# 2

# the TTT Tickler: a tic-tac-toe player

Raise your hand if you have ever spent time playing tic-tac-toe during some boring and never-ending school lesson! Just draw four crossed lines on any surface (whether it's wastepaper, an exercise book, or even a desk), and the game board is ready!

In this chapter, you'll learn the perfect strategy for tic-tac-toe, as well as how to play the game with the Tic-Tac-Toe Tickler (TTT Tickler), a LEGO MINDSTORMS NXT robot that will challenge you at every turn.

You'll find building instructions for two versions of this robot in the following chapters. Chapter 3 contains instructions for use with the original LEGO MINDSTORMS NXT set (8527), and Chapter 4 contains building instructions for the LEGO MINDSTORMS NXT 2.0 set (8547). You can see the two versions of the robot in Figures 2-1 and 2-2.

The two versions of the robot work exactly the same way. The differences are aesthetic, due to the varying assortment of parts contained in the two sets. For example, in the NXT 2.0 version, you can use the Zamor magazine to hold the balls; in the NXT 1.0 version, you need to build a magazine using the spare parts available.

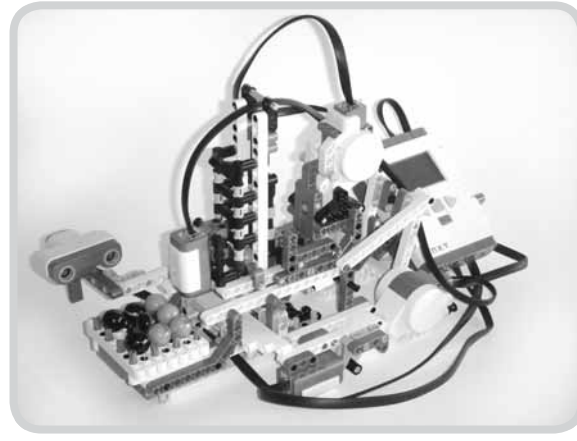


*Figure 2-1: The TTT Tickler built with the NXT 8527 set. (Notice the glass marbles used as marks—dark for you and light for the robot.)*

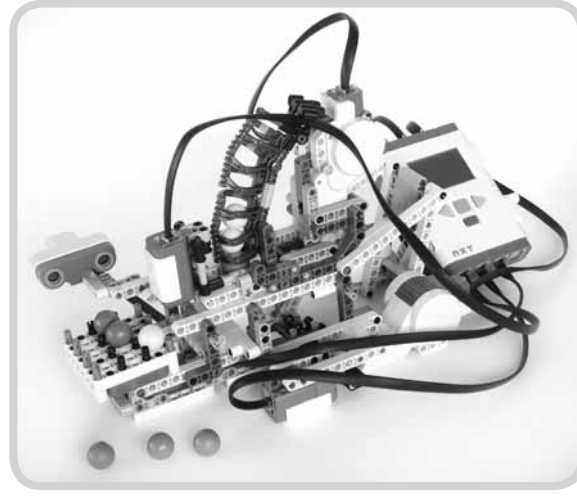


*Figure 2-2: The TTT Tickler built with the NXT 8547 set*

## make the perfect game

The game of tic-tac-toe is also known as noughts and crosses or hugs and kisses (in Italian, *filetto* or *tris*). The two players, O and X, alternatively draw their mark on a 3-by-3 grid. The player who places three marks in a horizontal, vertical, or diagonal row wins the game. Figure 2-3 shows an example in which player O starts and wins the game.

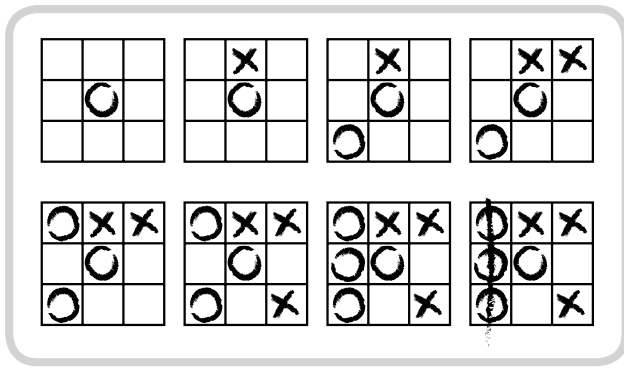


*Figure 2-3: An example of a tic-tac-toe match*

Once you've played tic-tac-toe a few times, you'll soon discover that when both you and your opponent play with the optimal strategy, the game ends in a draw.

**NOTE** **The simplicity of tic-tac-toe makes it ideal as an educational tool to explain the basic concepts of *combinatorial game theory* and *artificial intelligence*. These concepts are the subject of study of a branch of information technology, and they can be used to instruct a computer to play a game. For more on this topic, see the appendix.**

Have you ever wondered how to play a perfect tic-tac-toe match? The following are the rules to win (or at least to end in a draw). These are the same rules that I've programmed into the TTT Tickler robot to make it a flawless player! These rules assume that you are player O. Every time it's your turn, you should choose one of the following moves, depending on the state of the game. The rules are listed in order of decreasing priority.

1. **Try to win** If you have two marks in a row, put the third mark in an empty space to get three in a row and win the game (as shown in Figure 2-4).

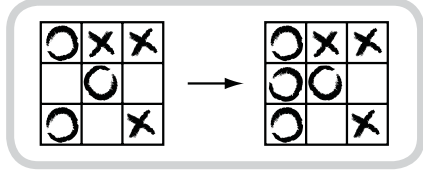


*Figure 2-4: Try to win.*

2. **Block the opponent** If your opponent has two X marks in a row, place your mark to block him (as shown in Figure 2-5).

