CHAPTER 1

Introduction

I have been impressed with the urgency of doing. Knowing is not enough; we must apply. Being willing is not enough; we must do.

—Leonardo da Vinci

This book is on two topics that at first glance may appear rather disconnected: Leonardo da Vinci and LEGO MINDSTORMS NXT. Yet, on reconsideration you might notice that not only do the stupendous mechanical designs of Leonardo have much in common with NXT robots, but so do Leonardo—the inventor and engineer—and modern NXT robot builders.

Leonardo's machines were based on established designs and existing mechanical parts but went beyond the tradition by combining high-technology components of his time with conceptual audacity and brilliant ingenuity, thus creating devices that aroused the admiration of his contemporaries as well as people today. Same goes for NXT robots and their creators—though certainly to a more minor extent. LEGO TECHNIC is a well-known and established way of building LEGO machines, while NXT may be justifiably considered as some kind of high-technology gadget. And already creations of stunning imaginativeness are appearing on the scene, pushing the possibilities of NXT robotics farther and farther beyond the limits.

So what stands more to reason than combining these two topics, thus bridging the centuries and reviving the thoughts of one of the most brilliant minds in mankind's history?

Most likely the majority of people know Leonardo as an artist, as the creator of such renowned works as the *Mona Lisa* or *The Last Supper*. But as you will see in the course of this chapter, his faculties, interests, and achievements were much more widespread.

You will take a look into Leonardo's life, examining five of his most prominent inventions. After that you will endeavor your first tour through the LEGO MINDSTORMS NXT universe.

Always keep in mind, though, that the following ramble can only provide a selection of the capabilities and achievements of this stupendous universal genius.

An Invention-Driven Tour Through the Life of Leonardo da Vinci

No doubt Leonardo di ser Piero da Vinci is one of the most ingenious men of modern history. Justifiably, he's also one of the most well-known: almost 500 years after his death, he hasn't ceased to arouse the imagination and admiration of contemporary people.

Media on Leonardo da Vinci is legion today (for a short selection, refer to the bibliography in Appendix D). To provide even an abstract of the many different aspects of his life, appreciating his capabilities on the areas of anatomy, art, and science, would decidedly be beyond the scope of this book. Instead, I will try to unveil his scientific career by throwing some highlights on a selection of his mechanical designs that may both serve as an illustration of the different fields of technological research he excelled in as well as help you approach his life and his way of thinking.

Renaissance Man

Like no other man, Leonardo personifies the *Renaissance*, a term meaning *rebirth* and denoting a time half a millennium ago when the focus of the Occident's highbrows shifted from metaphysical considerations to matters that from today's view may be considered "physical": interest in the human being itself; the scientific (rather than the philosophical) heritage of the antique; the different phenomena mankind encounters in nature; and the use of mechanical inventions for everyday life challenges. It's not without reason that the artwork that has become *the* symbol for the Renaissance is one of Leonardo's creations: *The Vitruvian Man* (Figure 1-1).

■ **Note** Giorgio Vasari, who wrote the first biography of Leonardo in his "Vite de' più eccelenti architettori, pittori e scultori italiani" ("The lives of the most excellent Italian architects, painters, and sculptors") in the 1550s, said that when famous Florentine artist Andrea del Verrochio saw Leonardo's work on the angel in *The Baptism of Christ*, he was so amazed that he resolved never to touch a brush again.

Even though there are other famous men such as Michelangelo, Albrecht Dürer, or Galilei Galileo who are connected to the Renaissance in the public mind, Leonardo da Vinci most likely represents more than anybody else the synthesis of all-embracing curiosity, open-mindedness, and ingenuity that characterized the Renaissance polymaths—qualities that seem to have become regrettably rare in today's fragmented scientific landscape.

■ **Note** Some other famous Renaissance artists such as Rafael and Michelangelo lived and worked in Rome when Leonardo moved there from Milan in 1513, but it seems Leonardo did not come into contact with them. Maybe he was too consumed with his own works then, as he had resumed his theoretical researches on the laws of optical reflection, in particular in connection with parabolic and concave mirrors. It is a topic he had come in contact with previously during his early apprentice years in Verrochio's workshop, where *concave mirrors*—collecting and amplifying the sun's light—were used for metallurgic purposes. It is said that it is here that Leonardo witnessed the welding of the two hemispheres to the golden ball that is located on top of the Florentine dome today.

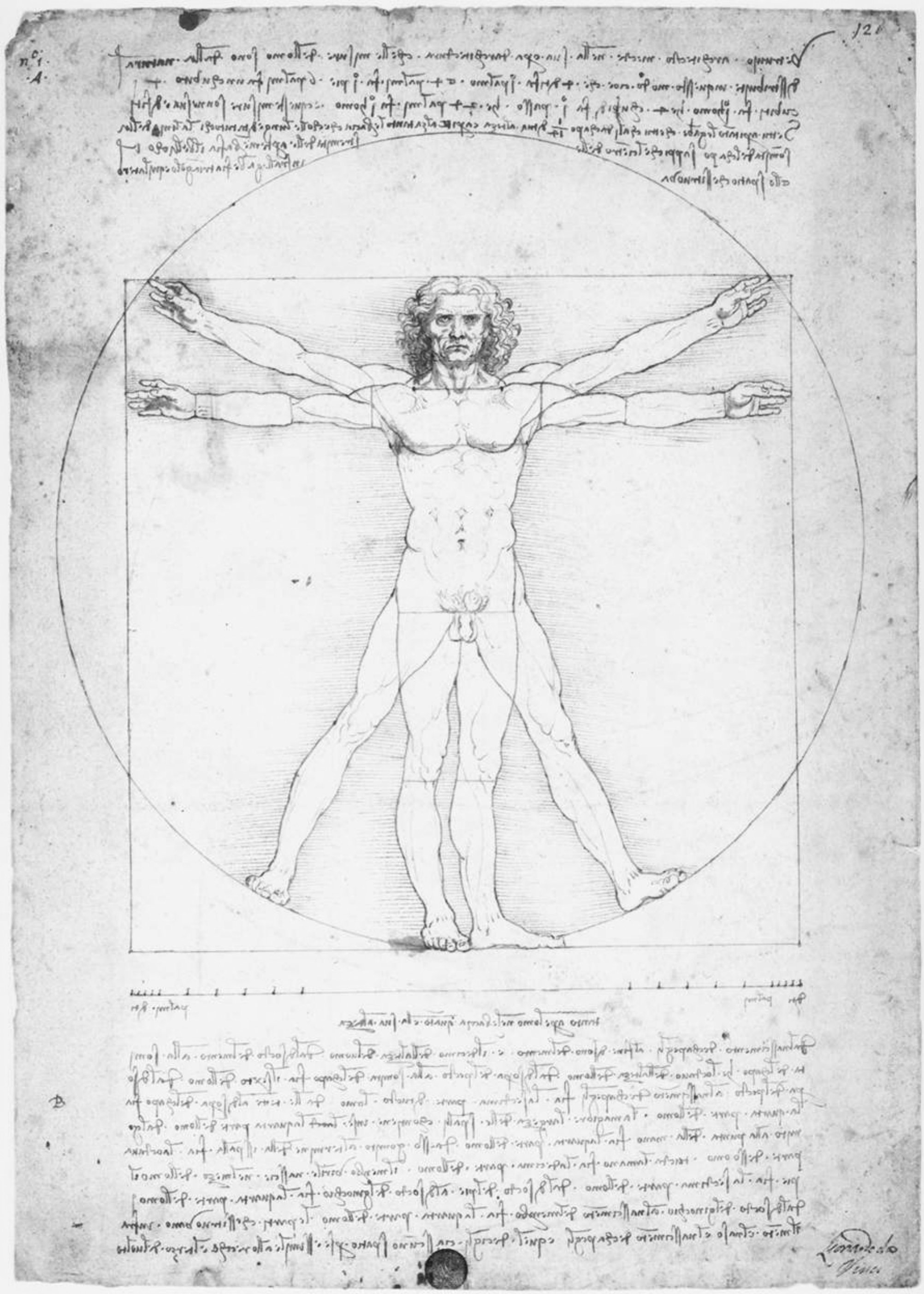


Figure 1-1. *The proportions of the human body in the manner of Vitruvius*

HISTORY OF LEONARDO

Leonardo spent much of his lifetime living in Milan. But he was no born Milanian; his place of birth on April 15, 1452, was Anciano, a small Tuscany village near Vinci, located in the vicinity of Florence.

