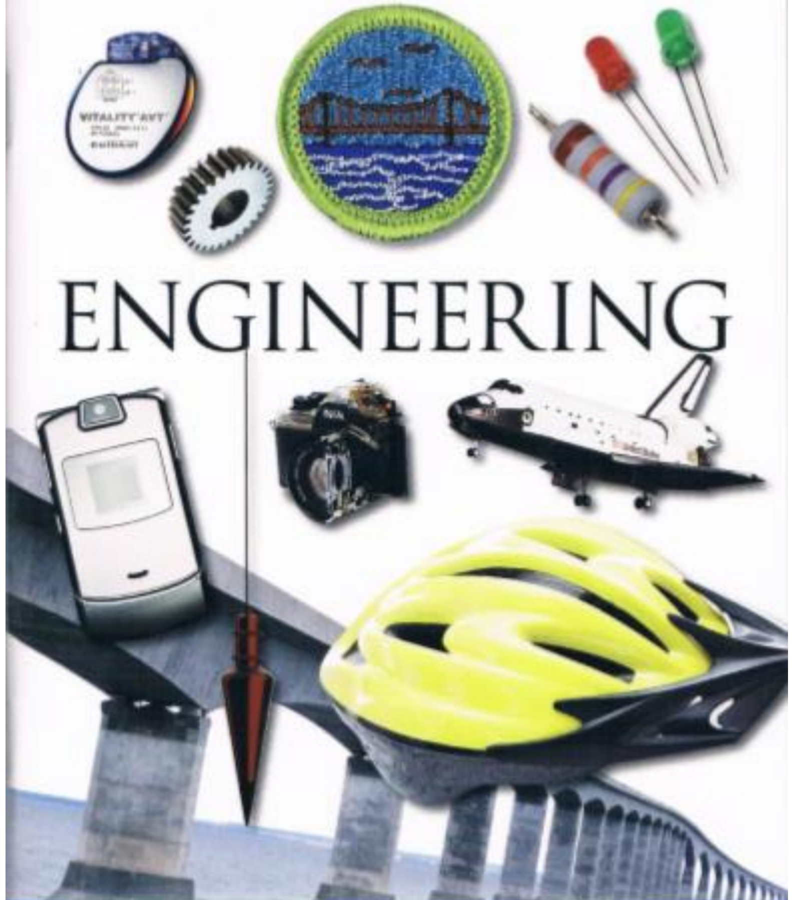
MERIT BADGE SERIES

ENGINEERING



BOY SCOUTS OF AMERICA

How to Use This Pamphlet

The secret to successfully earning a merit badge is for you to use both the pamphlet and the suggestions of your counselor.

Your counselor can be as important to you as a coach is to an athlete. Use all of the resources your counselor can make available to you. This may be the best chance you will have to learn about this particular subject. Make it count.

If you or your counselor feels that any information in this pamphlet is incorrect, please let us know. Please state your source of information.

Merit badge pamphlets are reprinted annually and requirements updated regularly. Your suggestions for improvement are welcome.

Send comments along with a brief statement about yourself to Youth Development, S209 • Boy Scouts of America • 1325 West Walnut Hill Lane • P.O. Box 152079 • Irving, TX 75015-2079.

Who Pays for This Pamphlet?

This merit badge pamphlet is one in a series of more than 100 covering all kinds of hobby and career subjects. It is made available for you to buy as a service of the national and local councils, Boy Scouts of America. The costs of the development, writing, and editing of the merit badge pamphlets are paid for by the Boy Scouts of America in order to bring you the best book at a reasonable price.