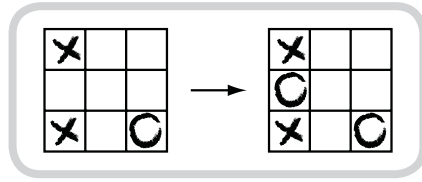


*Figure 2-5: Block your opponent.*

3. **Fork** Create an opportunity to win in two ways by making a fork (as shown in Figure 2-6).

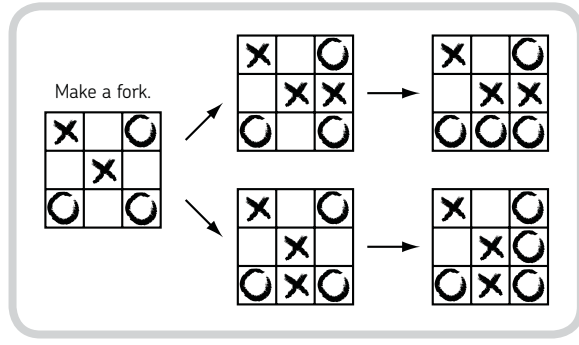



*Figure 2-6: Make a fork.*

4. **Block your opponent's fork** If there's a configuration where your opponent can fork, block that attempt. For example, you might try to put two marks on a row to force your opponent to block you (as shown in Figure 2-7).

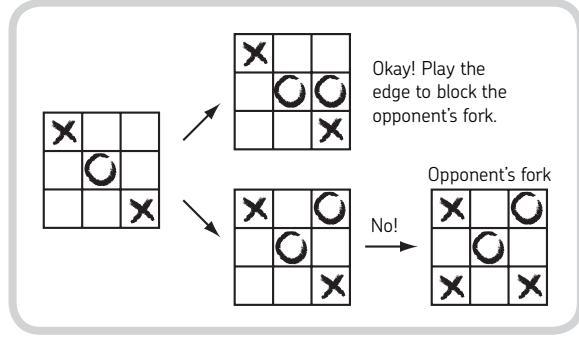



*Figure 2-7: Block your opponent's possible fork.*

When none of the above situations apply, here is the basic game play (as shown in Figure 2-8):

* Place your mark in a square in the center of the board.
* If your opponent places a mark in the corner, mark the opposite corner in the same diagonal.
* Place a mark in an empty corner square.
* Place a mark in an empty edge square.

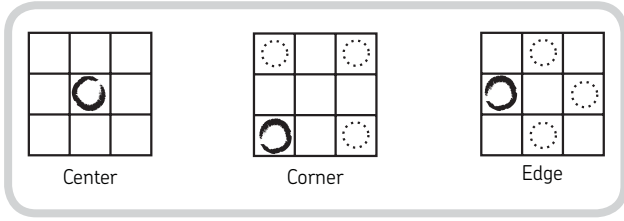



*Figure 2-8: Play in the center, in the corner, or in an edge square.*

When you play against the TTT Tickler, you are player O, and you make the first move; the robot is player X.

While it may seem like you can choose among nine possible places on the board at the start of the game, rotations and symmetries lead to only three possibilities: center, corner, or edge. In fact, when the board is empty, every corner or edge has the same strategic importance. As shown in Figure 2-9, placing your first mark in the center square offers you four possible winning configurations; more than any other option. Placing your first mark in a corner offers three potential winning configurations, and placing your first mark on an edge offers only two possible winning configurations.

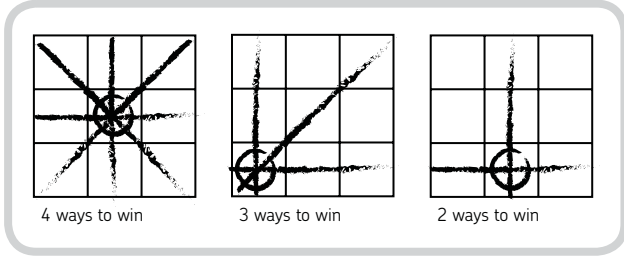



*Figure 2-9: Three possible choices for your initial move*

If you place your first mark in a corner, the robot (player X) will put its mark in the center square. If you place your first mark in the center square, the robot will place its mark in a corner square. If, however, you open with an edge mark, the robot responds by marking the center square (though marking an adjacent corner or an opposite edge would also be a good move). After the opening moves, the robot follows the preceding priority list to force a draw, or a win if you make a mistake!

# introducing the TTT Tickler

There are many LEGO MINDSTORMS robots that play tic-tac-toe, but none is like the one you are going to build.

**NOTE Mario Ferrari created his TTT robot in 1999 using the RCX brick. You can see his robot by going to *http://www.marioferrari.org/ttt.html*. More recently, in 2006, Bryan Bonahoom built the NXT robot W.O.P.R. (*http://mindstorms.lego.com/MeetMDP/BBonahoom.aspx*).**

The TTT Tickler is different because it's very compact. It uses one motor to rotate the board, another to move the arm linearly on the board, and a third to drop the balls on the board.

The robot's rotating board has nine spaces where you and the robot can place balls of different colors. When playing with the original NXT version, you can use dark and light glass marbles (five of each); with the NXT 2.0 version, you can use the Zamor Spheres included in the set. You should use green and blue balls (which appear dark to the sensor), and fill the robot's magazine with the yellow and red ones (which appear light to the sensor). As you should be able to see in Figure 2-10, the robot can reach all cells on the board by rotating the board in 45-degree increments and sliding the arm in and out.

