THE UNOFFICIAL LEGO® MINDSTORMS® NXT INVENTOR'S GUIDE

david j. **perdue**

Excerpts from "Chapter 4: Understanding the LEGO MINDSTORMS NXT Pieces" and "Chapter 14: Tag-Bot"

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.

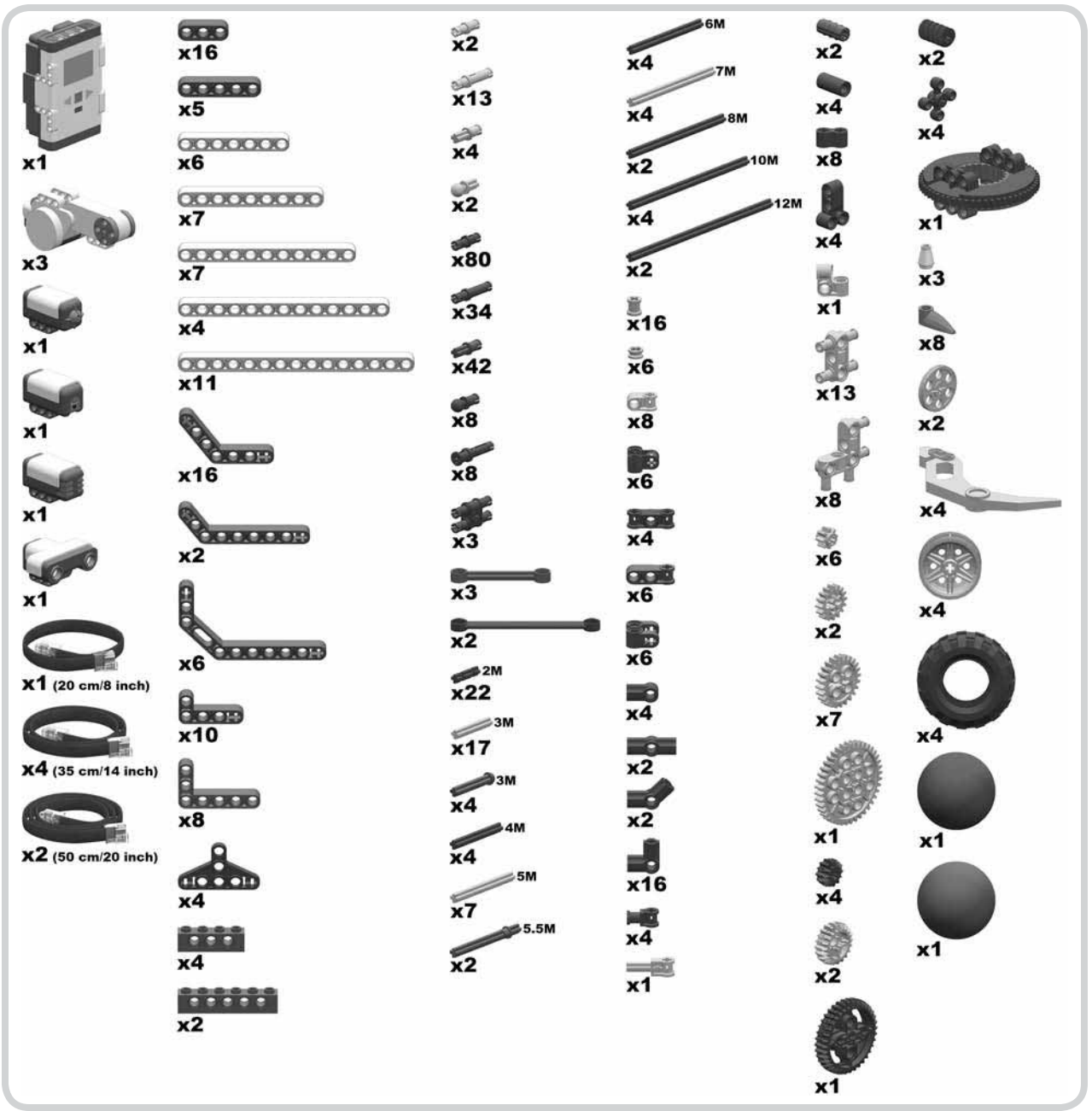


Figure 4-1: The types and quantities of pieces in the NXT set

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.