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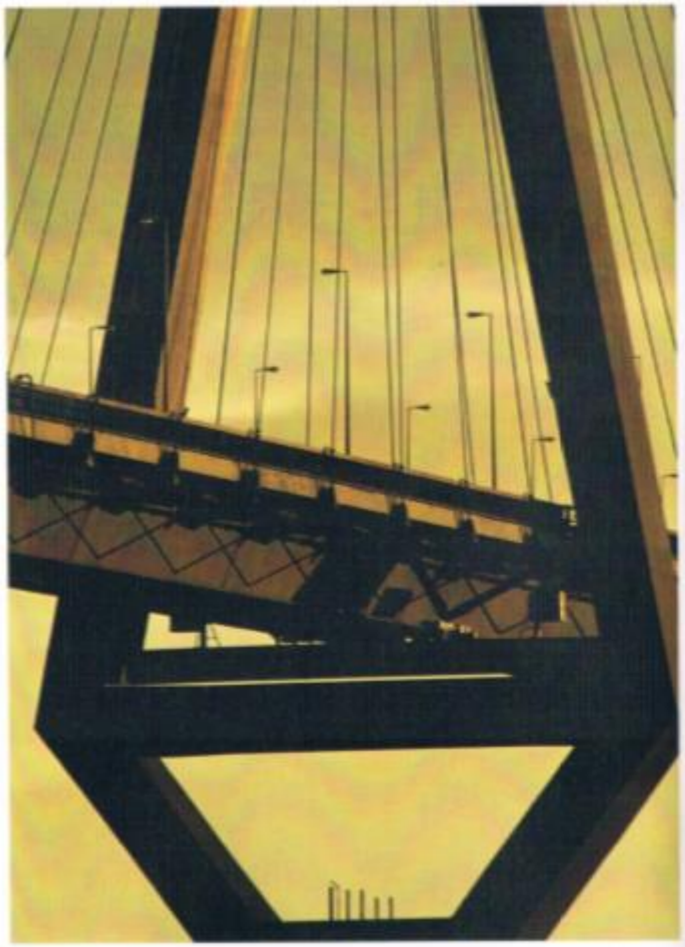

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Requirements

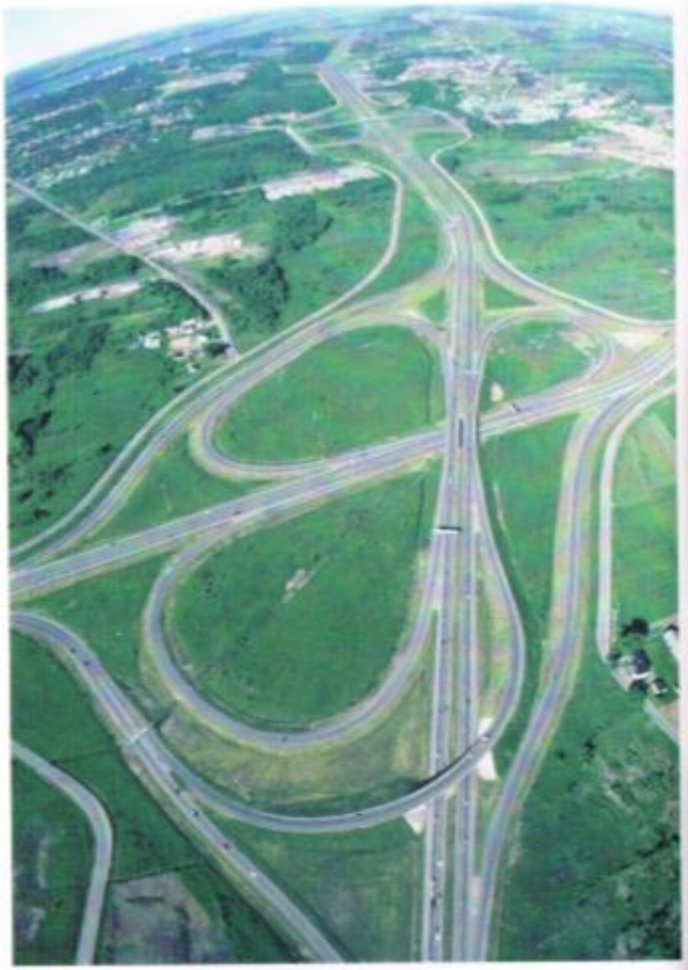
1. Select a manufactured item in your home (such as a toy or an appliance) and, under adult supervision and with the approval of your counselor, investigate how and why it works as it does. Find out what sort of engineering activities were needed to create it. Discuss with your counselor what you learned and how you got the information.
2. Select an engineering achievement that has had a major impact on society. Using resources such as the Internet (with your parent's permission), books, and magazines, find out about the engineers who made this engineering feat possible, the special obstacles they had to overcome, and how this achievement has influenced the world today. Tell your counselor what you learned.
3. Explain the work of six types of engineers. Pick two of the six and explain how their work is related.
4. Visit with an engineer (who may be your counselor or parent) and do the following:
   a. Discuss the work this engineer does and the tools the engineer uses.
   b. Discuss with the engineer a current project and the engineer's particular role in it.
   c. Find out how the engineer's work is done and how results are achieved.
   d. Ask to see the reports that the engineer writes concerning the project.
   e. Discuss with your counselor what you learned about engineering from this visit.

