick* is more commonly used.

table 4-2: the NXT connectors

number in figure 4-13	piece name	piece color (in NXT set)
1	12M axle	Black
2	10M axle	Black
3	8M axle	Black
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	Black
12	Bushing	Medium stone gray
13	Half-bushing	Medium stone gray
14	Friction peg	Black
15	Friction axle peg	Blue
16	Friction ball peg	Black
17	3M friction peg	Black
18	Bushed friction peg	Black
19	Double friction peg	Black
20	Peg (smooth)	Medium stone gray
21	Axle peg (smooth)	Tan
22	Axle ball peg (smooth)	Medium stone gray
23	3M peg (smooth)	Medium stone gray
24	Steering link	Dark stone gray
25	9M steering link	Black
26	5M pegged perpendicular block	Medium stone gray
27	3M pegged block	Medium stone gray
28	Cornered peg joiner	Medium stone gray
29	Double peg joiner	Black
30	Extended catch	Medium stone gray
31	Catch	Black
32	Peg extender	Black
33	Flexible axle joiner	Black
34	Axle extender	Dark stone gray
35	#1 angle connector	Black
36	#2 angle connector	Black
37	#4 angle connector	Black
38	#6 angle connector	Black
39	Cross block	Medium stone gray
40	Double cross block	Dark stone gray
41	Inverted cross block	Black
42	Extended cross block	Dark stone gray
43	Split cross block	Dark stone gray

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 4-14). 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 set includes 72 axles of 11 different types, which signals that the axle is indeed an important piece.

Figure 4-14: The 8M 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 4-15 demonstrates. However, using an axle with one or more round-holes allows the axle to spin freely, as the rightmost part of Figure 4-15 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 MINDSTORMS creations. 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 42 and in Chapter 6.

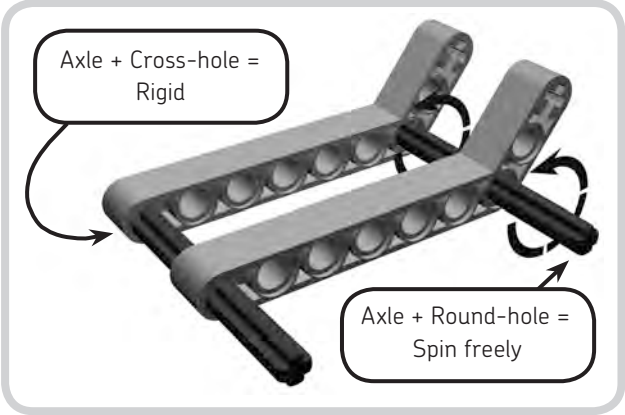

Figure 4-15: Using an axle in cross-holes creates a very rigid connection, while using an axle in round-holes allows the axle to spin freely.

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 set and other more recent LEGO sets, the axles are color-coded: All axles with an even module measurement (2M, 4M, 6M, and so on) are black, while all axles with an odd module measurement (3M, 5M, 7M, and so on) 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 Two axles are neither black nor medium stone gray. The 5.5M stopped axle and the 3M studded axle are dark stone gray. This difference in color merely signifies that these are specialized axles. Experimenting with them will reveal just how they're different from ordinary axles.

Finally, I must mention two important pieces that we call *axle accessories*: the bushing and half-bushing (Figure 4-16). 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. You'll always want to keep some of these pieces close at hand when working with axles.

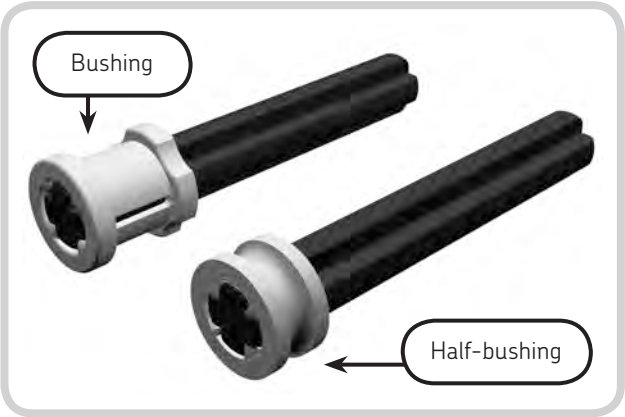

Figure 4-16: The bushing and half-bushing are assistants to the axle.

the pegs

Though quite small, pegs are also vital components of TECHNIC construction (Figure 4-17).* They can be used to easily yet firmly connect two or more pieces. The NXT set includes nearly 200 pegs of 10 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 4-17 is the most basic peg—in fact, it's 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 4-18 illustrates.