It is popularly believed that his mother was a peasant woman to whom his father, the wealthy Florentine notary Piero, was not married. Though not uncommon these days, illegitimate children in most cases did not have it easy back then. However, Leonardo was lucky. His father brought him to live with him and his wife at Vinci when he was five years old. In 1460, the family moved to Florence. Here Leonardo most likely received an excellent education. His later claims of being "almost illiterate" may be considered as intentional understatements.

At age 14, he became a *garzone* (studio boy) in the workshop of the famous Florentine sculptor Andrea del Verrochio, a possible indication of the parental diligence toward him. Verrocchio today is most well-known for his impressive equestrian statue of Bartolomeo Colleoni in Venice, but his workshop in Florence processed orders in many different areas: painting, bronze statues, bells, construction machines for the building of the Florentine dome, mechanical theater gadgets, metallurgic works, and armory. It was here where Leonardo started to develop his interest in military devices, though he was nominally employed as a painting apprentice, where he obviously excelled as well.

By 1482 when he left Florence for Milan, Leonardo was an independent master. In 1498, the French conquered the Duchy of Milan, driving the Sforzas out of power. Leonardo stayed there for one more year and left in 1499. It has been said that the reason for this decision was because the French archers used his life-size clay model of his planned *Gran Cavallo* horse statue for target practice. As a matter of fact, it was not the first time his artistic plans had been impacted by the war; in 1495, 70 tons of bronze that had been set aside for the *Gran Cavallo* was instead cast into weapons for the duke during a previous French assault.

After Leonardo returned to Milan in 1508, he was again driven away when in 1513 Swiss mercenaries hired by the city's patricians drove out the French. Leonardo moved to Rome where Giovanni di Medici, the son of the former Florentine sovereign Lorenzo (Lorenzo eventually became the infamous Pope Leo X), instructed his brother Guiliano to gain valuable acreage by draining the Paludi Pontine (Pontinian swamps) south of the Eternal City. Guiliano was happy to engage Leonardo for this sophisticated project.

Leonardo obviously had deeply impressed his French employers during his second stay in Milan. In 1517, the French King Francois I (nicknamed "le Roi-Chevalier," the Knight King) invited him to France to work as his first royal engineer. Leonardo moved into the manor house Clos Lucé, also called "Cloux," which was located next to the king's residence at the royal Chateau Amboise and which is a museum today open to the public. The king was a genuine admirer of his new first engineer ("No man had ever lived who had learned as much about sculpture, painting, and architecture, but still more that he was a very great philosopher," as he said), and eventually the two men became friends, though very unequal in age (Francois was 42 years younger).

Francois granted Leonardo and his assistants generous pensions that enabled Leonardo to concentrate on his theoretical studies about flying in his last two years of life. Now and then he performed some jobs also for the court that aroused stunned admiration—hydraulic systems for fountains, for instance, or, on the occasion of a visit of Florentine merchantmen, a mechanical lion (the symbol of Florence) that automatically opened its breast to spread lilies (the symbol of the French crown) on the delighted audience.

Leonardo died May 2, 1519, in the arms of King Francois. His remains were later moved to the chapel of Saint Hubert inside the castle; however, there is no longer any trace of them today, as many tombs were destroyed during the 16th century Wars of Religion.

Five Designs

This section explains the five designs you will build in this book:

- The armored car
- The catapult

- The revolving bridge
- The aerial screw
- The flying machine

The Armored Car

The armored car is one of Leonardo's most well-known designs. As with all of his inventions, it came to us by drawings produced by Leonardo himself, an exceptionally gifted draftsman. The armored car resembles the concept of the military tank invented at the beginning of the 20th century (Figure 1-2).

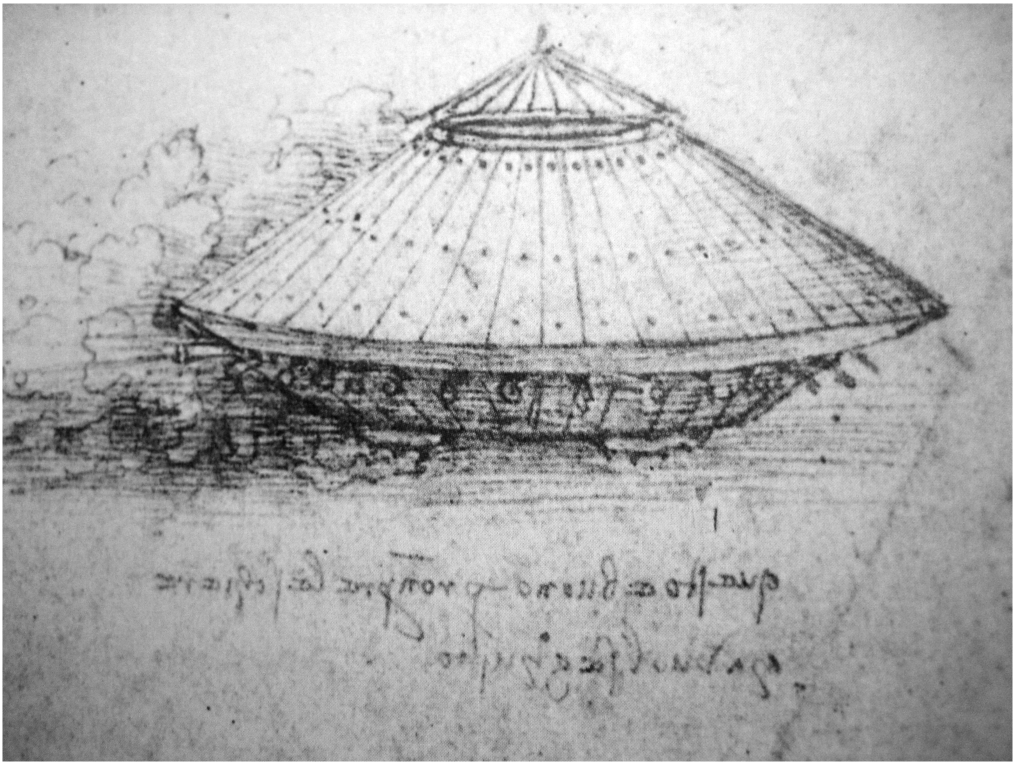


Figure 1-2. *The armored car*

Leonardo apparently drew this sketch between 1482 and 1485 when he was living in Milan for the first time. The drawing of the armored car may have been attached to a letter that Leonardo wrote or had had written (in the times of no word-processing software it was common to have important documents written by a paid expert) to the Duke of Milan, Ludovico Sforza, nicknamed "Il Moro," as an application of employment. Appendix B contains a translation of the complete text of this letter of application. Though we do not know the reception it got, machines of war were undoubtedly of major interest to a North-Italian sovereign in the politically unstable last decades of the 15th century. In the case of Ludovico that interest decidedly was a valid one, as the French drove the Sforzas out of Milan only some years later.

We may wonder about Leonardo's dealings in military aspects and may even find it reprehensible, but we must not forget that at this time, war was not considered unethical but rather was looked at as some kind of art—at least by those who did not directly suffer from it. Furthermore, it squared with the interest of the Renaissance engineers in technical methods, as machines of war were among the most complex classical devices. And last but not least, the rulers were willing to spend incredible sums for military technique—not unlike today—but even more interesting to engineers, potentates were the most important employers of their profession in times when unemployment insurance did not exist.

The Catapult

Leonardo's work on the catapult is another example of his interest in military devices. In contrast to the scientists in the medieval times, he did not confine himself to just copying the classical knowledge but used it as a base for enhancements and amendments, true to Newton's famous citation "If I have seen further it is by standing on ye shoulders of Giants" 200 hundred years later. Such is the case with the catapult; Leonardo invented a new spring mechanism that could generate higher energy for throwing projectiles farther (Figure 1-3).

