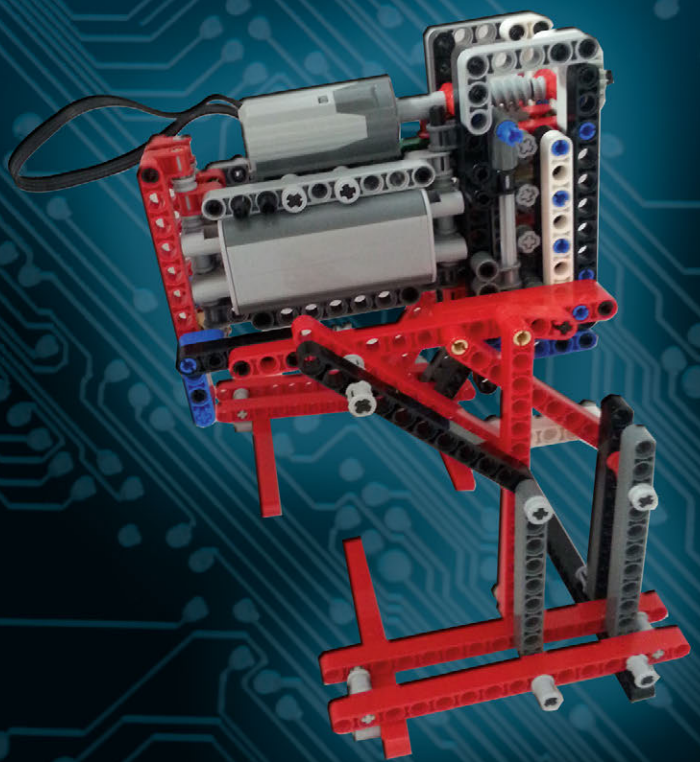
TECHNOLOGY IN ACTION™

LEGO Technic Robotics

DESIGN AND BUILD CUSTOM LEGO BOTS WITH LEGO TECHNIC



Mark Rollins

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This book is for any LEGO builder that dares to dream and then build what they can imagine. I would also like to dedicate this book to my wife, who showed me how to do a "photobox" that helped me to photograph my LEGO creations.

Contents at a Glance

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About the Author

Mark Rollins was born in Seattle in 1971 and attended Washington State University in Pullman, Washington. He graduated in 1994 with a degree in English. After college, he began to write skits for college-age groups.

After four years working for Walmart and another five years working for Schweitzer Engineering Laboratories (SEL), Mark decided to pursue a full-time career in writing beginning in 2005.

Since then, he has written for many tech and gadget blogs, including screenhead.com, image-acquire.com, cybertheater.com, mobilewhack.com, carbuyersnotebook.com, gearlive.com, zmogo.com, gadgetell.com, gadgets-weblog.com, androidedge.com, and coolest-gadgets.com. He has also written for video game blogs such as gamertell.com and digitalbattle.com.

In 2009, Mark decided to create his own tech and gadget blog known as www.TheGeekChurch.com. The purpose of the blog was to report on the latest in technology, as well as inform the church-going crowd (who are often not very technically adept) of the benefits of using more technology in their ministry. Since 2012, Mark has devoted his time to this blog and considers it his ministry and mission.

Recently, Mark has become a Tech consultant, offering his years of experience in technology to consumer electronics companies.

Mark currently resides in Pullman, Washington, with his wife and three children.

About the Technical Reviewer

Jurgen Krooshoop is the founder of Jurgens Technic Corner (http://www.jurgenstechniccorner.com) and is the creator of many LEGO Technic MOCs (My Own Creation) and modifications for original sets. He's been creating these models for over 30 years. Often these models are motorized and remote controlled using Power Functions.

He has specialized in making complete step-by-step building instructions for Technic models. He created professional instructions for many of his models and models of other well-known builders.

He exposes his models at big LEGO events, such as LEGO-FanWelt in Cologne, and is an active member of LEGO forums such as Lowlug.nl and Eurobricks.com.

Acknowledgments

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Introduction

I am certain that everyone has a different image in mind when they hear the word "robot." One definition I found while doing a Google search stated that a robot was "a machine capable of carrying out a complex series of actions automatically." A good example from real life would be a mechanical arm on an assembly line designed to place specific parts on a product, but that would be all it would do. A second definition for robot is "a machine resembling a human being and able to replicate certain human movements and functions." These are the robots that we see in speculative fiction worlds that are mechanical creations made by a human to resemble a human or other organic creation.

The robots in this book are not the kind that have a computer "mind." Sadly, you will not be able to create a robot that can do your housework. These will be robotics that you can take control of with LEGO Power Functions and use for work or play, and you will find that they are capable of a lot of things. If you want programmable robots that will do things for you, I recommend *Mindstorms NXT*, which I mention later in this Introduction.

A Brief History of Robots

The idea of a robot stems from ancient civilization, and it is very interesting to see how our imagination has led to actual creations. Since their mental conception, robots have delighted us in fictional literature as well as in actual reality.

I'm not certain whether the goal of robotics is to create a mechanical creation indistinguishable from a human being, but I think it is interesting that we have never actually succeeded in creating one, even with our modern-day technology. The thing that I find most interesting is that societies that predate the first century A.D. tried to imagine a sentient automaton.

The idea of creating more than just an automated robot has thrived in literature, and the development of realistic robots and robots from fantasy went hand and hand. Some say that Mary Shelley's 1818 novel *Frankenstein* was essentially "the first robot story," even though it seems to imagine the monster (who is never referred to as "Frankenstein") as a flesh creation.

As literature inspired the creation of robots, robots began to inspire the idea of teaching a machine to essentially "think," which in turn led to the development of modern computing.

I am not certain what draws us to these machines. Perhaps it is that we humans enjoy creating, and want to take it to the next step and create something that actually has the ability to create.

Isaac Asimov coined the term "Frankenstein Complex" to describe the fear of mechanical men. I suppose that the takeover of a mechanical race is merely hypothetical with our present robotic technology. Fortunately, I can promise that none of the robots described in this book, which you can create, will ever try to kill you!

Why a LEGO Technic Book on Robots?

Looking at our history, both literal and literary, we, as humans, have been completely fascinated with robots. Even though we may not ever create a sentient one like Data from *Star Trek: The Next Generation*, we can't seem to shake the desire to do so. I would imagine that some of you are reading this book while iRobot's Roombas zip around your carpet and suck up excess debris. No doubt that you have other technological creations in your home that were originally constructed by robots working long hours on the assembly line.