The LEGO color or light sensor on the end of the robot's arm should detect where you've placed your ball. The robot drops its balls on squares through a chute by pushing them out of the magazine with a cam mechanism driven by the vertical motor.

# user manual

In this section, you will learn how to play with the TTT Tickler. I've provided three programs for use with your robot: one to play tic-tac-toe using the NXT's screen, one to play with the robot directly, and one to recalibrate the robot's arm.

Because these are quite complicated programs written in the NXC language, I won't take you through writing them in this book; however, you can download them all from *http://tr.benedettelli.com/* or *http://www.nostarch.com/*. (Chapter 1 contains instructions on how to download files and programs to the NXT.) The following files are used:

**Compiled programs** *ttt_ai_1.rxe*, *ttt_tickler_1.rxe*, and *ttt_calib_1.rxe* (firmware 1.05); *ttt_ai_2.rxe*, *ttt_tickler_2.rxe*, and *ttt_calib_2.rxe* (firmware 1.28)

**Sounds** *! Blips 19.rso*, *! Click.rso*, *! Sonar.rso*, *Crying 02.rso*, *! Fanfare.rso*, *Goodbye.rso*, *Laughing 02.rso*, *Play.rso*, *Try Again.rso*, and *Yes.rso*

**Image** *ttt.ric*

## playing against the robot

To play against the robot, select the *ttt_tickler* program and press the orange button on the NXT. The robot should reset the board position, its arm, and the ball-ejection mechanisms. It will ask if you want to calibrate the sensor with the room based on the light around you (*ambient* light). Select **Yes** the first time you use the robot and then again every time the light conditions change. I suggest calibrating the light sensor often, ideally every time you turn on the NXT Brick.

Continue the calibration by following the instructions on the screen, which tell you to put a dark ball (a blue or green Zamor Sphere or a dark marble) on the central square and press the NXT's orange button. When you do, the robot measures the ball color and stores it in a configuration file called *ttt_s.cfg*. Continue to follow the instructions on the screen. Finally, remove all balls from the board and make sure that the robot has at least four balls in its magazine. Press the NXT's orange button again when you are ready to play.

You can choose to play against a Novice, a Normal, or an Expert opponent. Beating the Novice is quite easy, since it plays randomly. You can beat the Normal opponent using the strategy described in "Make the Perfect Game" on page 11, but it is up to you to discover its Achilles' heel! There is no way to beat the Expert opponent, but if you play well, you can tie.

Once you have chosen the robot's skill level, the robot waits for you to make the first move. It automatically detects your move by checking for the presence of your hand with the ultrasonic sensor, so make sure that when you put the ball on the board the robot can see your hand. (You'll know that it has seen your hand because the NXT will beep.)

Each time the TTT Tickler takes a turn it scans the board for open squares, skipping already occupied squares to save time.

Once the robot has scanned the board, it computes the best move and drops a ball from its magazine onto the board. This cycle repeats until the game ends, at which point you can choose to play another game or simply end. (If you have thrashed the robot and choose to stop playing, it is still a good sport and will see you off with a smile!)

## calibrating the robot

When the robot fails to place the sensor correctly or drops the ball in the wrong place, you should run the *ttt_calib* calibration program. You should calibrate the robot arm **only** if it often fails to drop balls into their correct places.

**NOTE** **Calibration is a delicate procedure that normally should be avoided. If you perform calibration incorrectly, the robot's arm may not move correctly. To restore the default calibration settings, simply delete the *ttt_a.cfg* file on the NXT.**

To delete an existing *ttt_a.cfg* configuration file, start the *ttt_calib* program, release the NXT's orange button, and press and hold it again immediately. The NXT should confirm the file deletion both on the screen and by making a sound. Alternatively, you can delete this file using the NXT Explorer (BricxCC in Windows) or the NeXT Explorer tool (NeXT Tools on a Macintosh).

Now, to begin the calibration, follow the onscreen instructions. **Rotate the knob on the shaft of the arm's motor by hand** (attached to OUT B) to slide the arm, saving each arm position by pressing the orange button as shown in Figure 2-10. It's very important to not move the arm directly or the motor angle may be recorded incorrectly; turn the knob instead.

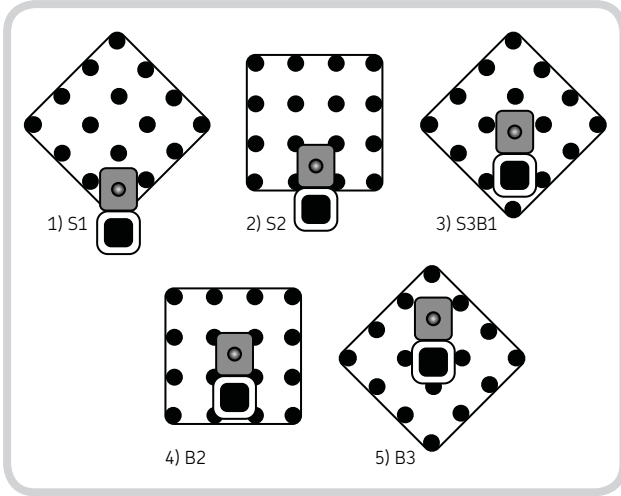



*Figure 2-10: The robot arm must be positioned by turning the knob on the motor by hand in order to perform the calibration.*

The arm positions are as follows:

**S1 (sensor position 1)** Move the arm so that the sensor spot is in the corner.

**S2 (sensor position 2)** Move the arm so that the sensor spot is on the edge.

**S3B1 (sensor position 3, ball position 1)** Move the arm so that the sensor spot is in the center and the ball can be dropped in the corner.