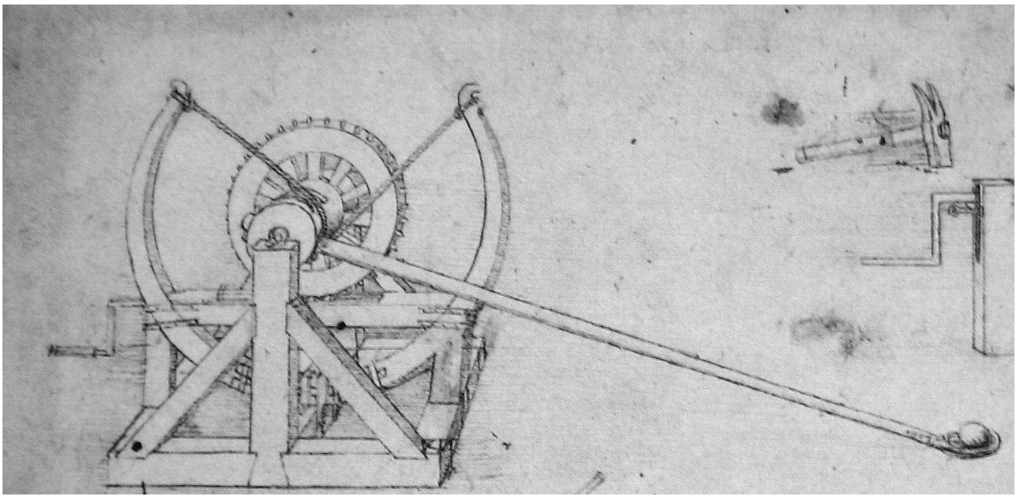


Figure 1-3. *The catapult*

Though fire weapons had already been established by the end of the 15th century and had found their way onto the European battlefields, they still suffered from a lot of "teething troubles." Hence, the well-proven concept of catapults was widely used, particularly at sieges where their multiple advantages—ease of use, high firing rate, high range, and the ability to launch a wide variety of different projectiles—provided a gain against cannons when using artillery against fortresses.

Leonardo made many designs for different types of catapults during his life, many of them during his early Florentine years. The one in question appears to have been produced during the first years of his work for Ludovico Sforza in Milan. It may have also been attached to the letter of application with the armored car.

We do not know how many of his military designs during his time in Milan made it into real deployment. Technical difficulties, impracticalities, and the fact that Leonardo was not employed by the duke as a military engineer but as the director of parades and festivities, might imply that many of his plans never left the theoretical stage. It's also possible the duke was not able to recognize the significance of Leonardo's designs and may have preferred other more practical and traditional competitors for the job. After all, Leonardo's position enabled him to run his own workshop alongside some apprentices. This gave him the opportunity to continue his studies without too many financial worries. During this time period, six major paintings, including *The Last Supper*, and a flood of technical drawings were created.

The manuscript for the catapult is part of Leonardo's Codex Atlanticus, which is preserved in the Biblioteca Ambrosiana in Milan. Many of Leonardo's drawings are collected in *codices*, collections of loose papers compiled by different collectors over the centuries. In most cases they are arranged not according to their original chronological order but, as was the custom in earlier periods, by a topical or even aesthetical scheme.

■**Note** These codices are today distributed over the museums of the world. For example, the Codex Leicester, a folio of scientific observations and illustrations on natural phenomena such as water, light, and gravity, was acquired by Microsoft's founder Bill Gates in 1994 and is put on public display once a year in a different city around the world. In 2007, it will be exhibited from June to August in the Chester Beatty Library in Dublin, Ireland.

The Revolving Bridge

The revolving bridge is contained in another manuscript that came to us with the Codex Atlanticus. It's an example of another area of Leonardo's interest: *hydrodynamics*, the science of the flow of water (Figure 1-4).

Leonardo dealt with studies on this topic during almost all of his scientific life. He believed water and air are similar substances and thus follow similar laws of flow. This was a surprisingly modern approach and was of particular interest to him in regard to his research on human flying, which you will read about in a later section.

Fortunately for him (and for the world), this interest squared perfectly with a practical need of his time: water was one of the major sources of energy then. The north Italian plain was plastered with water mills in these times. Furthermore, the rare roads were in bad shape and were more like paths than anything else. Hence, rivers and the sea were of utmost importance for transportation of goods and people.

As a consequence, cities such as Florence and Milan, with no direct access to the sea, were keen to spend a great deal of financial and material resources on making use of the rivers and any evolving engineering disciplines.

In Florence, young Leonardo was engaged in a canal project to make the Arno river navigable from Florence to the Mediterranean Sea. He was the first to propose this enhancement, according to Giorgio Vasari, the writer of Leonardo's first biography. In Milan, Leonardo made further contact with hydraulic engineering, learning a lot about it from Milan's impressive set of the so-called *navagli*, a network of inner-city canals. These experiences proved helpful when Leonardo turned his attention toward another water-related topic of even more military importance than today: bridges.

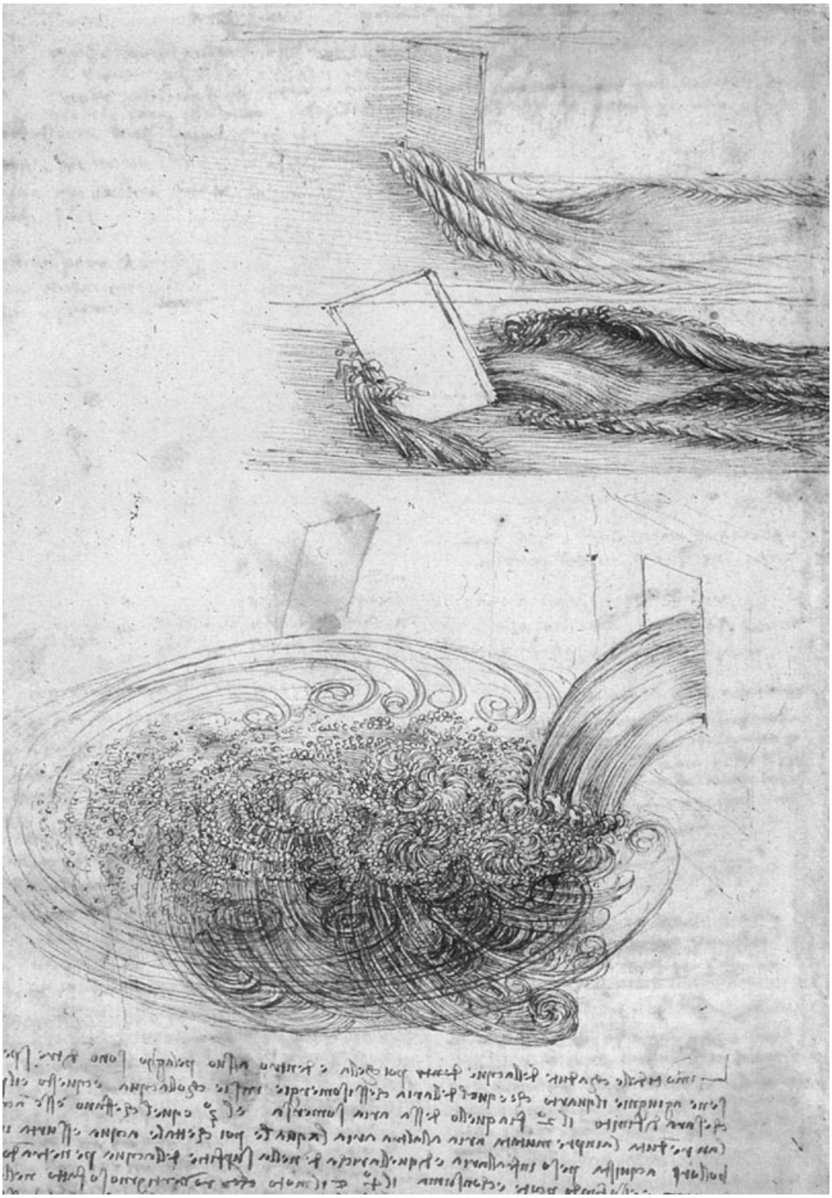


Figure 1-4. *Hydrodynamic study*

As cross points between streets and rivers, the two thoroughfares of transportation, bridges were of paramount relevance in military strategies. Bridges formed bottlenecks that could detain enemy troops. But this advantage could also be turned into a disadvantage if the enemy got a hold of the structure. Toward the end of his first decade in Milan, Leonardo developed a simple but effective concept to cope with this hazard: the revolving bridge. In his design, the bridge can be rotated around one of its end pylons (Figure 1-5). This way it could be moved away from the bank the enemy troops were approaching from, depriving them of the possibility to cross the river.