Figure 4-17: The peg

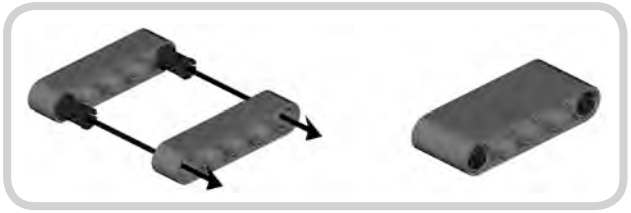

Figure 4-18: Two friction pegs connecting two 5M beams

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 set includes six different types of friction pegs (numbered 14 through 19 in Figure 4-13) and four different types of smooth pegs (numbered 20 through 23 in Figure 4-13). In terms of quantity, the NXT set includes mostly friction pegs, since you'll use these most often. If you build the example shown in Figure 4-19—using a 1 × 6 TECHNIC brick, a friction peg, and a peg—you'll better understand the concept of friction pegs and smooth pegs. Just twist the pegs with your fingers.

Figure 4-19: Twist each peg to feel the difference between a friction peg and a smooth peg.

NOTE **We use the term *smooth peg* when referring to smooth pegs in general (i.e., the smooth peg subcategory), but we drop the word *smooth* when referring to a specific smooth peg. When referring to a specific friction peg, however, I will always include the word *friction* in its name.**

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 peg and the friction peg—each have a slightly longer counterpart that we'll designate the 3M 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 friction peg and peg are 16 mm long, which corresponds to two modules (2M). The longer peg and longer friction peg are each just 8 mm longer, for a total of 24 mm (3M).

NOTE **In the NXT set and other more recent LEGO sets, pegs are color-coded to help you distinguish between friction pegs and smooth pegs. All smooth pegs are tan or medium stone gray; all friction pegs are black or blue.**

Finally, the NXT set includes two types of pieces that are called *peg accessories*: the steering link and the 9M steering link (Figure 4-20). (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.) These pieces are complements to the axle ball peg and the friction ball peg, and they offer very flexible forms of movement. If you want to better understand the flexibility of steering links, build either of those pictured in Figure 4-20. Incidentally, the famous Alpha Rex robot that appears on the front cover of the NXT set uses steering links.

Figure 4-20: Steering links and ball pegs work together. Both types of ball pegs work with both types of steering links.

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 4-13 and the pieces numbered 26 through 43, you'll get a sense for the diversity of this subcategory. Measuring is unnecessary for most of these pieces. Figure 4-21 shows the *cross block*, a very common and useful connector block, which has both a round-hole and a cross-hole.

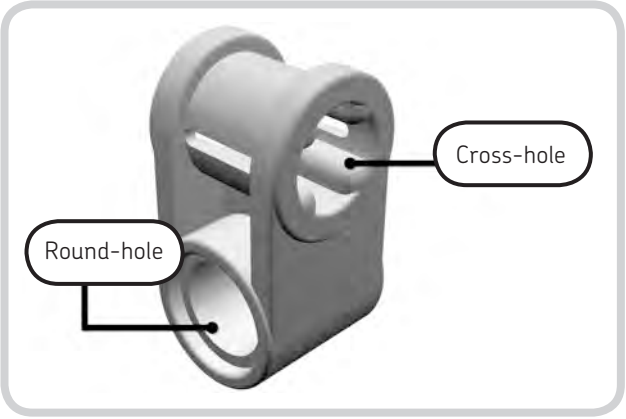

Figure 4-21: The cross block

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 4-22 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.