**B2 (ball position 2)** Move the arm so that the ball can be dropped on the edge.

**B3 (ball position 3)** Move the arm so that the ball can be dropped in the center.

At the end of the calibration procedure, the robot's moving parts should reset, and the NXT should display a summary of the new positions, as stored in the *ttt_a.cfg* file. At startup, the *ttt_tickler* program looks for this configuration file and, if it exists, loads its settings instead of the default ones.

### playing the screen-based tic-tac-toe game

You can also play tic-tac-toe on the NXT brick directly, without using the robot. Start the screen-based game by selecting *ttt_ai* and pressing the NXT's orange button. The game board should be displayed on the NXT screen.

When the program starts, you can choose the opponent's skill level. To select a square on the board, move the cursor using the NXT arrow buttons and confirm your move by clicking the orange button. The NXT should compute its move, update the screen, and repeat the cycle until the game ends.

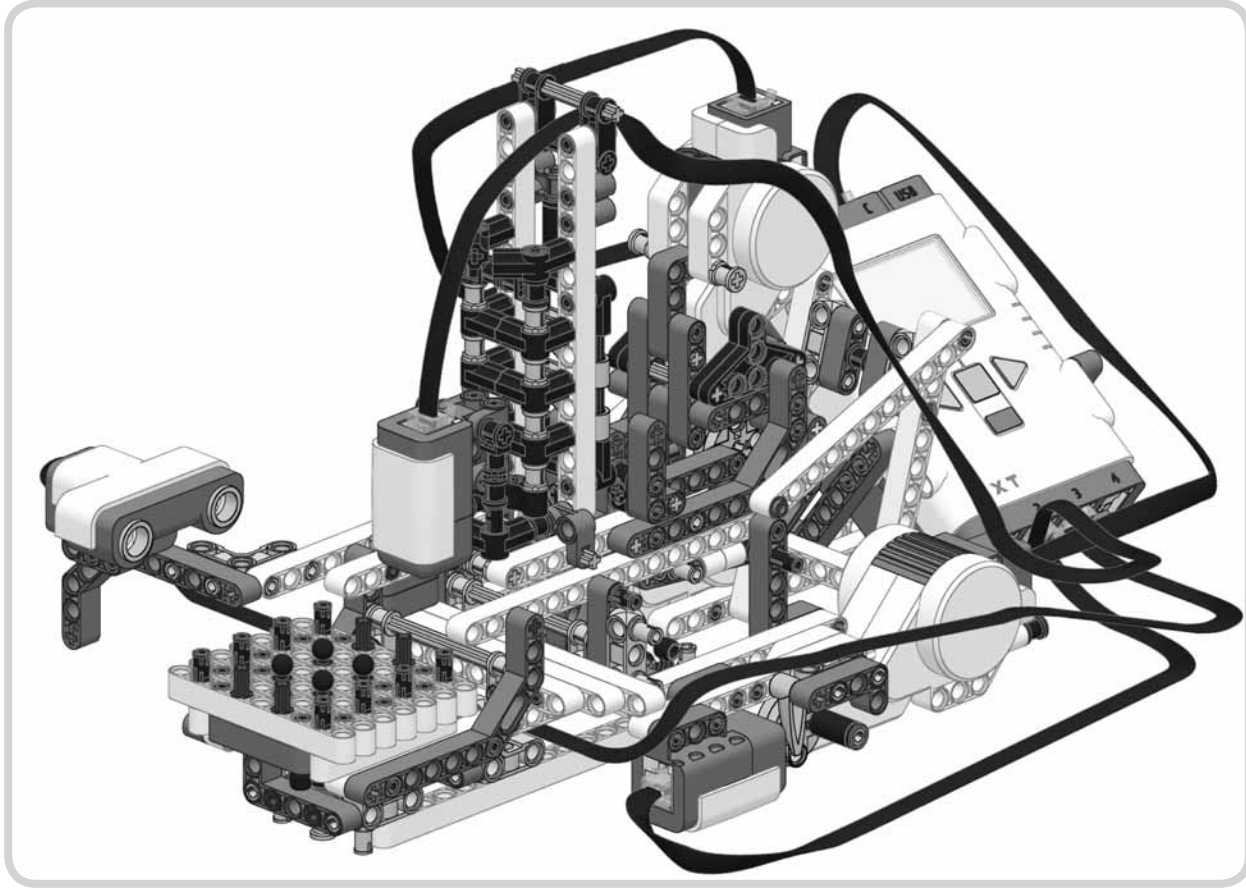
## summary

In this chapter, you learned the optimal strategy for playing tic-tac-toe, as programmed into the TTT Tickler, and how to use and configure your robot. Next, you will build the robot.