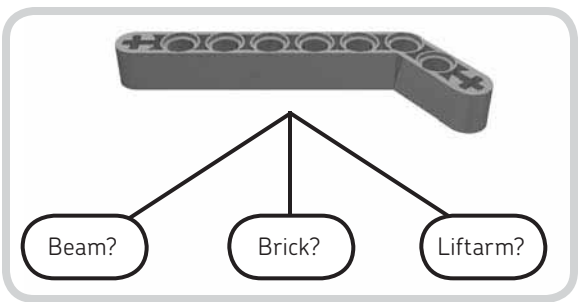


Figure 4-2: Should we call this piece a beam, *a* brick, *or a* liftarm*?*

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.

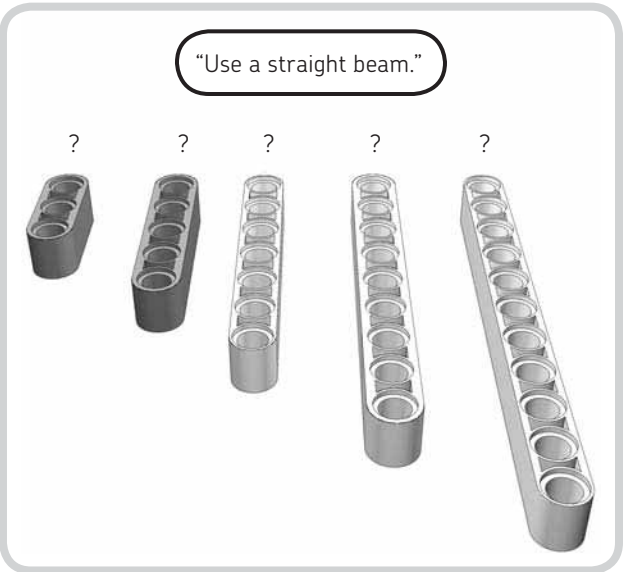


Figure 4-3: If you're told to use a straight beam, which kind of straight beam should you choose?