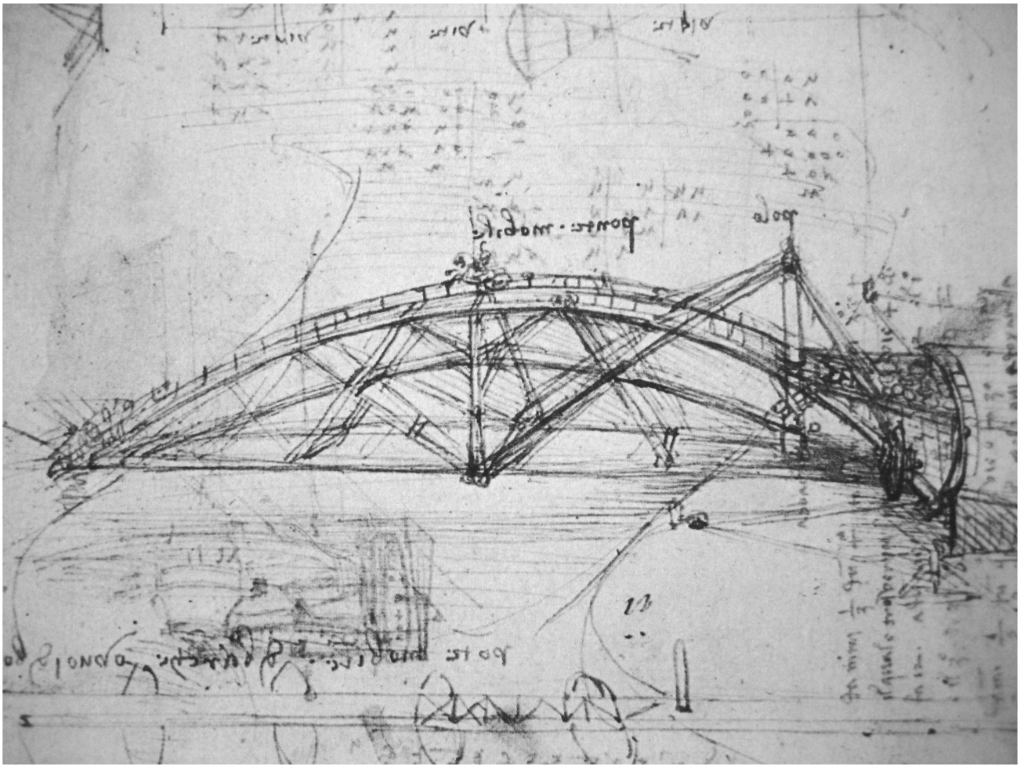


Figure 1-5. *The revolving bridge*

It is not known, though, if this bridge was ever been built somewhere around Milan.

When Leonardo left the city in 1499, he took his hydraulic knowledge with him and after three years of travel where he worked in different northern Italian cities, he found a cordial reception by the rulers of a city that was (and is) connected to water like none other: Venice.

As the Ottoman Empire had conquered Constantinople only five years before and was aggressively breaking into Venice's eastern borders, the Serenissima was in desperate need for skilled military engineers who had hydraulic knowledge also. As a result, in 1502, Leonardo joined the service of Cesare Borgio, who ruled the city as the doge. For the next two years, Leonardo planned and monitored the building of a defensive system on rivers, and even escorted the doge to a campaign in the Romagna. As an interesting side note, Leonardo did not appear to have many moral qualms about also working for the "other side"—an attitude he seemed to share with military suppliers of today.

Note Also in 1502, Leonardo planned a 720-foot bridge as part of an engineering project for Sultan Bajazet II. This bridge would be made completely from wood and was to span the Golden Horn, an inlet at the mouth of the Bosporus. Though it was never built in his time, in 2001 a Norwegian group reproduced it near the capital of Oslo, almost precisely 500 years after his first drawing (Figure 1-6).

Figure 1-6. *The Norwegian version of Leonardo's bridge project on the Golden Horn*

Leonardo decided to leave the Venetian service after two years and return to Florence. He changed his employer but not his profession. The Florentine Republic engaged him both as a military advisor as well as a hydraulic engineer. Again, both occupations were not completely separate, as one of his first projects was the intended diversion of the Arno River near Florence's old enemy, the city of Pisa, in order to disconnect it from its water supply. Other projects also dealt with the Arno, but were of a more civil nature, such as the plan to extend the navigability of the river and reinforce the embankment near Florence to prevent floods. For that, Leonardo developed some of his largest machines, huge structures intended for use in canal building. It was also in these Florentine years between 1504 and 1508 when Leonardo painted the *Mona Lisa*.

The Aerial Screw and the Flying Machine

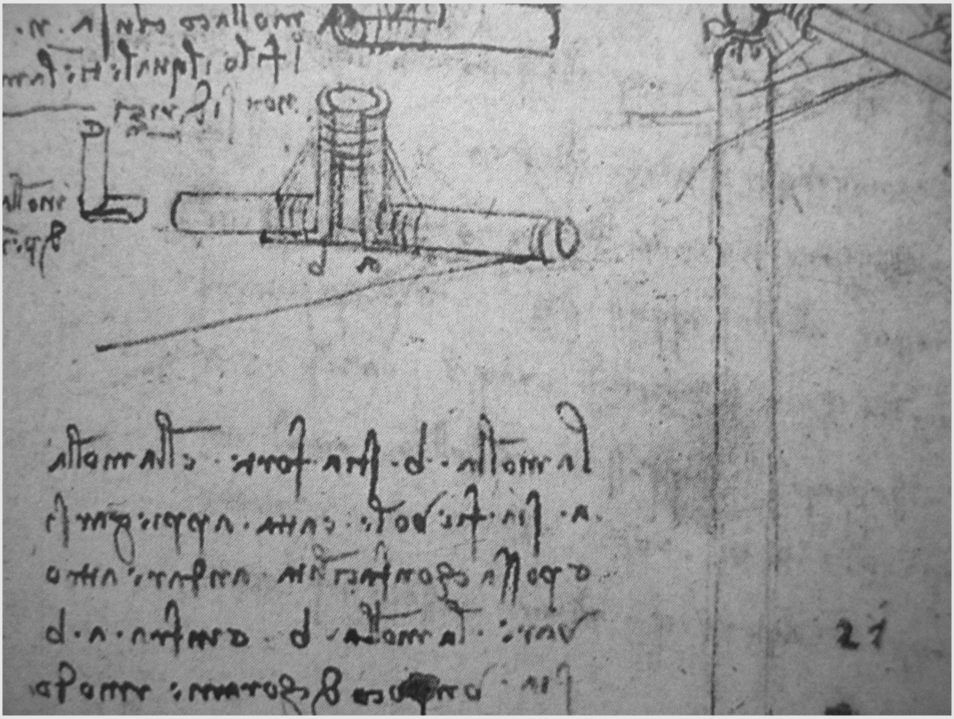
The beginning of the 16th century saw the maturing of Leonardo in an area in which he never presented any of his designs to a paying customer. No doubt this was due to their highly advanced and principally theoretical nature, for the matter in question was no less than the ability of human beings to fly.

OBSCURE MANUSCRIPTS

In spite of their advanced nature (or due to it), Leonardo's mechanical achievements did not contribute to the development of science and technology and did not influence technological progress in the early phase of modern history. His drawings were either obscure to his contemporaries and their offspring or totally unknown and remained so for 300 years. But in the 19th century, engineers were able to appreciate Leonardo's grasp of the mechanical.

More than 5,000 pages of his manuscripts are still available today. Apart from some superficial mentions of Leonardo and his works in some almanacs in the 16th century, these drawings are the only sources of his scientific research that have survived as far as we know.

Leonardo did not publish or otherwise distribute the contents of his notebooks. He did not wish for anybody to see or use his manuscripts. Apart from some drawings he produced for presentation to potential clients, his notes were intended for internal use, as some sort of mind maps. He even took up the habit of laying down the (often just fragmentary) textual explanations next to the actual drawings in mirror writing. In other words, he wrote from right to left so the finished text was the mirror image of normal writing, as shown in the illustration; he did so presumably in order to prevent possible business rivals from stealing his ideas.



Furthermore, Leonardo was left-handed, which would have made writing from left to right pretty cumbersome for him. Writing feathers were shaped to be used by "ordinary" right-handed people then. This left-handedness, though, has helped to distinguish manuscripts written by him from similar ones from this period of time.

Due to the worksheet nature of his manuscripts, many of them were reengineered and extended in the course of Leonardo's life, sometimes even with nontechnical content. This is what made his manuscripts obscure and ambiguous to external readers. In modern times, people are apt to attach concepts of today's world to them. For example, some people inaccurately think he invented the helicopter when he drew the aerial screw. We have to be very careful with such misinterpretations, though there are instances where Leonardo's ideas appear to anticipate modern inventions indeed.

Leonardo was fascinated by flight all of his life and had become convinced that a human being could fly by his own muscle power, an idea he was deeply committed to and didn't give up until his death: ".... you will see the human being with big wings created by him, who will lean against the resistance of air, vanquishing it, being able to outplay and to rise above it," he wrote in 1486. In his opinion, the principal issue was to develop enough energy for the lifting mechanism. That belonged to a class of problems that could be solved by engineering: amplifying the power generated by a human's body by mechanical means. Navigability once the person was in the air was apparently not in the focus of his efforts, as there are not any noteworthy steering contraptions found in any of his according designs.