LEGO Technic is most famous for its very realistic LEGO vehicles, but some of their sets focus on using Technic pieces to build some very interesting robotic creations. That changed in 2006, when LEGO introduced their LEGO Mindstorms NXT collection. I have tried out the Mindstorms NXT sets for myself and discovered that it is easier to make robots with pieces that seem specifically designed to be robot heads or arms and are completely programmable.

So I don't think the question is why write a book about how to create LEGO robots, but rather why write about how to create LEGO robots using nothing but LEGO Technic pieces and Power Functions. I don't feel any need to conceal that you could probably make robots easier and better with Mindstorms NXT kits, and Apress has several books on this subject. In the interests of full disclosure and displaying other good books from Apress, I recommend you go to www.apress.com and search for either LEGO or Mindstorms books.

If you want a Mindstorms book, you can find some there. If you want to, you could buy one of them, plus a Mindstorms kit, and start building. In this book I am focusing on LEGO Technic because I want you, the builder, to learn the basic building techniques so you can understand and perfect more advanced techniques. If you are reading this book, then you are a DIY person who doesn't mind doing some hands-on work. So yes, you could buy a toy robot that might do something better than the models I am describing here, but here you can actually learn how to make them. This is why I am going to spend a large part of Chapter 1 outlining how to use basic pieces from LEGO Technic. My goal as an author isn't that you just imitate the models in this book, but rather that you improve on them and create better robots.

LEGO Technic Robotics will teach you the basics, and understanding these basics of LEGO building will enable you to create better creations. You can then use the Mindstorms kits to simplify your work in the future.

How This Book Is Structured

I am not certain what level of LEGO builder you are. You may be just starting out and may never have put two LEGO pieces together. You might be someone who has been playing (or, if you prefer the adult term, building) with LEGO Technics for years. If you are the former, then this book is really going to help you out. If you are the latter, then you will enjoy creating the models in this book and discovering new techniques (or should I say Technics) for creating better creations.

- **Chapter 1: Where to Begin with Your LEGO Technic Robot Kit.** This chapter is as simple as it gets as I talk about basic Technic pieces and how they are used in creations. I also discuss how to purchase these pieces from popular sites like Brickfactory and LEGO's Pick a Brick, and I explain some techniques and tricks that are good to know when you work with them. I will also talk about software that will allow you to construct 3-D digital models of your LEGO Technic creations.
- **Chapter 2: Creating a Robot Body.** Using principles of geometry, this chapter talks about how to create a robot that can have squares, rectangles, and even triangles on its structure. This will be very helpful before creating robot arms and legs.
- **Chapter 3: Bring Your LEGO Technic Robots to Life with Power Functions.** I discuss the LEGO Power Functions and how they can bring LEGO Technics to life by allowing them to move. This chapter also explains how to create a wheeled base for a robot with four-wheeled steering, four-wheel drive, and suspension. Many of the concepts from my earlier LEGO Technic book are also reviewed here.
- **Chapter 4: Designing a Robot Arm.** Everyone wants a robot that can work its arms like a real person, and this chapter shows you how to create a robot limb that can bend at the shoulder, elbow, and wrist and even how to make an interesting artificial hand that can grip.
- **Chapter 5: Creating Robots with Extensions.** This chapter shows you how to make a robot with an extendable limb or waist. Here I detail two forms of extension with the rack and pinion and the scissorlift.

- **Chapter 6: The Robot Head.** This chapter discusses how to make a robot head and even how to give it expressions like eyes or a mouth. You may not be able to make it see, hear, and talk, but you can make it look like it does.
- **Chapter 7: Enabling a LEGO Technic Robot to Walk.** If you don't want your robot to roll around the floor on wheels, then you need to give it legs. This chapter shows you how to create a robot with two, four, or even more legs to make it walk.
- **Appendix A: Parts List.** This presents a complete list and description of all parts used in each project.

CHAPTER 1

Where to Begin with Your LEGO Technic Robot Kit

I'm sure you are anxious to get your hands on some LEGO Technic pieces and start building some robots. If you have worked with LEGO Technic before, you probably have a collection of all kinds of pieces from various sets accumulated throughout the years. I am going to assume that this is the case, but perhaps you are someone who wants to "start a LEGO Technic collection from scratch" or "from nothing". I'm trying to imply that the reader might be starting a LEGO Technic collection from nothing.

If you flipped through this book before you purchased it, then you will have seen a lot of instructions. If you want to try and build these LEGO creations yourself, you will obviously need to get specific LEGO Technic parts. There are several places online where you can do that, but it might be easier if you look at the Appendix in the back of this book. There you will find a list of all the parts you will need to build the individual models described in this book.

Before I start talking about where to purchase LEGO Technic pieces, let me say a few words about them. Traditional LEGO bricks are generally square and they come in brick form and flat bricks known as plates. They also have the studs to make them fit with the "female" side, but you will find that very few of the models in the book use studs at all. In their place are Beams, Levers, Axles, Connector Pegs, Bushes, Cross Blocks, Angle Elements, Gears, and various other Technic Miscellaneous Pieces.

LEGO Pick a Brick

The most obvious place to purchase LEGO Technic pieces is the LEGO web site itself. You can go to the official LEGO site at http://shop.LEGO.com. On the web site you will see under "Themes" the Pick a Brick section has a tab for "Categories," and here you can search for the LEGO Technic piece you are looking for under the Technic category. You can also do a search under Color Family. I know that some of you LEGO builders are sticklers for color and demand that your creations conform to a certain color scheme. You don't have that freedom if your LEGO collection is an amalgamation of many LEGO Technic sets over the years. In addition to searching by color, you can also search by its Brick Name, Element ID, or Design ID, which are specific designations that LEGO gives its parts.

If you are ever looking for a specific brick, you can do an Advanced Search on the left column using the Brick Name, which is the formal name for the brick. I will have to admit that will produce mixed results unless you know exactly what you are looking for. Later in this chapter, I will discuss some basic Technic LEGO pieces that you will need, and I will include the Element ID numbers.

When you are ready to purchase the part you are looking for, you can press the "Add To Bag" link and your individual pieces will appear in the "Brick Bag" column. When you have selected all the parts you need, just press the "Update Bag" and add the part to your personal Shopping Cart. Yes, you will need an account with LEGO to have your items sent to you, and you will be charged to that account upon checkout.