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

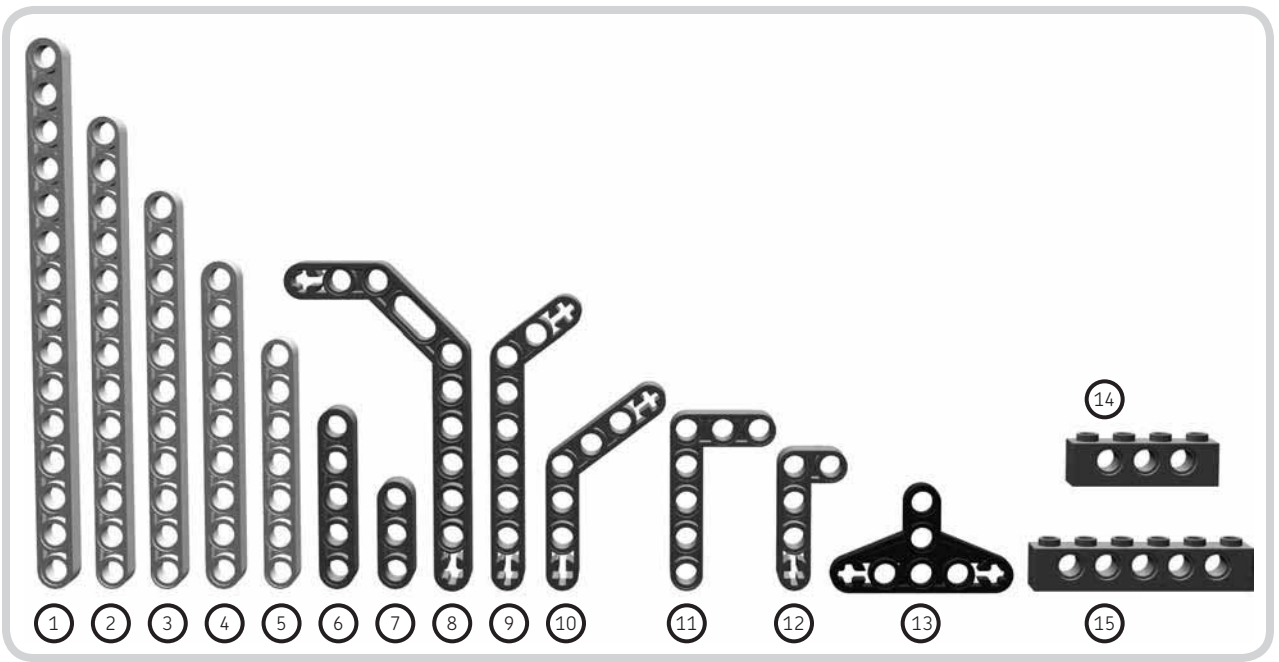


Figure 4-4: The beams in the NXT set

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).

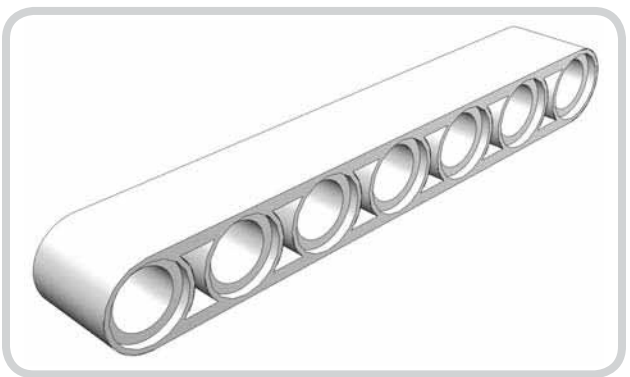


Figure 4-5: The 7M (straight) beam

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.

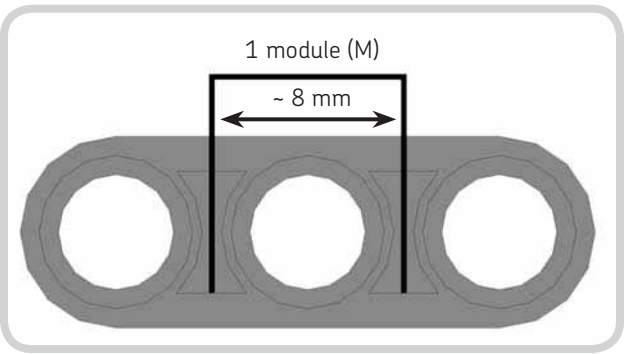


Figure 4-6: A module (M) is about 8 mm, the distance from the center of one hourglass-shaped depression to the center of the adjacent depression.

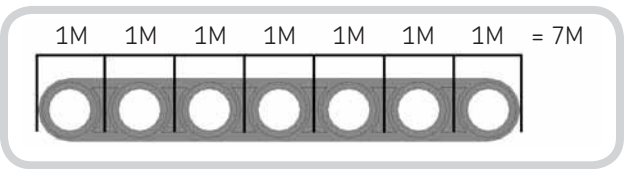


Figure 4-7: Add up the number of modules to get a total measurement of 7M.

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.

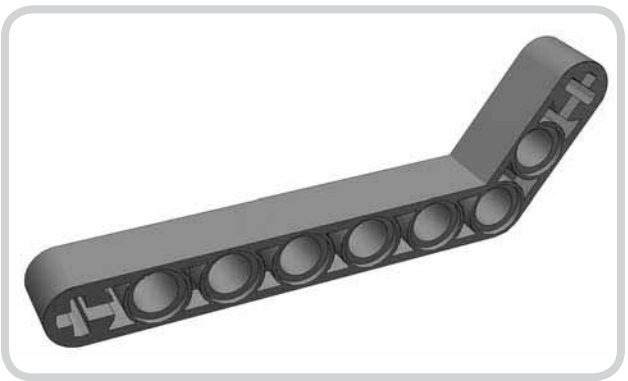


Figure 4-8: The 9M angled beam

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).