As previously mentioned, Leonardo considered air a substance that is a lightweight relative of water and thus would follow similar mechanical laws. This general idea led him in 1485 to the design of an *aerial screw*, a device that should "screw" itself into the air like a screw into water (Figure 1-7).

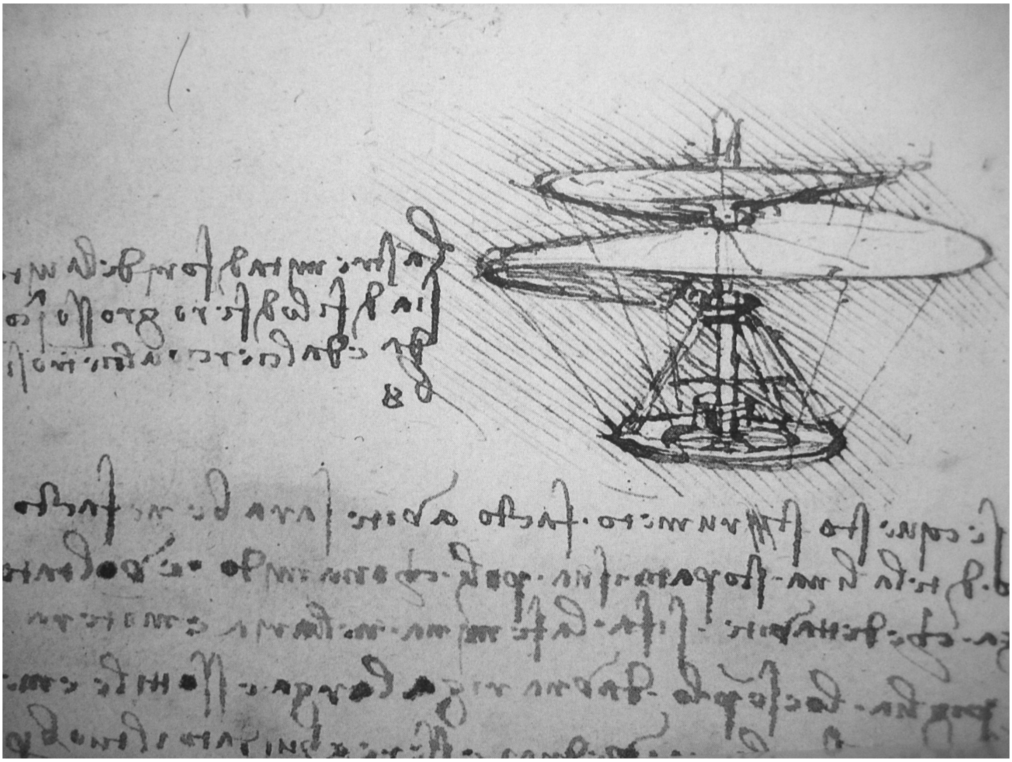


Figure 1-7. *The aerial screw*

In his opinion, the only major problem to solve was the generation of a revolution speed fast enough to make the whole device leave the ground. Obviously, the concept of lift and different levels of pressure on parts moving through the air was unknown to Leonardo, disqualifying the aerial screw as a helicopter; the aerial screw follows a completely different approach.

Leonardo developed many of his ideas for flying contraptions from his anatomical studies. In his opinion, the basic mechanical setup of all living creatures was similar. Hence, these capabilities were not out of the question (e.g., he intensely studied flying fish), in particular when appropriately supported by mechanical means.

Hence his approach toward flying was two-fold. On one hand, he followed the path of creating machines that should amplify man's power as far as possible. One or more pilots were meant to stand upright, sometimes even being required to move their heads and legs in addition to their arms to achieve maximum exploit of the body's muscles. On the other hand, he tried to mimic the mode of operation of birds, insects, and other flying animals, as in the case of his famous design of the flying machine (Figure 1-8).

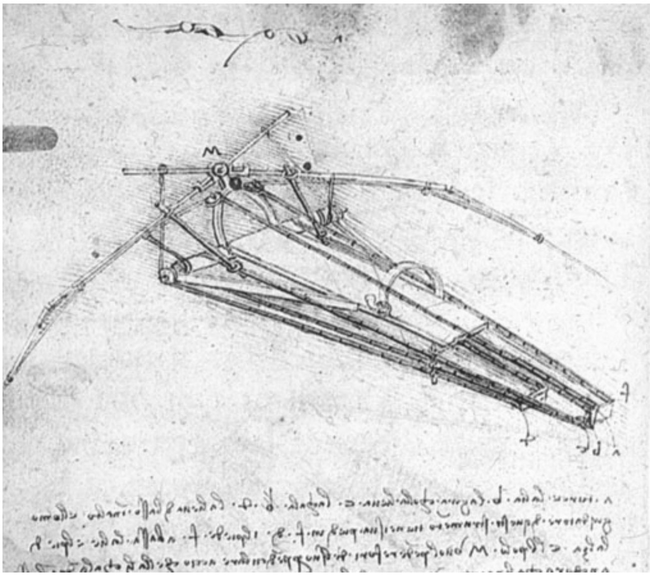
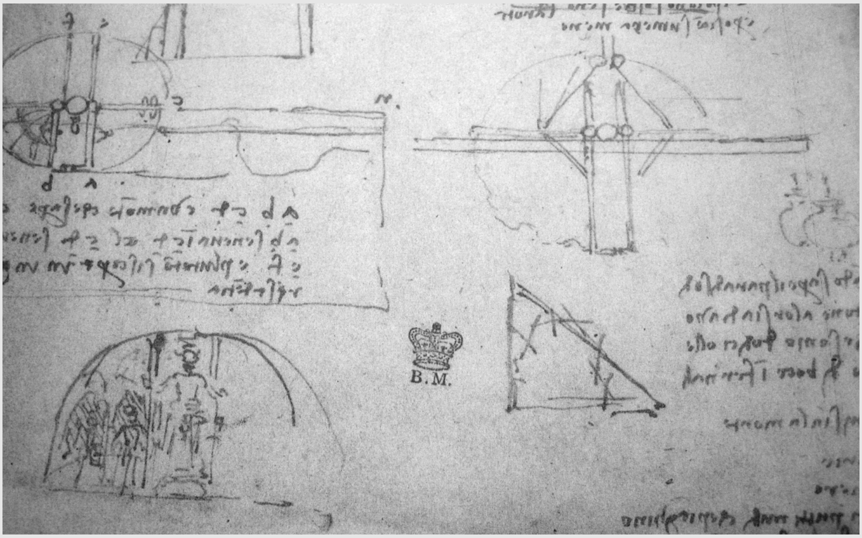


Figure 1-8. *The flying machine*

It was in the first decade of the 16th century that Leonardo wrote a treatise on the flight of birds. Though he tinkered with small models of many of his designs for empirical studies, there is no evidence that any of his flying machines—including the aerial screw and the flying machine—had ever been actually built during his lifetime. However, in our time some of them have been built and tested. His plan for a parachute has been certified to work by a skydiver who used it to jump out of a balloon 9,000 feet above the ground.

LEONARDO'S THEATER STAGE SET FOR ORPHEUS

Leonardo designed an ingenious theater stage set for the popular myth of Orpheus, shown in the following figure. It comprised two hemispheres that could be modeled and painted according to artistic need. They could be opened, closed, and rotated. Hence, with a dramatic theatrical effect, the underworld scene could be brought to the spectators' view by a circular and opening movement, with Pluto emerging on a platform from below accompanied by devils and furies.



It might seem surprising for an engineer to be involved in the theater. However, when considering that Leonardo held the position of director of parades and festivities during his first years in Milan, and that the fine arts and mechanical gadgets played an important part in the Renaissance, Leonardo's activities in that area do not appear that far-fetched. As a matter of fact, it was his capability as a musician that gave the impact for his initial visit to Milan in 1481. Having built a silver lyre in the shape of a horse's head, he presented it to Duke Lorenzo di Medici (nicknamed "Il Magnifico"), the ruler of Florence. The duke, who was given more to diplomacy and good relations with his neighbor cities than to war, considered the beautiful lyre an ideal gift of peace for the authorities of Milan. The duke felt that young Leonardo, who could not only play the lyre very well, but was considered by his contemporaries to be exceptionally talented, handsome, and charming, was ideally suited for the diplomatic mission of delivering the lyre to Ludovico Sforza. Leonardo not only delivered the splendid lyre to Ludovico but also played it in a musician's competition and, according to his biographer Vasari, "played the (horse-shaped) lyre better than any other musicians at Ludovico's court."

Leonardo designed a lot of machines intended for use in performances and already had acquired some reputation as a stage engineer during his first sojourn in Milan. For the Milanese paradise feast he created a set of revolving hemispheres populated with actors impersonating the planets.