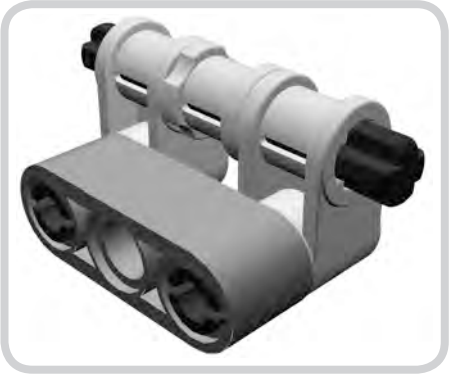

Figure 4-22: Connector blocks help you to create more interesting and complex structures and mechanisms.

the gears

Except for the electronic elements, LEGO gears are probably the most fascinating pieces in the NXT 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 4-23 presents the various gears included in the NXT set; match up the numbers above the pieces with the numbers in Table 4-3 for information about each piece.

table 4-3: the NXT gears

number in figure 4-23	piece name	piece color (in NXT set)
1	8t (spur) gear	Medium stone gray
2	16t (spur) gear	Medium stone gray
3	24t (spur) gear	Medium stone gray
4	40t (spur) gear	Medium stone gray
5	12t double bevel gear	Black
6	20t double bevel gear	Medium stone gray
7	36t double bevel gear	Black
8	Worm gear	Black
9	Knob wheel	Black
10	Turntable	Black/dark stone gray