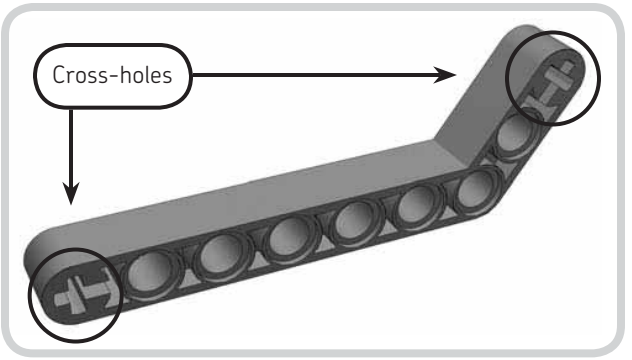


Figure 4-9: Some angled beams, such as this 9M angled beam, have cross-holes.

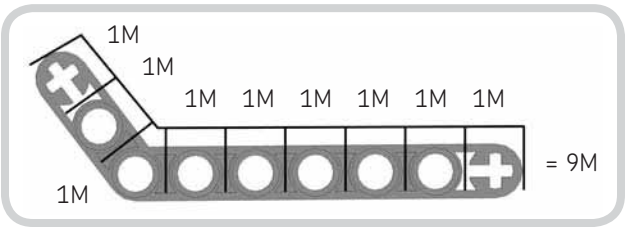


Figure 4-10: Measure an angled beam just as you would measure a straight beam.

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.

14

tag-bot

Most NXT robots interact with their environments using the variety of available sensors, and designing a robot that interacts with humans is especially fun. You'll create another mobile robot in this chapter; this time it's a robot named Tag-Bot (Figure 14-1) that plays flashlight tag. In this game, your goal is to shine a flashlight on Tag-Bot's light sensor for a short period of time, which "tags" the robot. Tag-Bot's goal is to dash around the room in an attempt to escape the light. When tagged, the robot says, "Game over" and then stops (don't worry—it won't chase you!).

Tag-Bot employs a *steering drive* in which the front wheels steer and the back two driven wheels are fixed. This configuration provides great stability, but it means that the robot cannot make tight turns or turn in place. Nevertheless, a steering drive is a viable solution for many types of projects. Positioned on the front of Tag-Bot are the light sensor, a sound sensor for activating the robot (e.g., by clapping your hands), and a rotating ultrasonic sensor for detecting objects. We'll begin this chapter by building Tag-Bot, and then we'll program and test the robot to perform basic and more advanced behaviors.

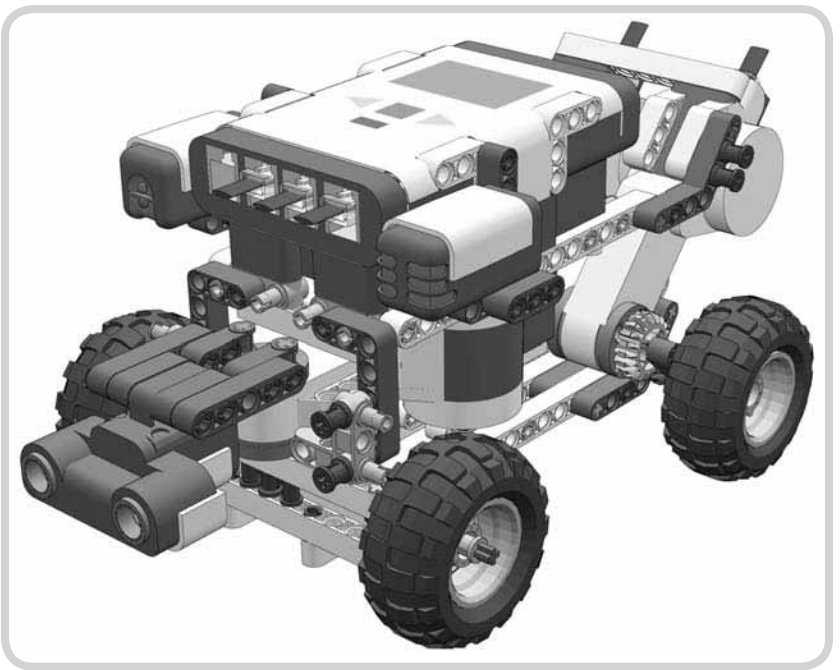


Figure 14-1: Tag-Bot plays a game of flashlight tag.