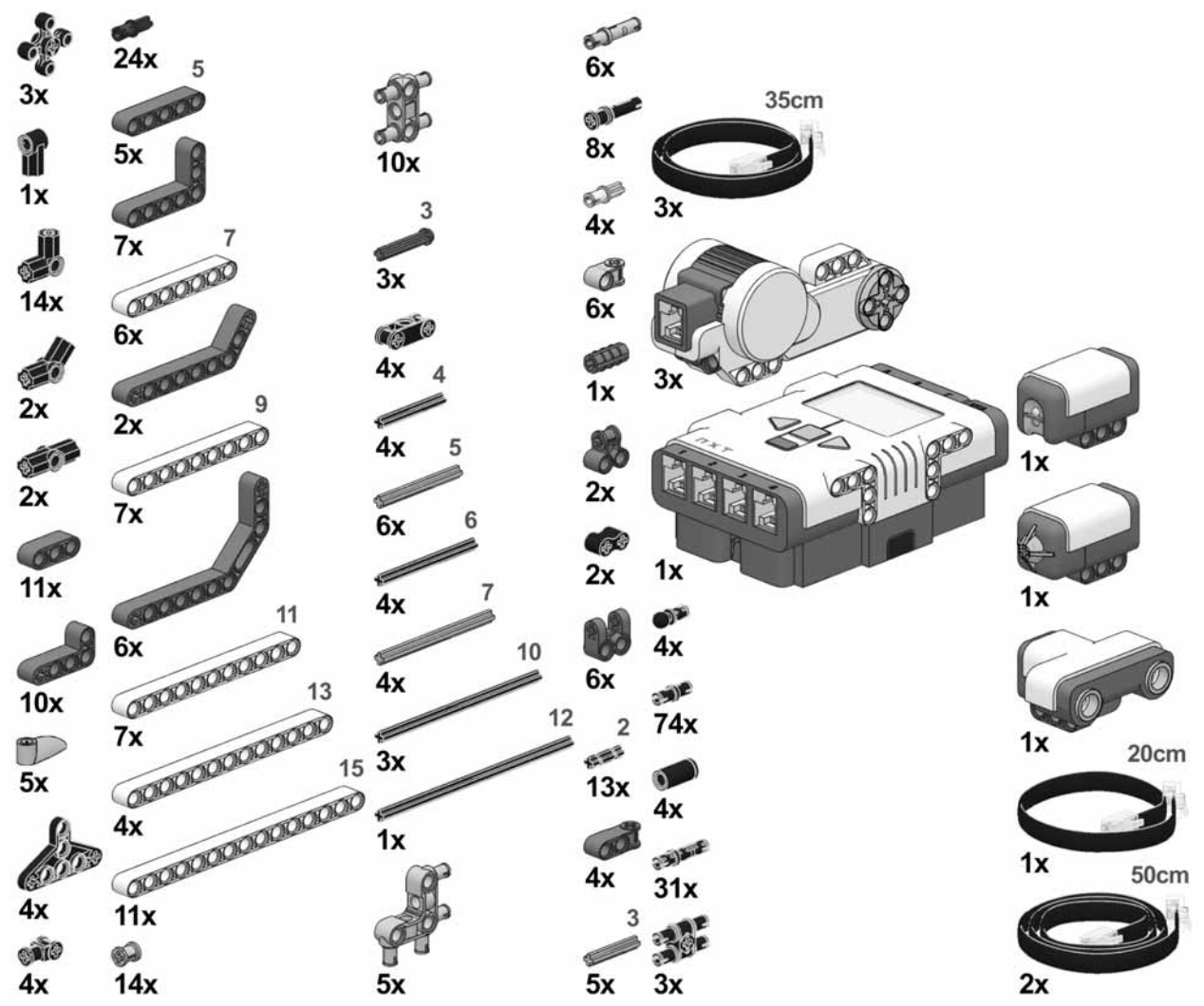
# 3

# building the TTT Tickler with the original NXT set

In this chapter you will build the TTT Tickler with the parts from the 8527 NXT set. Use some glass marbles as marks for the game: you will play with five dark-colored marbles and you should fill the robot's magazine with five light-colored ones.



# bill of materials



# main assembly

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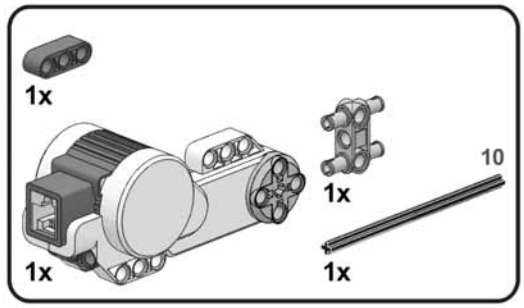


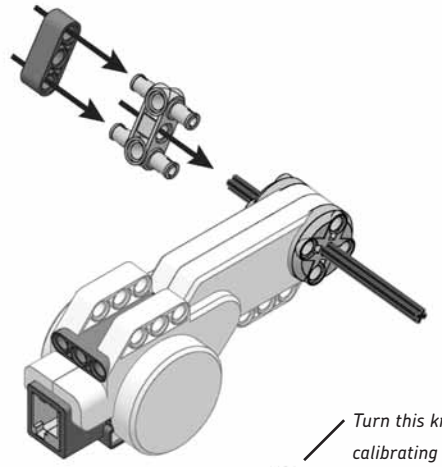

*Turn this knob by hand when calibrating the robot.*

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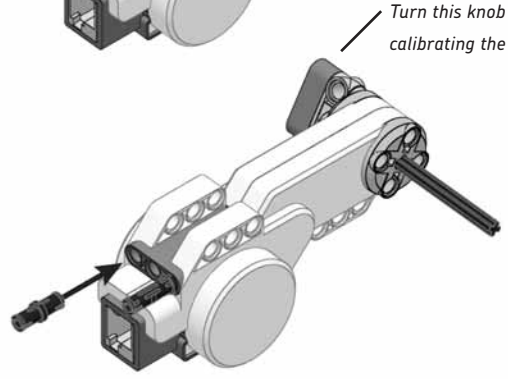

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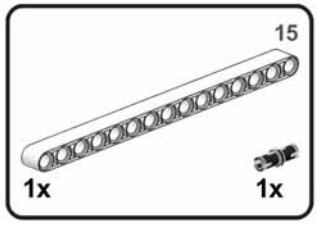