BrickLink

If you are looking for another place to find LEGO Technic pieces, I would suggest looking at BrickLink (http://www.bricklink.com), as shown in Figure 1-1. BrickLink is an unofficial LEGO marketplace, and it is often referred to as the "eBay of LEGO." If you want to buy or sell LEGO sets, new and used, this is the online place to shop.

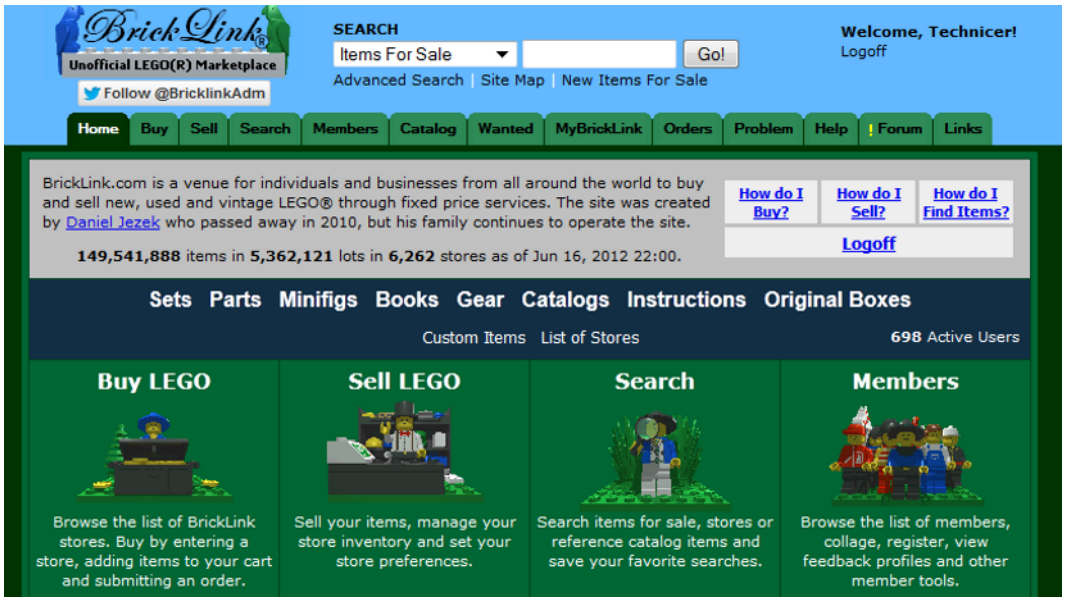

Figure 1-1. *The BrickLink site, a place to find LEGO bricks, both new and used*

If you click the Buy tab, you will have the option of purchasing several items, including sets, books, gear, catalogs, and parts. At the time of this writing, there are over 116 million parts available for purchase. Selecting the Parts tab will result in a category tree that branches out into several types of pieces, and there are 16 subcategories for Technic including:

- *Axle*: Anything that is an axle or has an axle attachment (see Figure 1-9).
- *Brick*: Any Technic shown in the Technic brick section in Figure 1-5, and some that I didn't show, is here.
- *Connector*: This is an umbrella term that refers to Angle elements and Cross Blocks (see Figure 1-22).
- *Disk*: These are disk-shaped pieces that I did not describe above. I don't really have them on any of the models in this book, and I don't really see them on more recent sets.
- *Figure Accessory*: At one point in time, Technic had figures that were to the scale of the Technic vehicles. They don't make them anymore, but here is a place where you can find the accessories like helmets and feet.
- *Flex Cable*: Some Technic sets have flexible cable that helps to create a more curvaceous shape. If that is what you are interested in, here is a place to find it.
- *Gear*: Parts like the one displayed in Figure 1-28.

- *Liftarm*: This refers to pieces like Beams and Levers, and all of their variations (see Figures 1-6 to 1-8).
- *Liftarm Decorated*: This refers to pieces that have stickers or printed graphics on them.
- *Link*: A good example of a piece that will be used for steering on a LEGO Technic construction.
- *Panel*: These are very big pieces that take up a lot of space. I didn't really use any of them in any of my models in this book.
- *Panel, Decorated*. Like the other Panel pieces, but these often have stickers or some type of graphics on them.
- *Pin*: This is where you would find various types of Connector Pegs, which you can see in Figure 1-12.
- *Plate*: These are flat bricks with Technic holes in them. I didn't discuss them in this book at all and don't really have any models in this book that use them.
- *Shock Absorber*: These are the types of pieces that I discuss in Figure 1-37.
- *Steering*: These are various parts that would go well with steering.

Please note that the names and descriptions of parts that BrickLink might not be exactly the same as the names I have given to the parts in this book. I used the official names that LEGO designates their parts from a program they have known as LEGO Digital Designer (LDD), and these names can be different from what BrickLink calls them.

If you are looking to buy many LEGO Technic pieces, BrickLink is very similar to LEGO's Pick a Brick in that you can assemble your parts in a shopping cart and then checkout when you are ready. I found that their catalog is a little more extensive and easier to search through if you are looking for a specific piece, and you might be able to get a deal on pieces if you buy them in bulk. If you are looking to build one of the models in this book and want to purchase every piece for it, this is one place to go. It is even possible to purchase entire Technic LEGO sets that the company used to sell. In case you don't know, LEGO refurbishes their catalog every year, so their inventory is constantly changing.

Web Sites for LEGO Instructions

Some of you might want to build a LEGO Technic set that you remember making several years ago, but, as I stated before, LEGO changes their models every year. You might be able to find the actual set with instructions on BrickLink, and the more recent ones on `LEGO.com`, but if you have all the pieces, all you really need are the instructions. I highly recommend looking at the web sites listed below, just to generate ideas for LEGO Technic robots.

The LEGO Official Site

Oddly enough, every model that is available for purchase on the official LEGO Technic web site has a place where you can click and download instructions as a PDF file that can be saved on your computer. I have noticed that more recent LEGO instructions have a parts list in them, and this is a good information so you can order them on Pick a Brick or BrickLink. Keep in mind that LEGO likes to introduce new pieces as often as it produces new models. You may find that some of the newer pieces are harder to find, and you might have figured out how to build around it in some simple or complex workaround.

Peeron

If you are interested in building Technic LEGO sets over the years, then I highly recommend that you go to a web site that contains both LEGO catalogs and instructions. I found that Peeron (`www.peeron.com`) is especially helpful with its database of LEGO sets and catalogs (Figure 1-2).