building tag-bot

Tag-Bot is composed of eight subassemblies and uses all three servo motors in the NXT set: Two motors are for driving and one is for steering. Figure 14-2 shows the BOM for Tag-Bot. Ideally, Tag-Bot would use a differential gear for the back wheels. During a turn, the robot's wheels travel different distances (the wheel on the outside travels the greater distance), and without a differential to adjust the distribution of power to the wheels, one wheel must slip. There isn't a differential

gear in the NXT set, so Tag-Bot simply does without. While this approach may not provide maximum efficiency, it does work!

NOTE **It's possible to build a "homemade" differential with pieces in the NXT set. I chose not to use one for Tag-Bot, however, because of the complexity it would have introduced. If you'd like to tackle that project, you can find building instructions at http://nxtasy.org/2006/08/15/differential.**

Now you're ready to build the subassemblies and then combine them in the final assembly. You'll construct the following eight subassemblies in the order shown:

* Left Drive subassembly
* Right Drive subassembly
* Steering subassembly
* Steering Motor subassembly
* Frame subassembly
* Ultrasonic Sensor subassembly
* Light Sensor subassembly
* Sound Sensor subassembly

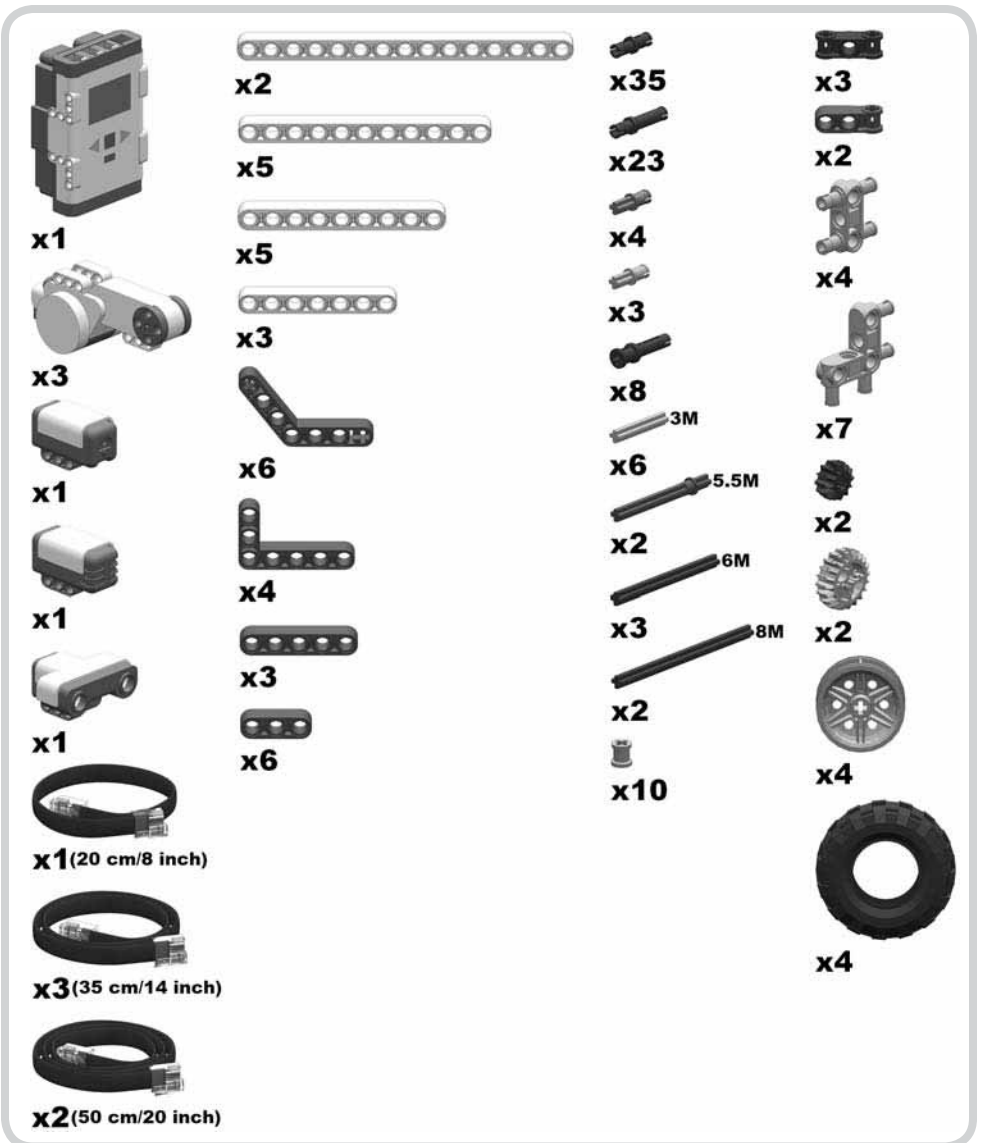
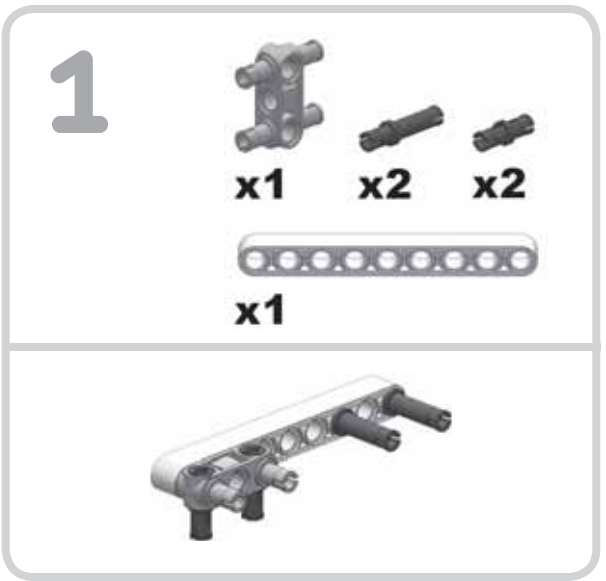