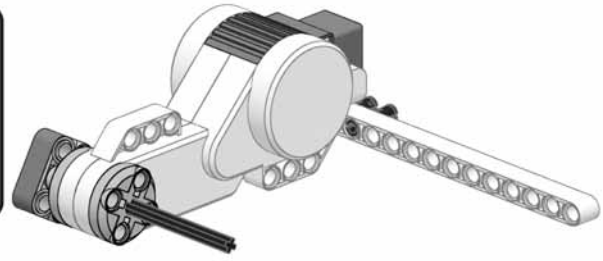

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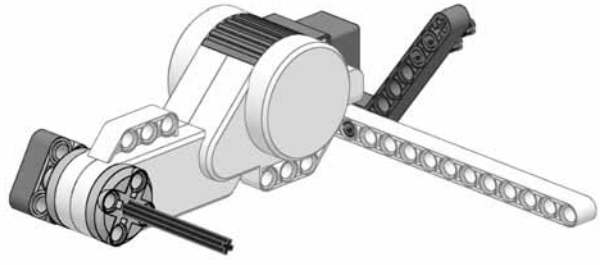

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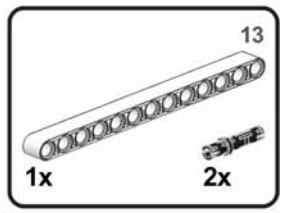


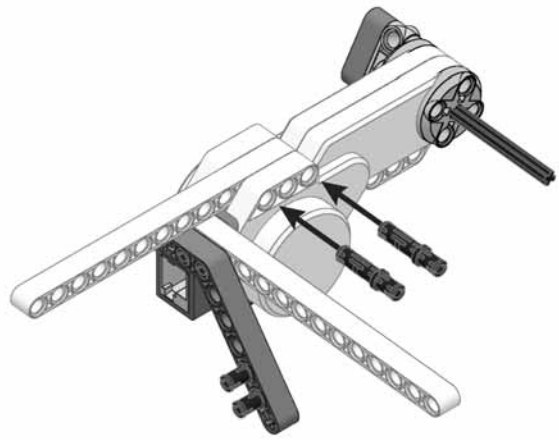

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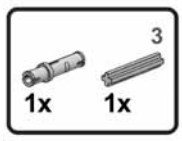


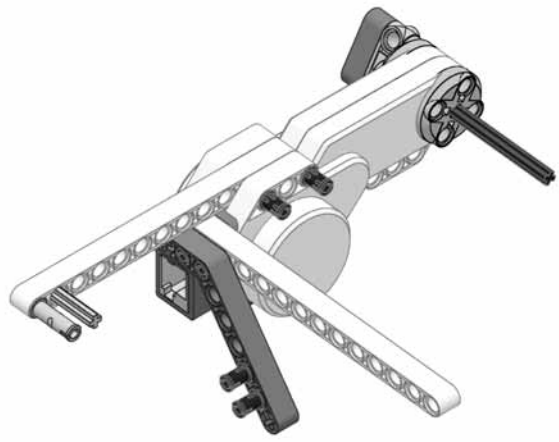

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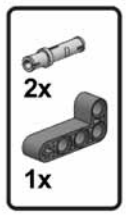


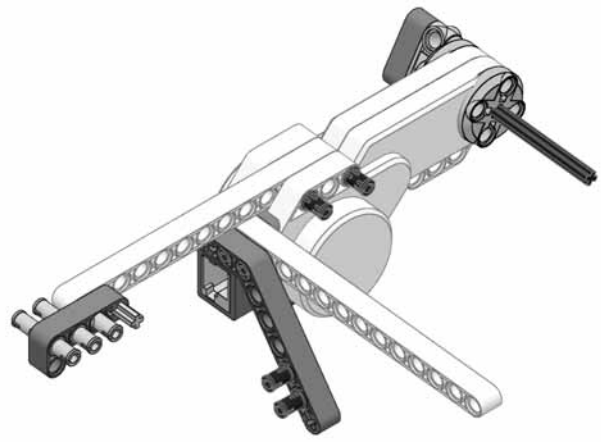

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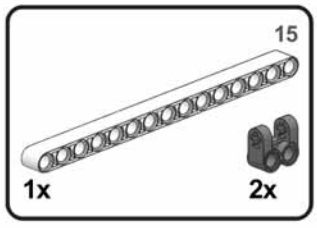


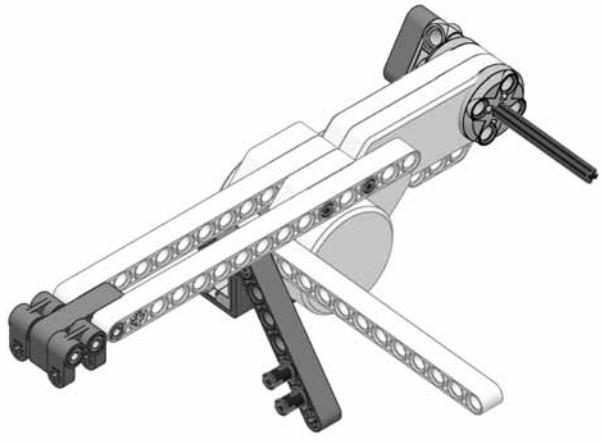

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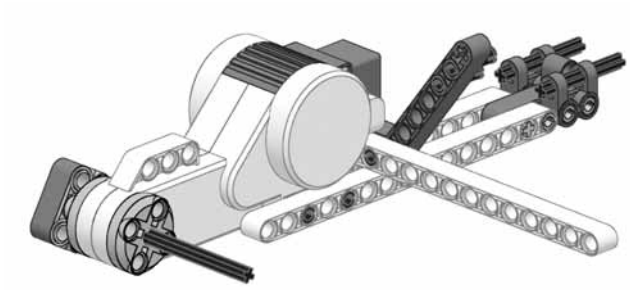