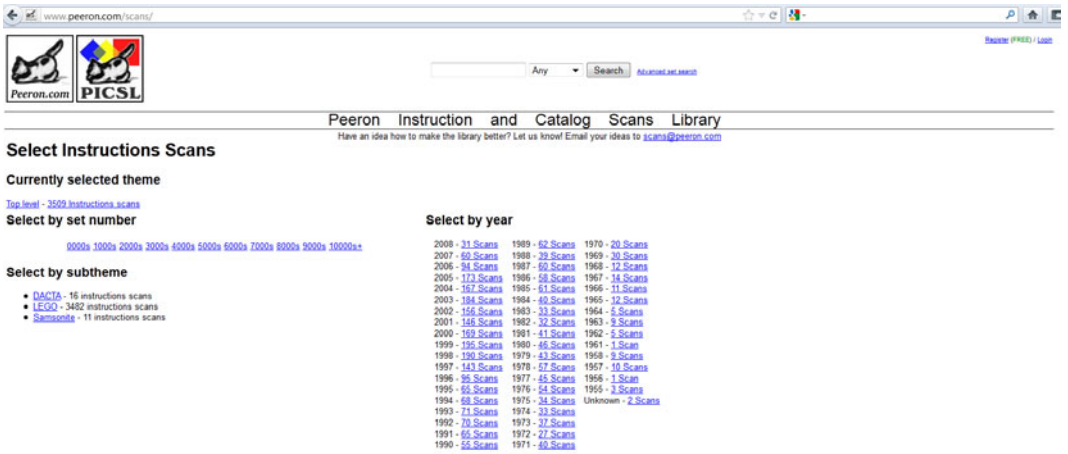

Figure 1-2. *A screenshot of the Peeron web site, a place to find instructions for LEGO sets*

I found that Peeron's inventory only goes up to the 2008 collections (as of this writing), and they often took a very long time to download. If you know the exact set you are looking for, then you should have no problem entering its name or ID number in the search engine and find its instructions and parts list. You might also be able to find a set if you know the date of its release. I will explain how to find Technic set numbers in the next section.

Brickfactory

I also found Brickfactory (`www.brickfactory.info/`) to be a helpful resource, and it does have some of the more recent collections (Figure 1-3). Generally, LEGO Technic sets are given a number that is in the 8000 range or higher, with the exception of the 900 series when the Expert Sets first began in 1977. You will notice that several model series like Bionicle are filed under the same umbrella with advanced Technic sets.

Figure 1-3. *The Brickfactory is a place to find all kinds of LEGO instructions*

You will discover that a lot of the models in Peeron and Brickfactory have most of their pieces available on Pick a Brick. Peeron is especially good at cataloging the individual pieces of a set, and you will find that a search for any set will reveal the individual pieces, including their individual Element ID. Unfortunately, you might discover that the Element ID on Peeron, BrickLink, or whatever site is a perfect match for the Element ID on Pick a Brick.

A Basic Introduction to LEGO Technic Pieces

There is no "ultimate set" of Technic pieces. The current selection in LEGO's catalog is for individual models, and some have many of one piece but not so many of another piece. If you are someone who isn't interested in spending too much of your budget on LEGO pieces, you learn to adapt your creations to the pieces you already have. In fact, you will discover that several of the creations in this book could probably be simplified with other LEGO Technic pieces, but I chose to stick to the basics for this.

A System of Storage for LEGO Technic Parts

As I said earlier, most LEGO enthusiasts simply build from whatever pieces they have based on the particular sets they have bought in the past. Before you do any building, I highly suggest you find a way to keep your LEGO Technic pieces organized. You will find you lose a lot of time rummaging through a pile looking for that one piece you need so you can move on to the next step.

As much as I like to hear the sound of LEGO bricks being scraped together, I like to keep my LEGO pieces organized in order to avoid long, drawn-out times of searching for "that right piece." I recommend buying some kind of tackle box, as the little drawers and storage containers on them are good for keeping pieces separate from one another (Figure 1-4). Another way is to purchase some kind of toolbox from a hardware or retail store that has drawers or other compartments for storing individual pieces. Of course you may not want this type of organization, and that is fine. The important thing is that you are have fun with this, and it does take quite a while to organize your LEGO pieces into sections like this.

Figure 1-4. *One way to organize LEGO Technic pieces, with tackle boxes*

Much of information in these next sections may seem elementary to most LEGO builders. I have already covered much of this in my first book, but I felt it necessary to explain the types of parts individually and their uses here. I will also show you how I organize my LEGO Technic pieces. You will note that in some illustrations, I don't have certain pieces, but I use an illustration from Peeron's LDraw just to show you what it looks like. See later in this chapter for more information about LDraw. Please keep in mind that the numbers on the illustrations are for the figure only, and I put the official LEGO ID number in parentheses so you can find it on Pick a Brick or BrickLink if the part is available for purchase.

This section discusses parts, but it is not meant to be an exhaustive list of what LEGO Technic parts are available to LEGO builders. As I mentioned earlier, LEGO creates new parts every year, and there are some parts that I deliberately didn't list here, as they were not used on any models in this book. I will also introduce other types of LEGO Technic parts in this book as I go, and will devote a lengthy section to it in the next chapter on Power Functions.

Occasionally, I will introduce a traditional LEGO brick into one of the instructions, but I didn't see a need to devote a section about what bricks and plates (flat LEGO pieces) to organize into drawers. If you want to, you could follow the pattern of organization in the illustrations below for your non-Technic bricks.

Technic Bricks

When LEGO introduced their "Expert Sets" in the late 1970s, they introduced a new kind of brick. These bricks have holes on the sides for Connector Pegs and Axles (see individual descriptions below). Sometime around 2000, LEGO Technic began to emphasize Beams rather than traditional studded pieces. Most LEGO Technic sets shun these Technic brick pieces now and generally are completely studless. In fact, I can honestly say that I only used a handful of LEGO Technic Bricks in the projects in my previous book. However, if you are a LEGO builder of any type, you could devote an entire drawer in your tackle box or toolbox for these bricks, by length. As you can see, the amount of round holes in the side is usually equal to the amount of studs on top, minus one (with some exceptions). Figure 1-5 shows how I have this arranged in my tackle box, and you can see that I have a large space devoted to Technic Bricks of unusual shapes. You will note that I don't have them separated by color, and not every type of piece has a place by itself. This is because I have very few of some pieces and a lot of another, and it is just easier to group similar pieces together.