Figure 14-2: A BOM for Tag-Bot

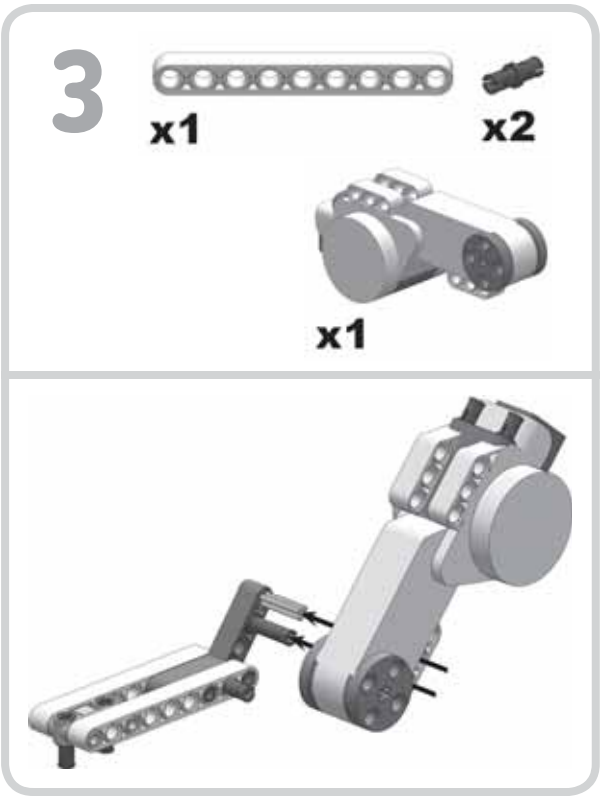
left drive subassembly

The *Left Drive subassembly* drives the left side of the robot. It has a gear train consisting of two gears—a 20t double bevel gear and a 12t double bevel gear—that gear up, resulting in a 3:5 gear ratio (see "Controlling a Gear Train's Performance" on page 54 for a discussion of gearing up and down). Does this ratio provide enough torque to effectively drive the robot? Given the strength of the servo motors and the fact that we're using two of them to drive the robot (one is included in the next subassembly), this gear ratio does in fact provide sufficient torque. Complete the following seven steps to build this subassembly.