5. Do ONE of the following:
   a. Use the systems engineering approach to make step-by-step plans for your next campout. List alternative ideas for such items as program schedule, campsites, transportation, and costs. Tell why you made the choices you did and what improvements were made.
   b. Make an original design for a piece of patrol equipment. Use the systems engineering approach to help you decide how it should work and look. Draw plans for it. Show the plans to your counselor, explain why you designed it the way you did, and explain how you would make it.
6. Do TWO of the following:
   a. *Transforming motion.* Using common materials or a construction set, make a simple model that will demonstrate motion. Explain how the model uses basic mechanical elements like levers and inclined planes to demonstrate motion. Describe an example where this mechanism is used in a real product.

   b. *Using electricity.* Make a list of 10 electrical appliances in your home. Find out approximately how much electricity each uses in one month. Learn how to find out the amount and cost of electricity used in your home during periods of light and heavy use. List five ways to conserve electricity.
   c. *Understanding electronics.* Using an electronic device such as a mobile telephone or portable digital media player, find out how sound travels from one location to another. Explain how the device was designed for ease of use, function, and durability.
   d. *Using materials.* Do experiments to show the differences in strength and heat conductivity in wood, metal, and plastic. Discuss with your counselor what you have learned.

   e. *Converting energy.* Do an experiment to show how mechanical, heat, chemical, solar, and/or electrical energy may be converted from one or more types of energy to another. Explain your results. Describe to your counselor what energy is and how energy is converted and used in your surroundings.
   f. *Moving people.* Find out the different ways people in your community get to work. Make a study of traffic flow (number of vehicles and relative speed) in both heavy and light traffic periods. Discuss with your counselor what might be improved to make it easier for people in your community to get where they need to go.

   g. *Building an engineering project.* Enter a project in a science or engineering fair or similar competition. (This requirement may be met by participation on an engineering competition project team.) Discuss with your counselor what your project demonstrates, the kinds of questions visitors to the fair asked, and how well you were able to answer their questions.
7. Explain what it means to be a registered Professional Engineer (P.E.). Name the types of engineering work for which registration is most important.
8. Study the Engineer's Code of Ethics. Explain how it is like the Scout Oath and Scout Law.
9. Find out about three career opportunities in engineering. Pick one and research the education, training, and experience required for this profession. Discuss this with your counselor, and explain why this profession might interest you.



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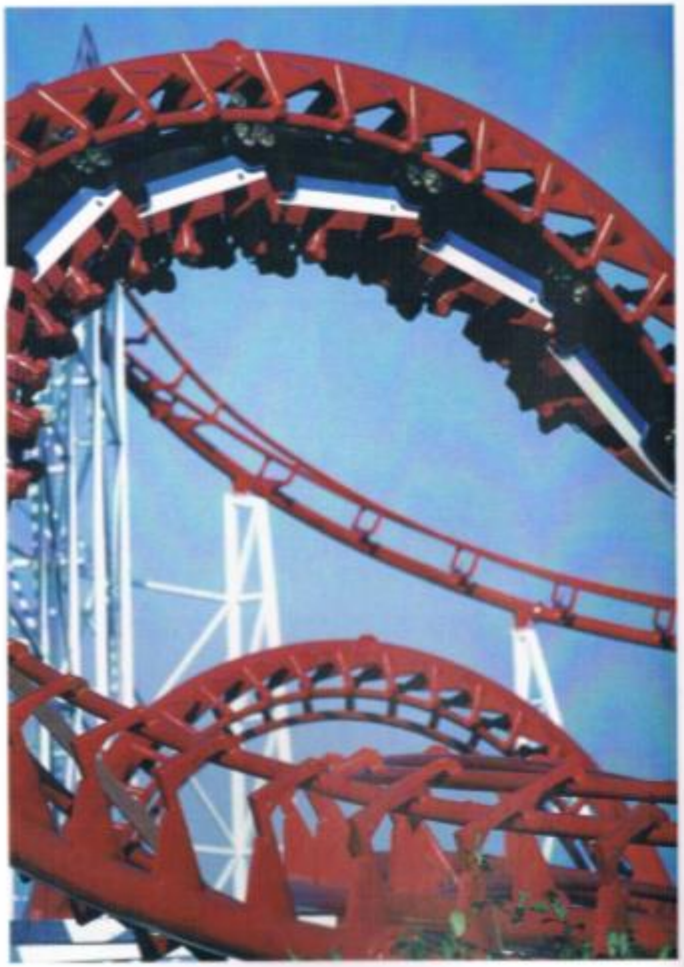