Yet, it likely was primarily not that part of his curriculum that induced the new rulers of Milan, the French, to offer him a position as *peintre et ingenieur ordinaire.* As a means of strengthening their position, the French were in need of skilled military engineers, and Leonardo still had an according reputation in the city. Eventually, in 1508, he accepted the offer and moved to Milan again. Here he not only turned to designing and building fortresses but again became concerned with hydraulic projects, this time with sluices, for a possible connection between Milan and Lake Como in the Alps. It was also during these years that he created the theater stage set for Orpheus.

■ **Note** In Vasari's biography of Leonardo, he said "[T]he greatest of all Andrea's pupils was Leonardo da Vinci, in whom, besides a beauty of person never sufficiently admired and a wonderful grace in all his actions, there was such a power of intellect that whatever he turned his mind to he made himself master of with ease." Because there is no known portrait of Leonardo in his youth, the only hint of how the great man may have looked is in two supposed self-portraits in his later years. One of these is shown in Figure 1-9.

Figure 1-9. *Supposed self-portrait of Leonardo*

The LEGO MINDSTORMS NXT

Now that you are acquainted with Leonardo and his life, let's take a look at the other topic this book deals with: LEGO MINDSTORMS NXT. In this section you will become familiar with the components that make up the new NXT, bridging Leonardo's world and applying this knowledge to his mechanical designs and reviving them with modern means.

In 1998, LEGO released the first generation of its MINDSTORMS line, the RCX: kits consisting of electric motors, sensors, LEGO bricks, and LEGO TECHNIC pieces grouped around a central controlling unit. Along with a bunch of extension kits, it developed into the most successful product in the company's history. Eight years later its successor, the LEGO MINDSTORMS NXT, finally saw the light of day, first in the United States in August 2006, and two months later in Europe.

The NXT ships in two versions:

- The retail version with 577 parts.
- The education base set with only 431 parts, but with a rechargeable battery and charger. It lacks the retail version's programming software, which is sold separately under different licenses for schools.

Hardware

Let's take a look at the hardware components of the NXT. There are four main categories:

- The central controlling unit: the NXT Brick
- Output devices: motors
- Input devices: sensors
- Means of communication: Bluetooth

The NXT Brick

The central component of the NXT is the programmable controller, also known as The Intelligent Brick (Figure 1-10). It's the NXT's brain, featuring a 32-bit ARM7 microcontroller with 256K flash and 64K RAM memory—running at 48MHz—and a second 8-bit AVR microcontroller with 4K flash and 512B RAM memory, running at 4MHz.

The four input ports are used for connecting the sensors, while the three output ports are for attaching the motors (Figure 1-11). The connections are digital, hence it is possible to extend the amount of available sensor and motor ports by adapters.

Figure 1-10. *The NXT Brick*

As shown in Figure 1-11, the connections are made using cables that resemble telephone cables, though the end connectors are mirrored, allegedly to prevent children from connecting their NXT to the telephone box. One of the input ports is IEC 61158 Type 4/EN 50 170–compliant, meant to be used for future high-speed expansions.

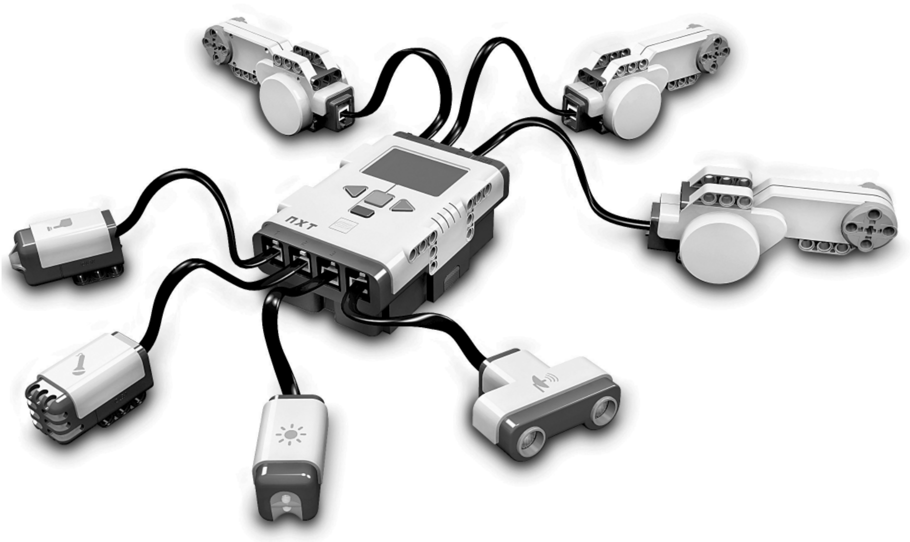


Figure 1-11. *The NXT Brick with motors and sensors attached*

The connection to the PC can be established over a USB cable attached to a USB 2.0 port next to the output ports or over the Brick's Bluetooth connectivity, which is also a means for communication with other Bluetooth-enabled devices such as PDAs or mobile phones.

On top of the Brick, there is a 100 × 64 pixel LCD display and four buttons that control the Brick's operating system: orange for on/off; dark gray for clear/back; and two light-gray buttons for navigating the menus displayed on the LCD.

A built-in speaker provides 8kHz sound quality over a sound channel with 8-bit resolution and a 2kHz–16kHz sample rate.

The Brick is powered by six AA batteries that do not come with the retail kit, or a rechargeable battery pack that comes with the education base set.

Oh, and if you always wanted to know how the Brick looks inside, see Figure 1-12.

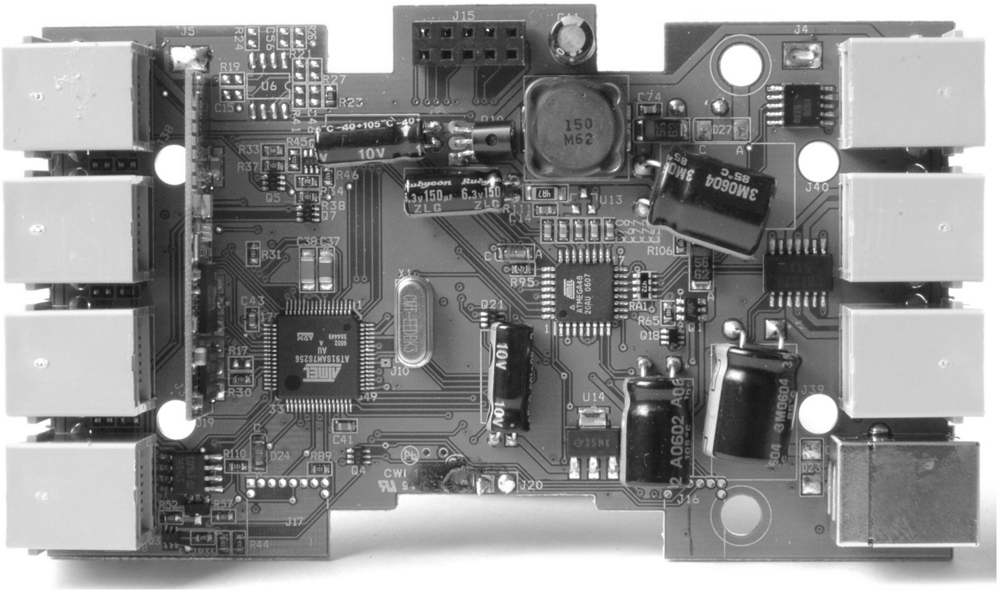


Figure 1-12. *The Brick's inner life (Image courtesy of Jürgen Stuber)*

■ **Caution** Don't try opening the Brick at home!

Motors

The NXT kit comes with three motors (Figure 1-13).

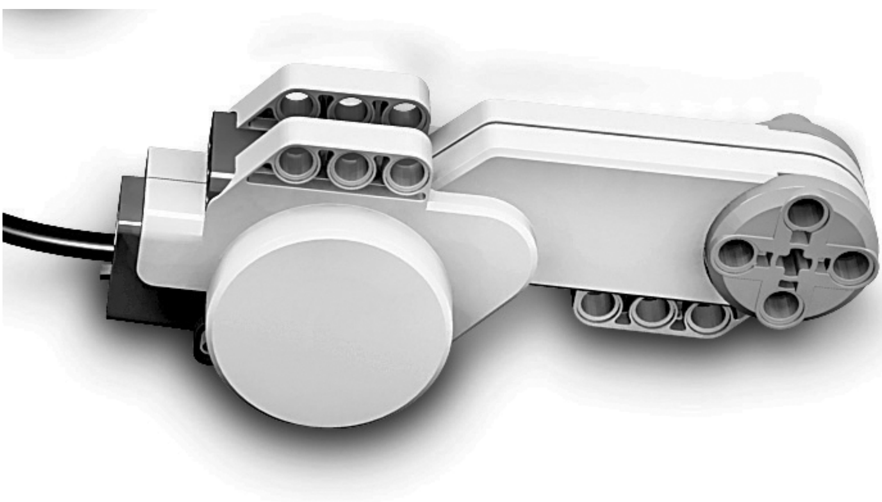


Figure 1-13. *A NXT motor*

You will notice that they appear rather large and bulky compared to the RCX motors. This is due to the high inner gearing that makes the motors much more powerful and reliable than the RCX's motors (Figure 1-14). But as a result, NXT robots are much larger than RCX ones.