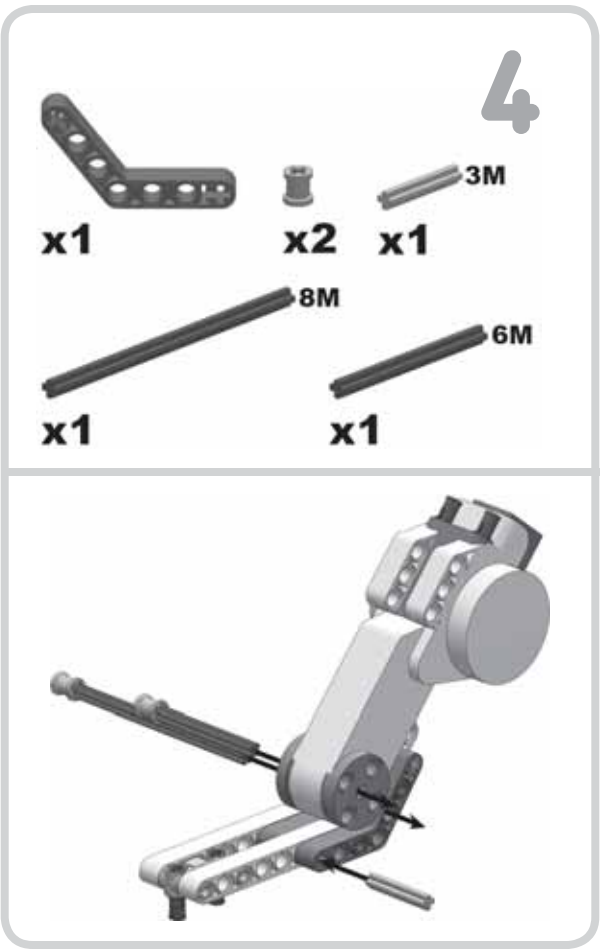


Step 1: Begin by snapping a 3M pegged block and two 3M friction pegs into a 9M beam. Next, add two friction pegs to the pegged block.

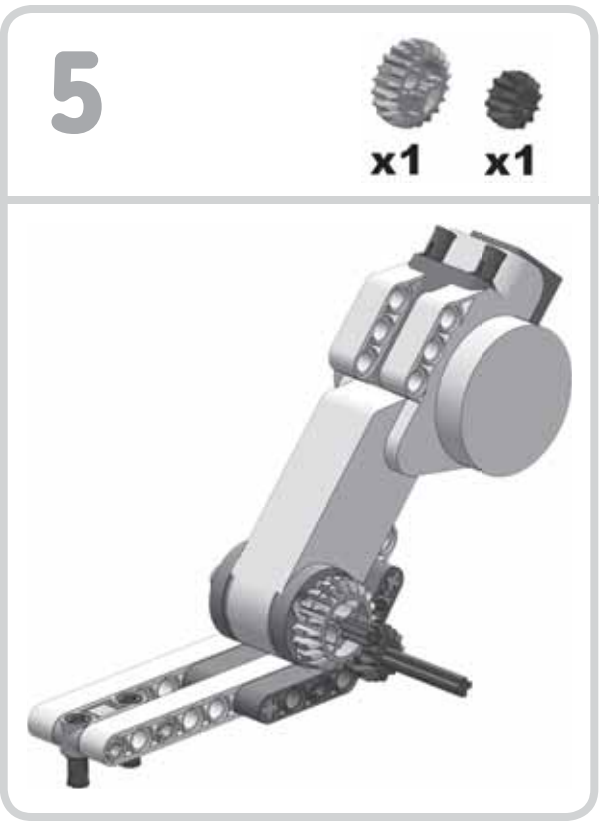
Step 2: Add a 7M angled beam, two 3M friction pegs, and a 3M axle.