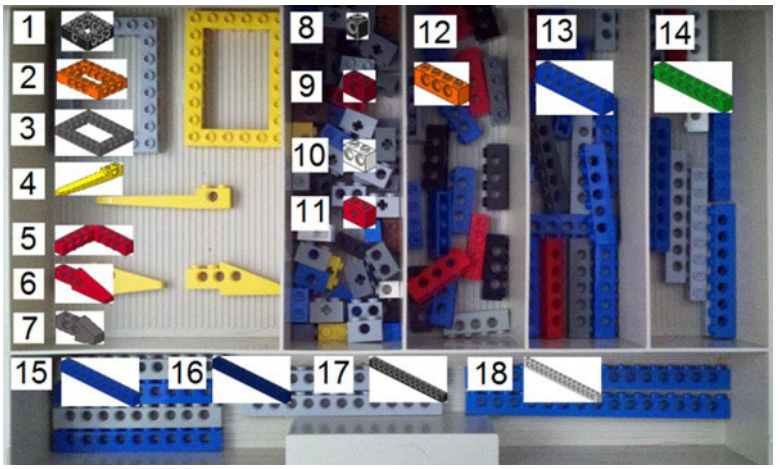

Figure 1-5. *A method of storing LEGO Technic Brick in a tackle box drawer*

■ **Note** The numbers in Figures 1-5 through 1-9, 1-12, 1-22, 1-28, 1-37, and 1-38 correspond to the numbers in the parts list that immediately follows the respective figures. I put the official LEGO ID number in parentheses in the list so you can find it on Pick a Brick or BrickLink, if the part is available for purchase.

1. Brick, 4 × 4 (32324). It is possible to make the same shape by assembling certain bricks together, but depending on your creation, it might be much easier to have this shape in one form. This is one of three fused quadrilateral shapes that LEGO has available.
2. Brick, 4 × 6 (32531). Just like the 4 × 4 Brick, but slightly larger.
3. Brick, 6 × 8 (32532). Also like the 4 × 4 Brick, and also larger.
4. Technic Fork (2823). This is essentially a 1 × 2 Technic Brick with an odd extension that takes it to a length of 6M. I think it is called a Fork because it used to be in LEGO sets with forklifts. It certainly resembles a basic prong of a standard factory forklift.
5. Angular Brick 5 × 5 (32555). Like traditional LEGO Bricks, LEGO Technic Bricks also have corner pieces. Most of the traditional LEGO corner pieces are 2 × 2 bricks at a right angle, but this Technic model is 5 × 5 and will come in handy for all sorts of creations.
6. Wing Section, Rear (2744). A while back, LEGO Technic had sets with airplanes that used LEGO Technic Bricks. This was before Technic sets started using Beams (see next section), and this piece could create a Wing Section.
7. Wing Section, Front (2743). Like the Wing Section, Rear, this LEGO Technic Brick can form an excellent wing section in the form of a LEGO brick.
8. Technic Brick, 1 × 1 (6541). This is essentially a 1 × 1 LEGO Brick, but with a hole for an Axle or Connector Peg (see sections below). As stated before, the amount of round holes on the side of a LEGO Brick is generally equal to the number of studs, minus one. This is one exception.
9. Technic Brick, 1 × 2 (3700). This is a 1 × 2 LEGO Brick, but with a single round hole in the middle.
10. Technic Brick, 1 × 2 with Two Holes (32000). This is like the 1 × 2 Technic Brick, but this one has two holes. It is one of two exceptions to the rule of studs and round holes, as explained earlier in this section.
11. Technic Brick, 1 × 2 with Cross Hole (32064). This is just like the 1 × 2 LEGO Brick, but instead of a hole for a Connector Peg or Axle, it has a Cross Hole made purposely to hold an axle in place (see part description below).
12. Technic Brick, 1 × 4 (3701). With one exception, LEGO Technic Bricks generally have an even number of studs, and this is one of the smallest at a length of 4M with three round holes on the side. The rest of the Technic Bricks increase by 2M or two studs, and the number of round holes on the side is equal to the number of studs, minus one.
13. Technic Brick, 1 × 6 (3894).
14. Technic Brick, 1 × 8 (3702).
15. Technic Brick, 1 × 10 (2730).
16. Technic Brick, 1 × 12 (3895).
17. Technic Brick, 1 × 14 (32018).
18. Technic Brick, 1 × 16 (3703).

Beams

As I mentioned earlier, the emphasis of recent LEGO Technic sets has been less about traditional LEGO pieces like Bricks and more about studless Beams. As you can see, organizing them is simple by length (Figure 1-6). Unlike Technic Bricks, the number of holes on the beam is equal to the length. Except for the 2M length, all beams tend to have an odd number of holes. Note that some of the Beams have a circled number beside them, and this is to indicate their length in terms of LEGO studs.

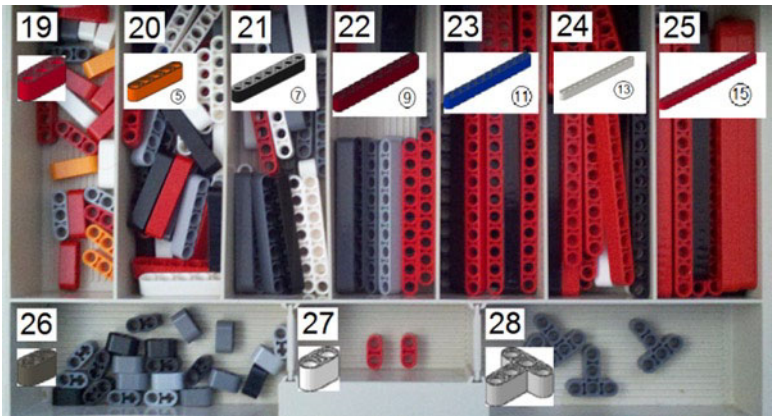

Figure 1-6. *A drawer in a tackle box filled with LEGO Beams*

19. Technic 3M Beam (32523). This is the beginning of the odd-numbered beams, which will increase by 2M in the next six drawers.
20. Technic 5M Beam (32316).
21. Technic 7M Beam (32524).
22. Technic 9M Beam (40490).
23. Technic 11M Beam (32525).
24. Technic 13M Beam (41239).
25. Technic 15M Beam (32278).
26. Technic Beam 1 × 2 Beam with Cross and Hole (60483). Also known as a Cross and Hole Beam, this has the unique ability to have a round hole for a Connector Peg or Axle and a cross-shaped hole made specifically for an axle. You will see this used in many creations in this book.
27. Technic 2M Beam (43857). As stated earlier, most Beams are odd numbered in their measurement. This 2M Beam is the only exception, save for the previously mentioned Cross and Hole Beam.
28. Technic T-Beam 3 × 3 (60484). This is essentially two 3M Beams fused together into a T Shape, and you will find that angled Beam pieces help on a lot of creations.