Introduction

Engineers turn ideas into reality. For example, they will take the plans drawn on paper for an exciting new roller coaster—a design with loops, drops, and corkscrews—and figure out how to build it so that it will be fast, safe to ride, and affordable to build. Engineers devise all sorts of things, ranging from a tiny, low-cost battery for your cell phone to a gigantic dam across the mighty Yangtze River in China.

The work of engineers affects every part of our lives—at home, at school, and at work. We have engineers to thank when we use escalators at the shopping mall, watch TV on the latest flat-panel screen, or get scanned for disease with the latest imaging equipment at the hospital.

Engineering touches so many parts of our lives that it has been divided into many different specialties. Civil engineers create the dams, bridges, and roadways on which we rely every day. Mechanical engineers develop machines and engines. Software engineers create computer programs. Biomedical engineers develop new medical devices to help us live longer and healthier lives. Aerospace engineers develop new aircraft and spacecraft. Petroleum engineers help discover and extract new sources of oil. And that is just a short list of engineering specialties.

An engineer will use both science and technology to meet needs. Famous inventors like Thomas Edison, Alexander Graham Bell, Henry Ford, and Benjamin Franklin were not called engineers, but innovators like them have been turning ideas into useful products for centuries. Franklin's experiments with electricity are among his many accomplishments. Edison's first electric lightbulb dramatically changed American life. Bell's telephone changed the way we communicate with one another. Ford not only made an engineering contribution to the design of early automobiles, but also transformed manufacturing by introducing the assembly line concept.

A Little History

Engineering has been around for a long time. Here are just a few examples of the many amazing engineering feats of the past.

Pyramids at Giza

Great Pyramid of Giza. In 2600 B.C., the ancient Egyptians built the Great Pyramid of Giza, which was the tallest structure in the world for thousands of years afterward. The project took more than 20 years to build and required the precise cutting and placement of more than 2 million blocks of stone.

Great Wall of China

Great Wall of China. In the third century B.C., the Chinese started building the Great Wall. It would not be completed for another 1,800 years. The wall stretches for 1,500 miles across northern China, averaging 25 feet high and 15 to 30 feet wide at the base.

Taj Mahal

Taj Mahal. The Taj Mahal was completed in Agra, India, in 1654 as a monument to emperor Shah Jahan's wife. It is a complex of numerous structures, including a mausoleum, mosque, minarets, walls, watchtowers, and gardens.

The Royal Road. In the 1400s, the Inca Indians of South America completed the Royal Road, a major roadway up to 52 feet wide that ran from what is now Santiago, Chile, to Quito, Ecuador. Until the late 1800s, it was the world's longest road. Parts of it crossed the Andes Mountains at elevations of almost 12,000 feet.

The builders of these ancient wonders used many of the same principles that modern structural engineers apply, though they were limited to the knowledge and technology of their day. As time passed, and knowledge and technology advanced, marvels of engineering became even more impressive.

Modern Marvels

In 1994, the American Society of Civil Engineers came up with a list it called the "Seven Wonders of the Modern World," which amounted to the greatest civil engineering feats of the 20th century.