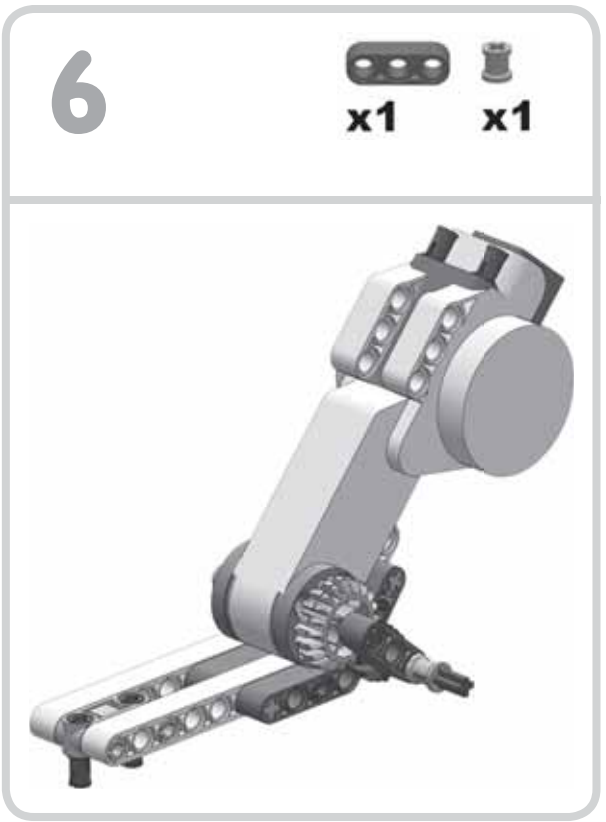
Step 3: Add another 9M beam and a motor to the 7M angled beam. Then connect two friction pegs to the top of the motor.



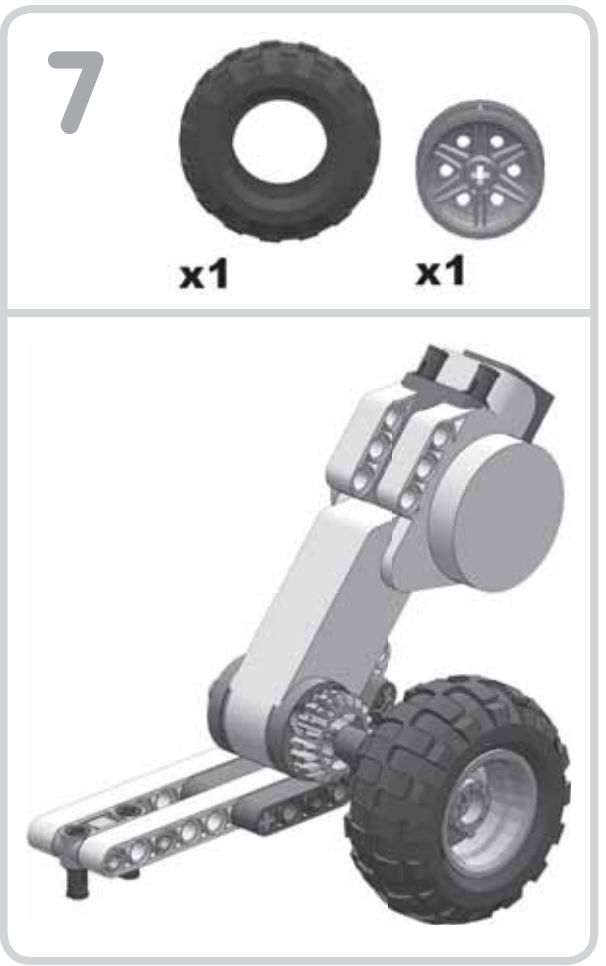
Step 4: First, attach another 7M angled beam. Next, push a 3M axle through the two 7M angled beams. Finally, add bushings to 8M and 6M axles and then push them through as shown, with the 6M axle running through the motor's output shaft and the 8M axle running through the 7M angled beams.



Step 5: Connect a 20t double bevel gear to the 6M axle and a 12t double bevel gear to the 8M axle.



Step 6: Place a 3M beam over the axles, and then secure the lower axle with a bushing. The orange shaft head on the motor wiggles around, so the 3M beam prevents the gears from separating.



Step 7: Finish by attaching a balloon wheel and a balloon tire. Make sure that the side of the wheel with spokes is facing toward the motor.