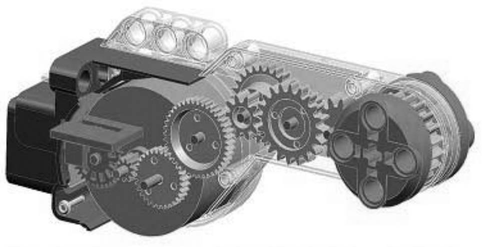


Figure 1-14. *Inner gearing of the NXT motor (Image courtesy of LEGO Education)*

NXT motors are *servos*. That means that their internal position and state can be controlled from an external unit—in this case the NXT Brick. This is done using the in-built rotation sensor, enabling the Brick to control the motor very accurately. It can be rotated precisely up to 1 degree or run at a particular speed. Furthermore, two motors can be easily synchronized, which allows for precise straight driving. Anyone who has built a mobile RCX robot will quickly remember the problems these robots have staying on a straight course.

Since the controlling Brick can track changes of a motor's state, a motor can also be used as a "wired remote control."

Sensors

Sensors allow the NXT robot to get insight about and respond to the outer world. To this end, the NXT kit comes with four types of sensors; the kit contains one of each. There are additional sensors available, created and sold by third-party vendors.

Touch Sensors

The touch sensor is like a bumper; it enables the robot to detect press-and-release events. This kind of sensor can be used to detect very near obstacles. Figure 1-15 shows a touch sensor.

Figure 1-15. *The touch sensor*

Light Sensors

The light sensor is a rudimentary device that lets the robot "see" in a very limited sense. Measuring the amount of light that reaches the sensor's inlet, it allows for distinction between bright and dark, similar to an amoeba. Figure 1-16 shows a light sensor.

Figure 1-16. *The light sensor*

Though there's no built-in color detection, areas of different colors will give rise to different numerical values of reflected light. After all, these are not absolute but relative values, depending for instance on ambient light. This makes color detection with the light sensor pretty unreliable and context-dependent. The light sensor also has a small lamp to emit a red light, which is useful for illumination of dark environments and for amplification of reflected light.

Sound Sensors

The sound sensor is the robot's "ear." It can detect sounds in two different modes. First, it uses a mode called *adjusted decibels (dbA)* that mimics the way the human ear actually measures ambient sound. This means that the sensitivity of the sensor is adapted to the sensitivity of the human ear, ignoring very low or very high frequencies. The other mode, called *standard decibel (db)*, is simpler and plainly registers the whole frequency bandwidth equally.

Figure 1-17 shows a sound sensor.

Figure 1-17. *The sound sensor*

The sound sensor will deliver its results as percentages of its maximum volume of 90 decibels (which is equal to the noise of a lawn mower). For instance, values up to 5% reflect silence, 5–10% reflects distant talking, and 10–30% reflects nearby talking or low music.

It stands to reason that this kind of measurement does not allow for very precise control of the robot by sound. In particular, it's not meant to be used for voice recognition or the like.

Ultrasonic Sensors

The ultrasonic sensor is a type of sensor that is new to the MINDSTORMS world and has not been available with the RCX. Its eyelike shape might be considered to be like the robot's eyes, indeed enabling it to have a look at what's around it. Figure 1-18 shows an ultrasonic sensor.

Figure 1-18. *The ultrasonic sensor*

The sensor works in the way bats or submarines detect objects, with sonic signals of high frequency that are reflected by an object and received by the sensor again. The sensor is able to compute the distance to the object by measuring the running time of a single signal. Hence, the sensor can be used to attain two kinds of information—whether an object reflects signals at all, and if so, how far away it is. Depending on its mounting on the robot and the kind of object it detects, the LEGO ultrasonic sensor's detection range is up to 100 inches.

The ultrasonic sensor mainly serves as a means for touch-free object detection. Its great advantage to the touch sensor is that no physical contact with the object is required. This makes it possible to avoid objects much earlier. Yet, there's a drawback to this also. The sensor can't be used in an area where another ultrasonic sensor is actually at work. The sensor's signals will be interlaced with the signals of the other. Furthermore, since the signals are not labeled as its own, it will not be able to distinguish the reflection of its signals from the emission of the other sensor. Moreover, surfaces that swallow up or disperse signals, such as soft, round, or very jagged ones, are hard to detect and apt to be missed.

Bluetooth

Bluetooth is an industrial specification for wireless personal area networks and provides a way to connect and exchange information between different kinds of devices, such as PDAs, mobile phones, computers, cameras, and so on, via a globally unlicensed short-range radio frequency. Figure 1-19 shows a Bluetooth adapter.

Figure 1-19. *A Bluetooth adapter*

In addition to the USB cable discussed in the earlier section on the NXT Brick, the NXT allows for wireless communication also by providing Bluetooth Class 2 connectivity. Thus, an NXT Brick can talk to and receive messages from other Bluetooth-enabled devices such as a computer, a mobile phone, or other NXT Bricks up to the distance of approximately 10 meters.

The Bluetooth connectivity is established using the LEGO MINDSTORMS NXT Software (Figure 1-20).

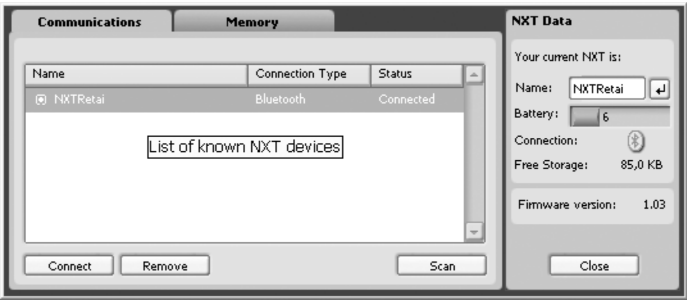


Figure 1-20. *LEGO MINDSTORMS NXT Software utility for the NXT Bluetooth connectivity*

In particular, this connectivity can be used to upload or download programs or other software artifacts from or to the Brick or to remotely control the robot.

The Brick can be connected to up to three other devices at a time. However, it can only communicate with one at a time.

The NXT device can be made invisible to other devices. The Bluetooth connectivity can even be switched off completely, mainly to save battery power.

It should be noted that NXT supports only particular Bluetooth stacks, for instance the Bluetooth software included in Microsoft Windows XP Service Pack 2 and WIDCOMM Bluetooth Software for Windows version 1.4.2.10 SPS or newer. A complete list can be found on the official LEGO MINDSTORMS NXT web site at `http://mindstorms.lego.com/`.

Software

Like any programmable device, the NXT requires a good deal of software. Without it the Brick and its attached hardware components would simply be a collection of plastic and metal lying motionless on your table.

To bring a NXT robot to life, you need some things that pretty much all computerized gadgets depend on:

- Operating system: the firmware
- Data store: the NXT file system
- Administrative tools: the Try Me feature and the programming software

Firmware

The NXT Brick brings along its own *firmware* (a piece of software that is embedded into hardware), which can be thought of as the operating system of the NXT. Since it is stored in the flash memory, it will not be erased if you switch off the NXT or remove the batteries.

The firmware comes with the kit and has to be downloaded from the PC to the NXT at least once. However, you may erase it or reload it as often as you wish (well, almost—there's a limit of around 70,000 times after which the involved hardware components won't work reliably any more), for instance, when there are updated versions of the firmware available. New versions of the firmware are released frequently; the official version at the time of the writing of this book was 1.05.

You can even replace it with other kinds of appropriate firmware that may offer better performance, particular features, or support for a special programming language. An example of the latter is RobotC, a language for the NXT that runs on its own separate firmware. This firmware has to be downloaded to the NXT before you can use the language.

You will have a look at RobotC in the following chapter.