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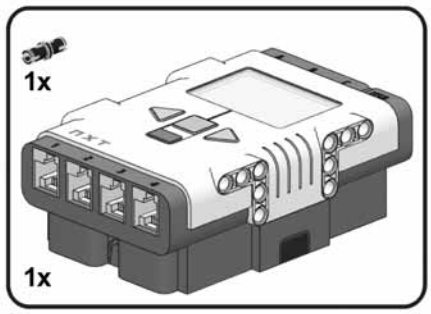


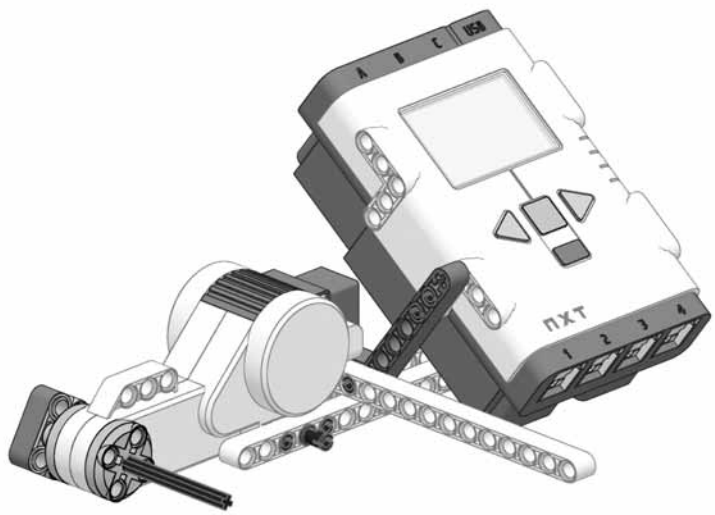

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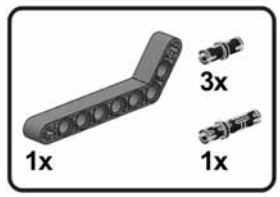


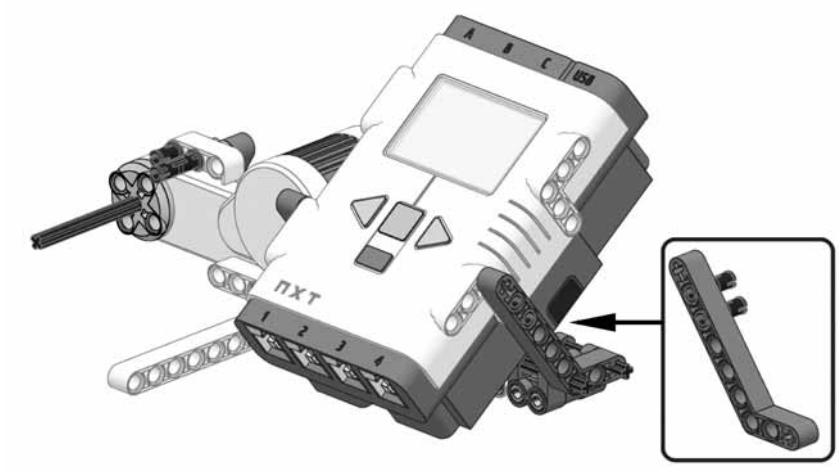

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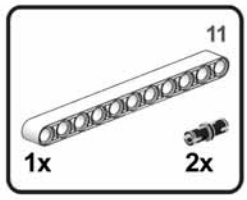