In addition to these straight beams, there are also beams at angles, and because of their number and size, I have devoted another drawer in the tackle box to them (Figure 1-7). In Chapter 2, I will discuss how to create triangular and trapezoidal creations with these Angular Beams.

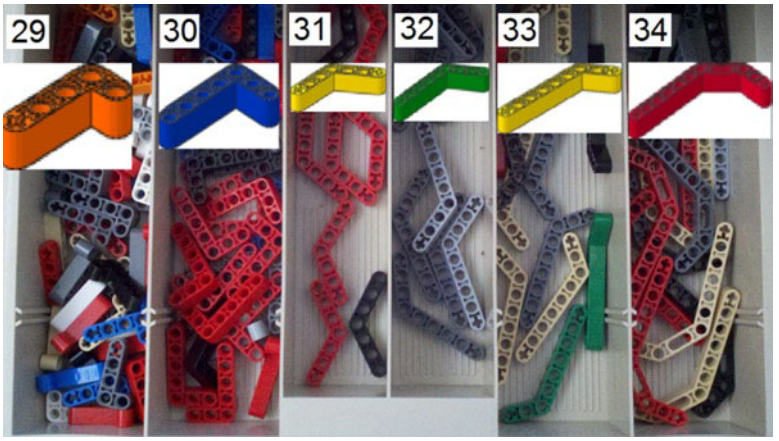

Figure 1-7. *Another drawer for LEGO Beams*

29. Technic Angular Beam 4 × 2 (32140). Like the T Beam, this is the merging of two Technic Beams to form a 4 × 2 Beam at a perfect right angle. This works well when creating square or rectangular creations. You will notice that one of the holes is cross-shaped, perfect for an axle.

30. Technic Angular Beam 5 × 3 (32526). Like the 4 × 2 Angular Beam, this is another 90-degree Angular Beam that is slightly larger at 5 × 3. Unlike the 4 × 2 Angular Beam, there is no cross-shaped hole on one end.

31. Technic Angular Beam 4 × 4 (32348). This Angular Beam is at an angle of 53.1 degrees. Note the cross holes at each end.

32. Technic Angular Beam 4 × 6 (6629). This Angular Beam is like the 4 × 4 as it is at the same angle at 53.1 degrees, but it measures at 4 × 6.

33. Technic Angular Beam 3 × 7 (32271). This Angular Beam has the same angle at 53.1 degrees, but measures at 3 × 7.

34. Technic Double Angular Beam 3 × 7 (32009). This particular Beam has two 45-degree angles, so it is essentially a 90-degree angle with a good curve to it.

Levers

Levers are essentially half the width of a Beam, and stacking two of them equals one Beam. Like the Beams, they often have Axle holes on the ends of them (Figure 1-8).

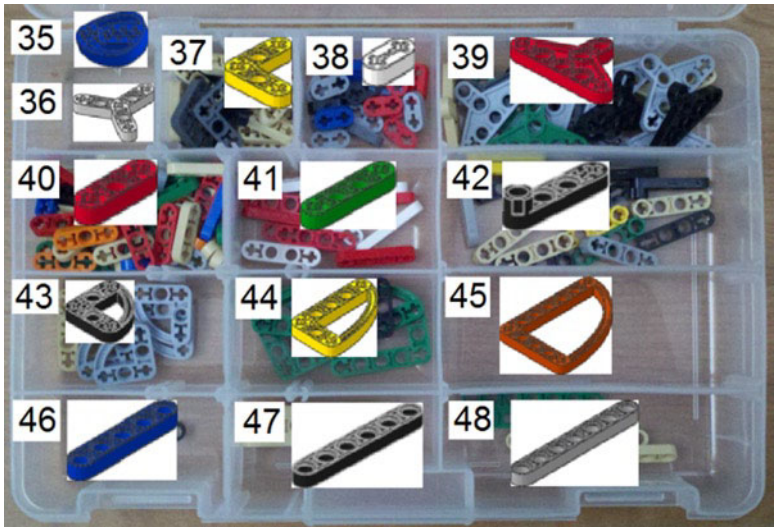

Figure 1-8. *Various LEGO Technic Levers*

35. Technic Comb Wheel (6575). This is not really a wheel in shape, but this lever is slightly round and it is good for securing things. I am guessing that it is called a Comb Wheel because it looks slightly like a comb.

36. Technic Lever 3 × 120 (44374). This propeller-shaped lever is called a 3 × 120 because there are three beams measuring 3M at 120-degree angles of one another.

37. Technic Lever 3 × 3M (32056). This is essentially two 3M Levers fused together at a 90-degree angle. Such a piece, with cross-shaped holes at its vertices, helps for all kinds of creations.

38. Technic 2M Lever (41677). This lever has two cross-shaped holes and is 2M in length, very helpful for securing Axles in place.

39. Technic Triangle (2905). This piece has an odd shape with five round holes and two cross-shaped holes.

40. Technic 3M Lever (6632). This type of Lever has a cross-shaped hole on each end and a round hole in the middle.

41. Technic 4M Lever (32449). This type of lever is larger than the 3M, with two round holes in its middle and a cross-shaped hole on each end.

42. Technic 4M Lever with Notch (32006). The only difference between this piece and an ordinary 4M Lever is that the "notch" at the end is as thick as two stacked Levers (1M). You will find many places where this will work to your advantage.

43. Technic Half Beam Curve 3 × 3 (32449). This particular lever looks similar to the 3 × 3, but it has a circular curve joining two ends.

44. Technic Half Beam Curve 3 × 5 (32250). This is very similar to the Half Beam Curve 3 × 3, but it is larger at an elliptical curve at 3 × 5.

45. Technic Half Beam Curve 5 × 7 (32251). Like the Half Beam Curve 3 × 5, this also has an elliptical curve, but larger at 5 × 7.