In summer 2006, LEGO released a software developer's kit (SDK) that included documentation for interfacing with the MINDSTORMS NXT driver on the PC or Mac as well as documentation for the executable file format on the NXT and how the firmware's Virtual Machine (VM) executes these files. Moreover, the company published the firmware itself as open source in December 2006.

NXT File System

The NXT's flash memory also contains a file system named Table of Contents (TOC). It is used to store persistent artifacts such as programs and data files and allows for a maximum number of 63 items. You can inspect the file system by using a utility of the LEGO MINDSTORMS NXT Software (see Figure 1-21). Note the different types of files on the Brick, as displayed on the left panel.

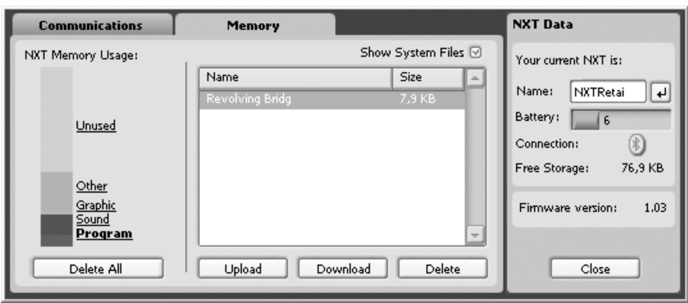


Figure 1-21. *LEGO MINDSTORMS NXT Software utility for inspecting the NXT file system*

Try Me

The NXT comes with a built-in program that provides a graphical menu on its display. Here you can do several administration tasks such as switching the Bluetooth connectivity on or off, connecting to other devices, starting or stopping programs, or getting information on the state of your Brick.

One of the most helpful features is the Try Me function. Using it, you can test all the sensors and motors attached without having to write a program for it. For instance, you can attach one or two motors to the output ports and run them in a given sequence, or test the reaction of an ultrasonic sensor.

Programming Software

The NXT kit also provides its official programming environment, the LEGO MINDSTORMS NXT Software. We already have encountered it in the hardware section and will have a look at in Chapter 2.

The NXT Community

When LEGO at the end of 2005 announced the NXT, a community for it was instantly created on the World Wide Web. The Internet appears to be the perfect platform for NXT aficionados. This community is still growing, with new blogs, private NXT-related sites, and new videos every week.

This section takes a short look at some of the most prominent and popular parts of the community.

The MINDSTORMS Developer's Program

At the end of 2005, the LEGO Group's robotics team announced a program called MINDSTORMS Developer Program (MDP). An exclusive group of 100 people was provided with beta versions of LEGO MINDSTORMS NXT kits to test them and help guide the product development process for NXT. Another more limited handful of LEGO aficionados (called "MUPpets" based on the name of the project: MINDSTORMS USERS Program) were included in the actual product development. There was no application process, and the existence of this group was not made public.

During the winter of 2005/2006, more than 96,000 robotics enthusiasts from 79 countries between the ages of 18 and 75 applied online for the MDP. In February 2006, the 100 lucky ones (including this book's author) were chosen and given access to an online forum that was set up to provide feedback. The members of the program were and still are under a nondisclosure agreement, whereas some parts of the MDP were allowed to be made public after May 1, 2006.

Until the official end of the program in August 2006, most of the members were extremely busy with exchanging ideas on the NXT with LEGO and influencing the product to be released. All parties participating in the MDP consider it a tremendous success today. It's not surprising, therefore, that LEGO set up a successor, called the MINDSTORMS Community Partners (MCP) program where approximately 20 people, partly chosen from the MCPs, are meant to help establish and deepen the connection between the NXT community and the LEGO Group.

LEGO.com MINDSTORMS Community NXT

Some of the major results of the MCP, information on some of its most committed members, and a lot of interesting robots can be found on LEGO's official community page at `http://mindstorms.lego.com`. This site is also the place for announcements, press releases, and company news regarding the NXT product. It also features downloadable media such as wallpapers, desktop icons, and a web site toolkit for building your own NXT web site. It is the exclusive source for new releases of the LEGO MINDSTORMS NXT Software. Moreover, LEGO has started to provide building instructions for advanced robots designed by the LEGO robotics team, including the recent sound-playing robot and a truly prodigious classic cuckoo clock.

However, the most interesting feature on the web site arguably is NXTLOG, most likely the largest repository for NXT robots on the Web. It's a fully moderated community where members may upload their NXT projects with photos, descriptions, and building instructions, thus sharing their designs with the community. Each week projects are chosen as "Projects of the Week." By April 2007, there were more than 1,800 projects published. Everyone, including those who do not have a project of their own to contribute, is welcome to get inspired by the contents of NXTLOG. Hence, whenever you are out of ideas for your next NXT, feel free to have a look there.

MINDSTORMS Education NXT

When LEGO launched LEGO MINDSTORMS in 1998, it also developed LEGO MINDSTORMS for Schools, the educational version of the MINDSTORMS concept. It was meant to help students become familiar with science, technology, engineering, and math. To this end, LEGO MINDSTORMS for Schools combines the LEGO MINDSTORMS system with the very popular programming software ROBOLAB.

Today, LEGO MINDSTORMS for Schools is used in more than 25,000 educational institutions worldwide, from elementary schools to universities.

The educational branch of LEGO, called LEGO Education, has been very active in supporting teachers in providing new ways of teaching traditional curriculum areas. The basic idea is making the teaching and learning of science and technology an adventure by focusing on firsthand experience with construction, mechanisms, energy, and programming techniques. The traditional way of memorizing external knowledge is discouraged here; instead, students are asked to use their individual problem-solving skills and imagination in challenges while cooperating with their fellow students.

LEGO has created a separate version of the NXT kit for the educational branch. With the arrival of this kit, the MINDSTORMS Education NXT site (`http://www.legoeducation.info/nxt`) was created. It is targeted particularly at teachers and other educators, but other people can also find a lot of interesting material there, including a NXT blog, building instructions for a lot of unique robots, and a store where you can buy a lot of NXT-related items; some of them available exclusively.

The NXT STEP

With *blogs* (web sites where entries are made in journal style and displayed in a reverse chronological order) becoming enormously popular in the past few years, those related to the NXT have also sprung up like mushrooms. One of the earliest and still most popular blogs is The NXT STEP (`http://thenxtstep.blogspot.com`), founded by MDP James Kelly in March 2006 and coauthored by a lot of other members of the MDP (including, once again, this book's author).

The NXT STEP has gained a reputation for not only being very active and often the first blog to spread news on the NXT but also for setting a high standard for qualified content. The blog has become pretty popular since its creation; it's listed on the official LEGO NXT community page and reached its 900th post as of April 2007, with more than 30,000 unique visitors in that month.

nxtasy.org

Another increasingly successful means of communication in communities are *forums*, essentially web sites composed of a number of member-written threads, where each thread entails a discussion or conversation in the form of a series of posts. It stands to reason that this kind of exchanging of information is perfect for a NXT robot community, and it's no surprise that today there are a lot of NXT-related forums to be found on the Web. One of the first was nxtasy.org (`http://nxtasy.org`), founded by Eric Salinas in June 2006. It quickly became the largest online forum for the NXT, having gained almost 750 members by March 2007.

Besides the forum and several subforums that deal with NXT software, hardware, projects, and other general topics, there are frequent challenges to the members. In addition, there's an active blog with prominent contributors and a repository with a lot of interesting NXT robot projects.

mynxt.matthiaspaulscholz.eu

I'll take the opportunity here to draw your attention to my own NXT-related web site at `http://mynxt.matthiaspaulscholz.eu`. It's linked to many of the previously mentioned sites and has found and is still finding the interest of a lot of people. For instance, around 3,000 unique visitors went to the site as of March 2007.

The site features a bunch of robots created by me along with their building instructions, links to NXT-related tools, programming languages, and other NXT-related information on the Web as well as a Middle-European-focused events page and a contact page where you can send messages to me; I always try to respond.

It goes without saying that the NXT universe is growing still, and there's an abundance of other interesting web content out there related to the NXT.

For a list of some other sites that I consider worthwhile, refer to Appendix D of this book.

Summary

In this introductory chapter, you made a tour through Leonardo's life, built around some of his most prominent inventions. You should now be familiar with him and his major works and be able to put them into perspective with the historical context of the Renaissance era as well as appreciate their uniqueness. You also met the latest member of the LEGO MINDSTORMS family, the NXT, and learned about its components and capabilities. I hope that you are looking forward to implementing Leonardo's inventions with LEGO, as you will do in the following chapters.

Last but not least, I introduced some of the main protagonists of today's NXT online community. You should know by now where to start when making your first steps with the NXT. In the following chapter, I will acquaint you with some of the most interesting programming environments.