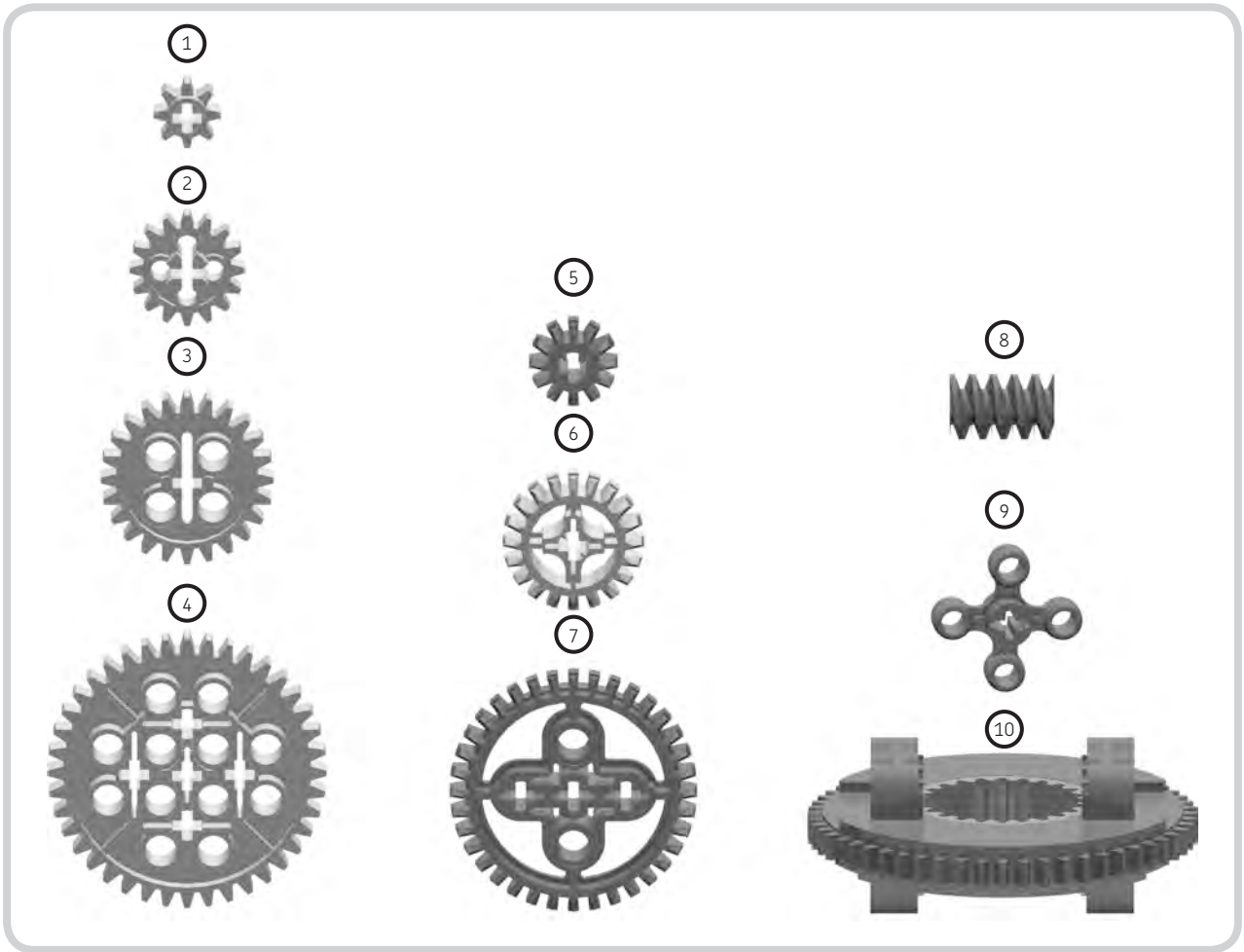

Figure 4-23: The gears in the NXT set

How do LEGO gears transmit motion? They accomplish this task through their teeth, as Figure 4-24 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.

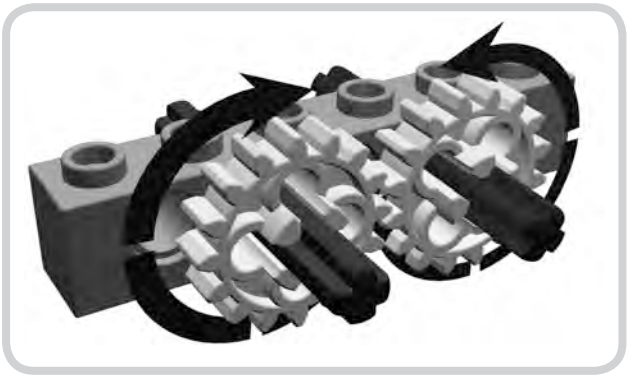

Figure 4-24: When two gears mesh, motion can transfer between the gears and, subsequently, their axles.

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 16 teeth would have a measurement of *16t*. The gears in Figure 4-24 are 16t gears.

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

* Spur gears
* Double bevel gears
* Other gears

spur gears

Figure 4-25: The 8t gear

A *spur gear* is the simplest and most common kind of gear (Figure 4-25), and it typically engages other gears positioned on parallel (non-intersecting) axles, as shown in Figure 4-24. There are four types of spur gears in the NXT set: the 8t, 16t, 24t, and 40t. Due to the LEGO spur gear's prevalence, we usually omit the *spur* before its name: For example, we call the spur gear with twenty-four teeth a *24t gear*, not a *24t spur gear*.

double bevel gears

Figure 4-26: The 20t double bevel gear

A *double bevel gear* (Figure 4-26) 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 perpendicular angles (Figure 4-27). Second, like spur gears, double bevel gears can mesh when positioned on axles that *are* parallel, as shown in Figure 4-24. The NXT set doesn't contain any bevel gears, but it contains three kinds of double bevel gears: the 12t, 20t, and 36t. (Note that, when referring to these pieces, we do keep the *double bevel* before their names.)

Figure 4-27: Here 20t double bevel gears are engaging on skewed axles.

other gears

I've included the final three types of gears in this category: the worm gear, the knob wheel, and the turntable. For various reasons, we don't include measurements as part of their names.

The *worm gear* can engage all the toothed gears in the NXT set, but only when they're positioned on skewed axles. Figure 4-28 illustrates how a worm gear meshes with another gear, in this case, a 24t gear. While rotating, the worm gear's teeth (or *tooth* as you'll learn in Chapter 6) slide across the other gear's teeth to make the other gear rotate. Interestingly, the worm gear must *always* turn the other gear, which the arrow in Figure 4-28 signifies. Some of the main reasons for using the worm gear are that it can create significant *torque* (power) and it can greatly reduce rotational speed. We'll explore these concepts in Chapter 6.

Figure 4-28: In this setup, a worm gear engages a 24t gear. The worm gear always rotates the other gear, not vice versa.

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.

The *turntable* is a powerful gear made up of two parts, one dark stone gray and the other black, that can turn independently; twist both parts with your hand to see for yourself how this functions. If you look carefully at your turntable, you'll notice that there are teeth on the outside of the black part and the inside of the dark stone gray part. Thus, if you secure one part to a robot and engage the other part's teeth with another gear, the engaged part moves or rotates. How is this useful? You can build an entire section of a robot on the engaged part, which allows you to easily (and safely!) rotate part of your robot. Robotic arms and other stationary creations often use the turntable in this manner.

the miscellaneous elements

We have reached the fifth and final category of NXT 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 4-29 presents all of these miscellaneous pieces; match up the numbers by the pieces with the numbers in Table 4-4 for information about each piece. Although these pieces may not seem especially useful, you'll find that they can be indispensable in some of your projects.