46. Technic 5M Half Beam (32017). This Half Beam is aptly named as it looks like a 5M Beam split down the middle, with five round holes.

47. Technic 6M Half Beam (32063). This piece is just like the 5M Half Beam, but measures in at 6M. Since LEGO doesn't make any 6M Beams, you can also stack two of these atop each other and get the same effect.

48. Technic 7M Half Beam (32065). This is just like the 5M Half Beam, but measures in at 7M.

Axles

Like the Beams, the Axles can be easily organized by length (Figure 1-9). Axles are like bolts in the LEGO Technic world. You can use them to link just about anything, and their cross shape ensures that they fit on cross holes securely.

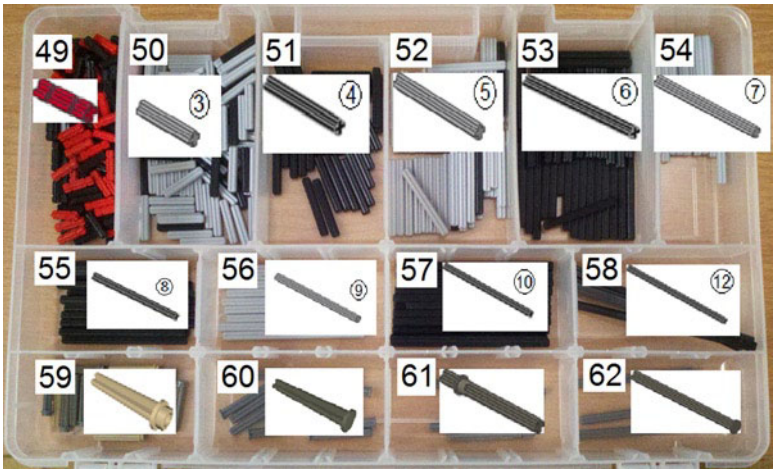

Figure 1-9. *A collection of LEGO Axles*

Like the Beams, the number in the circle is an indicator of the length.

49. Technic Axle 2M (32062). You can see in Figure 1-9 that 2M Axles comes in different colors, and I have noticed that newer ones come in a shade of red. Usually 2M Axles are notched, but I'm not certain why that is. Perhaps it is to make it easier for the LEGO builder to pry out.

50. Technic Axle 3M (4519). You can see in Figure 1-9 that some of the 3M Axles are black, but I have noticed newer sets using gray for the 3M. Generally, most Axles with an odd-numbered measurxement are gray in color.

51. Technic Axle 4M (3705). This is the second smallest of Axles with an even number in measurement. These even-numbered measured Axles are generally black in color.

52. Technic Axle 5M (32073). Like the 3M Axles, there are a few black 5M Axles in Figure 1-9, but these are usually gray.

53. Technic Axle 6M (3706).

54. Technic Axle 7M (44294).

55. Technic Axle 8M (3707).

56. Technic Axle 9M (60485).

57. Technic Axle 10M (3737).

58. Technic Axle 12M (3708).

59. Technic Axle 3M with Knob (6587). Unlike ordinary 3M Axles, these have a bump on the end that can serve as a perfectly good LEGO stud.

60. Technic Axle 4M with Stop (87083). Like the 3M Axle with Knob, the 4M with Stop has something that will make certain the Axle can only go so far. Although the stop is not a LEGO stud, I found these useful in a lot of projects, like when you need a 4M Axle to stay put.

61. Technic Axle 5.5M with 1M Stop (59426). This piece is really 5.5M in length, and the stop is not placed at the end, but rather 1M from the end on one point. This is good for situations with wheel axles and other projects.

62. Technic Axle 8M with Stop (55013). This is just like the 4M Axle with Stop, but twice as long.

Technic Axles in Action

In this book, I am going to show several LEGO models that you can build with the step-by-step instructions. I think it is worth my time to show you how some of these LEGO Technic parts work together. In Figure 1-10, you can see three 3M Axles with Studs on the left, followed by a 4M with Stop, a Technic Axle 5.5M with 1M Stop, and an 8M Axle with Stop.

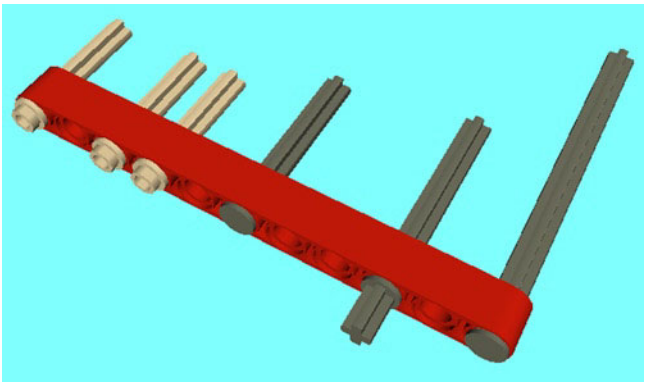

Figure 1-10. *A normal LEGO Technic 11M Beam with four types of Axles. Note how each type "caps" off a round hole in some way*

Each of the Axles in Figure 1-10 are stuck in such a way that they cannot be pulled out from their "uncapped" ends. You will find that in LEGO Technic creations, it is good to have Axles (not to mention other parts) secured on one end. Note the application of some other pieces in Figure 1-11.

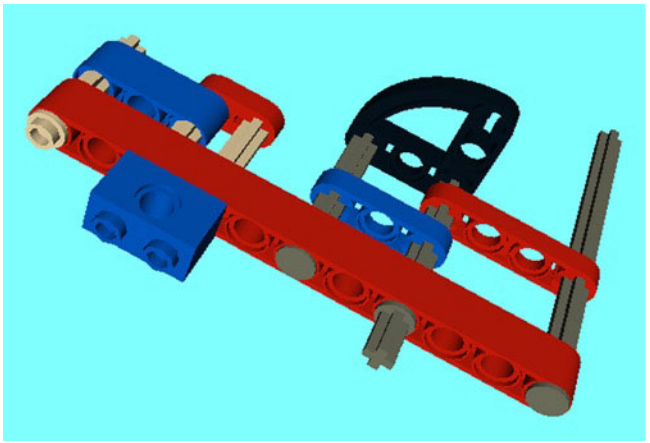

Figure 1-11. *This is the same structure as in Figure 1-10, but it shows how LEGO Technic Bricks, Beams, and Levers can fit on Axles*

You will note in Figure 1-11 that the two 3M Axles with Studs make it possible to stick on a 1 × 2 Technic LEGO Brick. It is possible to slide on the 3M Beam and 2M Lever. You will notice the varieties of Lever parts on the 4M Axle with Stud, 5.5M Axle with 1M Stop, and the 8M Axle with Stop.