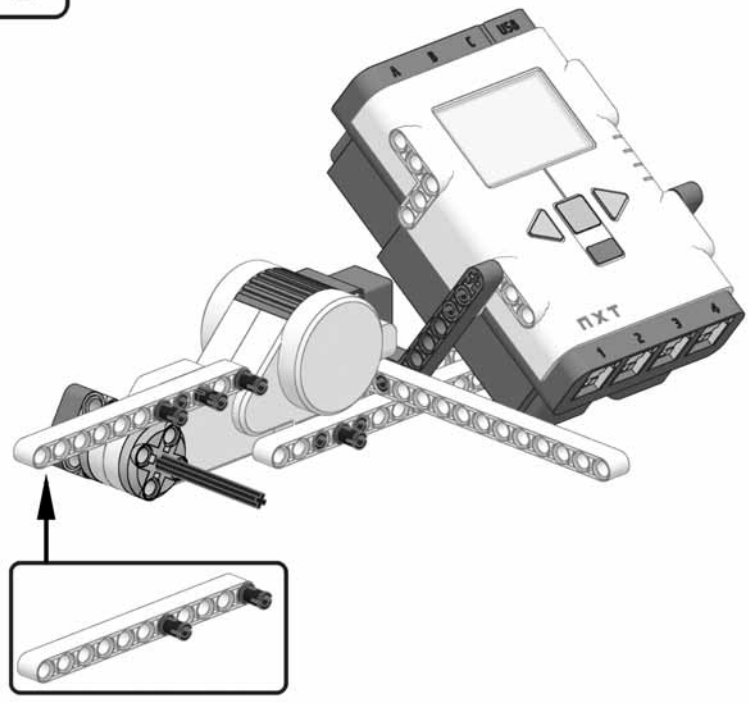

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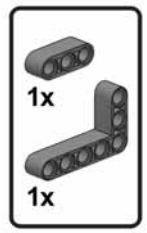
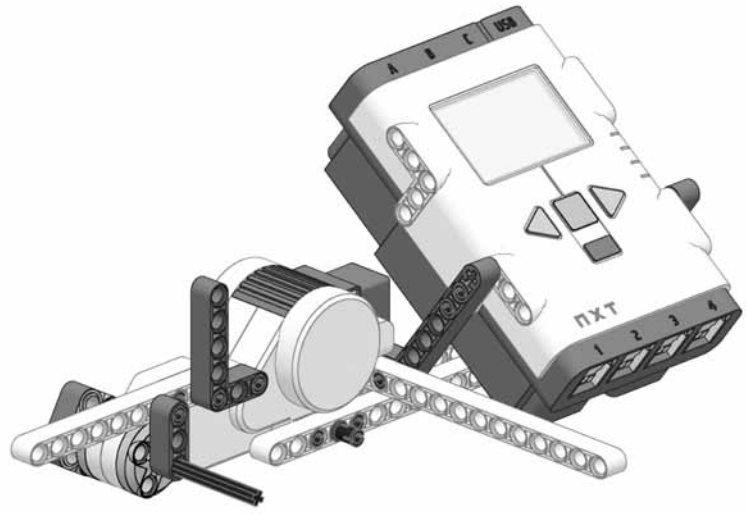
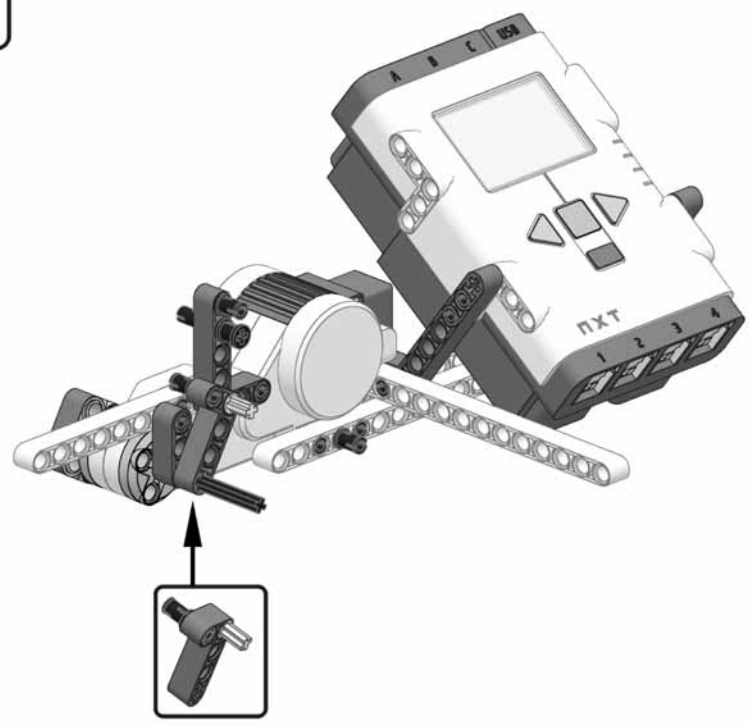
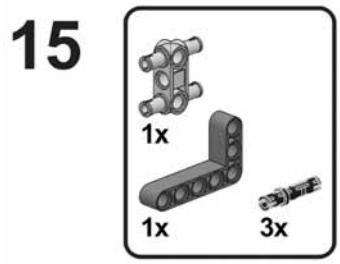
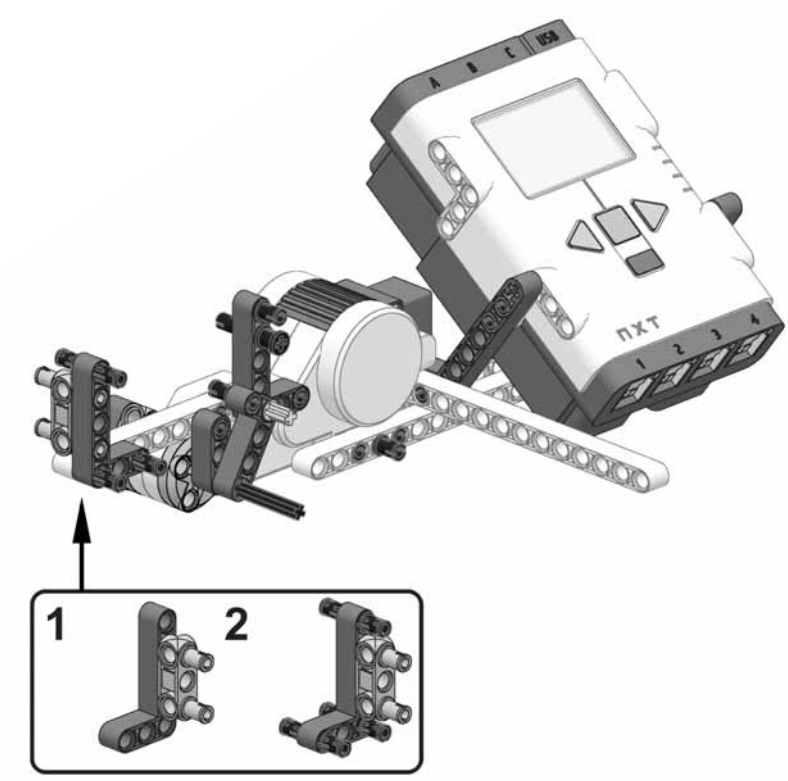


**14**




## base