The applications of these pieces are as varied as the pieces themselves. The blue and red balls are items your robot can use in an activity; you might design a robot to find the ball, push the ball, collect the ball, throw the ball, kick the ball, or do something else with the ball (be creative!). The TECHNIC pincer, TECHNIC tooth, and 1 × 1 cone are great decorative pieces, but they can also serve important functions (the pincer and tooth can be especially useful in grabbing mechanisms). In the NXT set the balloon wheel, balloon tire, and pulley wheel typically act as robot wheels, but even these pieces can serve unconventional purposes. In Part IV you'll see some of the many ways these miscellaneous pieces can be put to use.

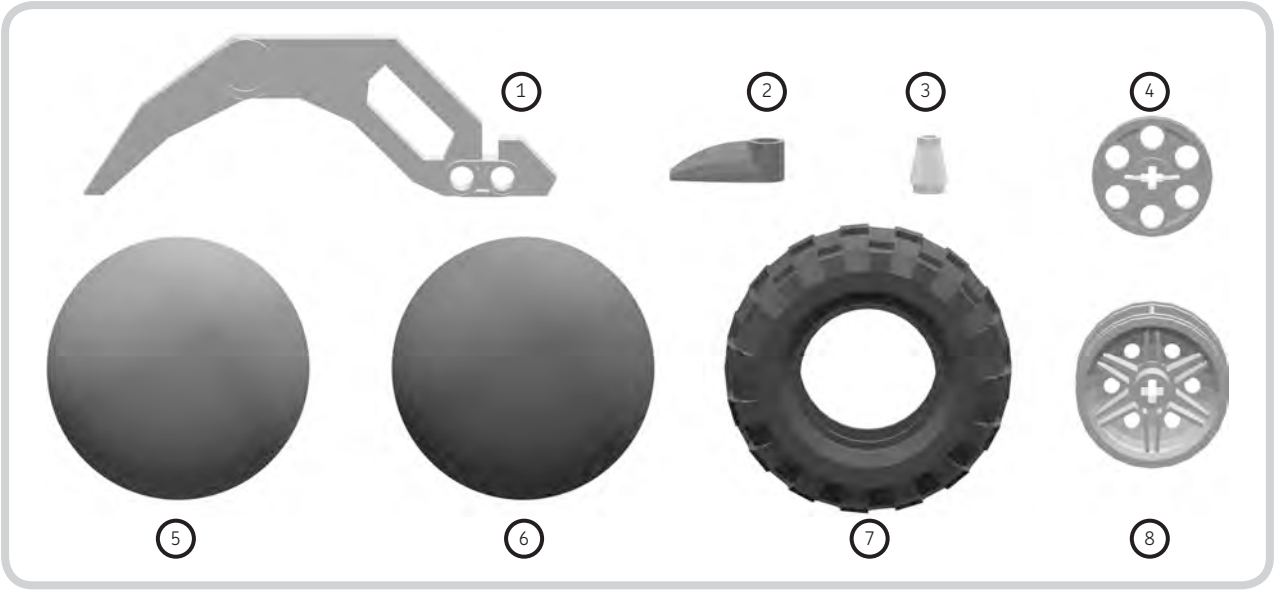

Figure 4-29: The miscellaneous elements in the NXT set

table 4-4: the miscellaneous NXT elements

number in figure 4-29	piece name	piece color (in NXT set)
1	TECHNIC pincer	Pearl gray
2	TECHNIC tooth	Orange
3	1 × 1 cone	White
4	Medium pulley wheel	Medium stone gray
5	Ball	Blue
6	Ball	Red
7	Balloon tire	Black
8	Balloon wheel	Medium stone gray

conclusion

Exploring the topic of LEGO MINDSTORMS NXT construction is incredibly fun, but 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 set. We began by familiarizing ourselves with the NXT pieces as a whole and detailing some underlying concepts, and then we proceeded to examine each of the five categories of pieces in the NXT set: electronics, beams, connectors, gears, and miscellaneous elements. In the following chapter, you'll learn practical techniques for building effective structures for NXT robots.