In spite of these extra parts in Figure 1-11, none of these Axles are firmly held in place. For extra security in LEGO Technic, you can use both Connector Pegs and Bushes.

Bushes and Connector Pegs

If Axles are the nuts of the LEGO Technic world, then the Bushes are the bolts. The Bushes are a very common part in LEGO Technic builds, and they slide very easily on a Axle and are made to hold them in place. Like the other aforementioned parts, you will accrue a lot of these.

The Connector Pegs (sometimes called pins) are also very common parts, and they click into place in the round holes of the Beams or other LEGO Technic pieces. You will accrue a lot of Connector Pegs, and I consider them the "rivets" of the LEGO Technic world. There are other parts described in this section, and you can use them to link Beams and Levers together, and they come in many forms.

You will notice that Figure 1-12 is a sectioned-off container with these several types of parts, and you will see parts that look very similar but are different colors. The reason why I sectioned off the similar parts is because even though they look alike, they produce different effects. Some of the Connector Pegs have "friction," which means they do not spin as easily as the ones that do not have friction. You will discover that there are some times when you want a piece to spin freely and easily, so you will then want the pieces that do not have friction. Then there are times where you want a construction to lock securely in place, so using a piece with friction is your best course of action. I will discuss more about specifics of construction later in this chapter and other chapters, but here I only wanted to call it to your attention.

Figure 1-12. *A collection of Technic Connector Pegs and Bushes*

63. Technic Beam 3M with Four Snaps (48989). I'm not certain just how to describe this, but it has four connector pegs, with round holes on another and a round hole in between the connector pegs. It is very useful for securely locking something with a round hole together.

64. Technic Steering Knuckle Arm 2 × 1 × 3 (33299). This is like a Lever with half a Connector Peg on one side and a cross-hole notch on the other. I believe it is called a Steering Knuckle Arm because it comes in handy for constructions that require steering.

65. Technic Module Bush (32138). This is similar to the 3M Beam with Four Snaps. It has two Connector Pegs on each side, but no 1M space in the middle. You can insert an Axle in the middle via the cross-shaped hole.

66. Technic Plastic Motor Crank/Cross (2853). If you insert a 2M Axle into one side of a 2M Lever, you will essentially have this part. It is often used for motors, but they have other uses as well.

67. Double Bush 3M (87082). This is essentially a Connector Peg 3M in length with a round hole in the middle.

68. Technic Friction Snap with Cross Hole (32054). As I mentioned earlier, some pieces have friction and some do not. I thought that the Friction Snaps had looser pieces, but I don't think they do any more. Perhaps older sets have this, as I seem to have a handful in my own LEGO Technic collection that spin quite freely. Normally, the part that has friction has a different part number, but I could not find any alternative part number for this one.

69. Technic Connector Peg (3673). This piece is designed to snap into a round hole and the other will snap into another hole.

70. Technic 1 1/2 Connecting Bush (32002). This piece is three-fourths the size of a Connector Peg, with a bump half the size on one side. The half-sized bump is good for securing a round hole of a Lever.

71. Technic Connector Peg with Knob (4274). Similar to the 1 1/2 Connecting Bush, it has one side that is a Connector Peg and the other side a knob that is a hollow LEGO stud.

72. Technic Connector Peg with Cross Axle (6562). One side is a Connector Peg, the other side a 1M Axle. This piece can link up a part with a round hole and a part with a cross hole very securely, and still allow for some spinning.

73. Technic Connector Peg 3M (32556). This Connector Peg can hold two 1M pieces on one side, so it can join three Beams together so they can freely spin.

74. Technic Friction Snap with Cross Hole (32054). The Connector Peg that you see here has some friction on it so you can lock two things together securely, and they will not spin too freely.

75. Technic Connector Peg with Friction (2780). Like the other type of Connector Peg, this has some friction going on. I would have to say that this is the part, along with the Bushes, are the parts that I use the most with LEGO Technic creations, as it is the easiest way to link two parts with round holes together.

76. Technic Bush (6590). This piece is about 1M in length, and fits snug on an Axle. It is made to hold an Axle in place and has many other uses.

77. Technic Half Bush (32123). The Half Bush is only 1/2 M in length and has the same function as the Technic Bush.

78. Technic Connector Peg with Friction and Cross Axle (43093). This is the Connector Peg/Cross Axle with Friction.

79. Technic Connector Peg 3M with Friction (6558). This Connector Peg can hold two 1M pieces on one side, so it can join three Beams together so they cannot freely spin.

Let's look at how these parts work with other LEGO Technic parts. I will begin with the Connector Pegs, those with friction and those without.

Technic Connector Pegs in Action

Figure 1-13 shows a 15 Beam with some Connector Pegs and other beams attached. On the left is a Connector Peg with Friction, and one peg is enough to allow the 5M Beam to turn 360 degrees. Since it has some friction, it won't spin like a well-oiled machine, and it has a limited degree of holding its angle. It is good for when you want a part of your project to turn, but not too freely.

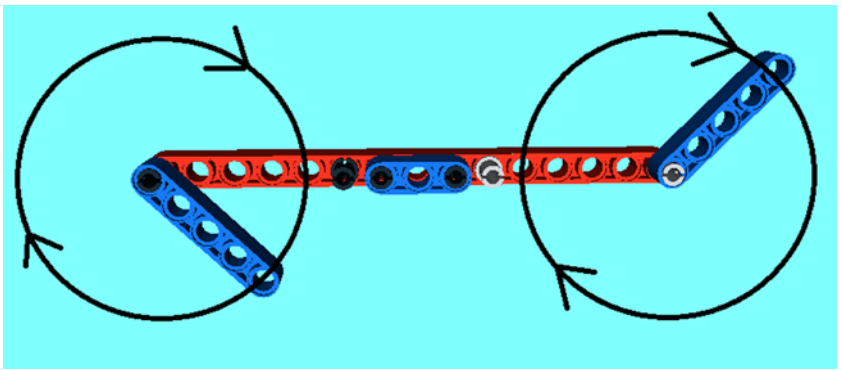

Figure 1-13. *A 15M Beam connected to a 3M Beam and two 5M Beams with two types of Connector Pegs*