Channel Tunnel. This remarkable 31-mile-long tunnel runs under the English Channel, between England and France. For much of its length, the tunnel lies 130 feet below the ocean floor. Instead of explosives, engineers used huge tunnel-boring machines that cut through rock and removed debris. The Channel Tunnel consists of three linked, parallel tunnels—one for each direction of travel, and a service tunnel that runs in between.

Canada's National Tower. The CN Tower, standing 1,815 feet above the city of Toronto, Ontario, is the world's tallest free-standing (using no guy wires) building. Some 1,465 feet up the tower is the "Sky Pod," the highest observation deck in the world. From there, you can see up to 75 miles away. The CN Tower was built to withstand wind gusts of up to 250 mph.

CN Tower

Empire State Building

Empire State Building. The first building in the world to have more than 100 floors was this 102-story skyscraper completed in New York City in 1931. For 41 years, it was the tallest skyscraper on Earth. The spire atop the 1,472-foot structure was originally designed to be a mooring mast for airships.

Golden Gate Bridge

Golden Gate Bridge. A beautiful 1.7-mile-long bridge in California, completed in 1937, spans the "Golden Gate" strait, which serves as the entrance to San Francisco Bay from the Pacific Ocean. The suspended-deck bridge uses tall towers and enormous cables to support the road surface below, which carries six lanes of traffic.

Itaipu Dam

Itaipu Dam. This 5-mile-wide dam, completed in 1982, spans the Parana River on the border of Brazil and Paraguay in South America. The Itaipu is the world's largest hollow gravity dam. A hollow gravity dam has empty chambers inside, making it cheaper to build, but still has enough mass to hold back water using its sheer weight. Until recently, the Itaipu was also the largest hydroelectric dam in the world.

Netherlands Delta Works. For centuries, the Dutch have fought to keep the sea at bay with levees (or dikes), seawalls, and water pumps powered by windmills. But large parts of the country fall below sea level. When a disastrous flood in 1953 killed more than 1,800 people, the nation undertook a huge engineering project to protect its citizens. It raised thousands of miles of dikes along the seashore and riverbanks, and built dams and storm surge barriers.

Panama Canal. This 48-mile ship canal, completed in 1914, connects the Atlantic and Pacific Oceans across the Isthmus of Panama in Central America. By linking the two oceans, the Panama Canal saves ships from having to travel thousands of extra miles if going around South America. Engineers devised a clever system of locks to raise ships from sea level up to the level of inland artificial lakes. After crossing the isthmus, boats are lowered back to sea level in another set of locks.

Panama Canal

What Does an Engineer Do?

Engineers work to solve problems. They may build roads or cars, design factories or computer games, or study traffic problems or the best way to make a chair. They find ways to make life easier, safer, and more productive by putting new knowledge and skills to work or by more efficiently using established methods and processes.

Engineering can be defined as the application of science, mathematics, technical knowledge, and practical experience to solve problems. The result is the design, creation, and operation of useful products, structures, machines, systems, and processes.

Creating better methods and products is important because, besides meeting people's needs more successfully, innovation also can save money. Engineers are always looking for ways to cut costs and improve efficiency. That allows companies to sell their products at a lower price, which stimulates competition and improves consumers' lives. For example, a typical desktop computer costs a third of the price it did 15 years ago.

Engineering Today

For more about electronics and computers, see the *Electronics* and *Computers* merit badge pamphlets.

Engineering breakthroughs don't happen only on a grand scale. Many innovations occur on a tiny scale—in a test tube or on a circuit board. The digital world we now live in took off with the invention of the transistor. This fingernail-sized switch and amplifier replaced the bulky glass vacuum tubes used in early radios and televisions. Suddenly these products could be smaller and less expensive and could be powered on batteries.

Over time, transistors were further miniaturized from hundreds to now millions of tiny transistors placed on a single integrated circuit. The integrated circuit made possible such products as the pocket calculator and digital wristwatch. Later, engineers designed the first microprocessor, putting all the circuits needed for a computer's central processing unit (its "brain") onto a single chip. This innovation made possible the personal computer, cellular telephone, and advanced missile technology.

Engineering innovations have advanced technology with lightning-quick speed. For example, which telephone do you think is more common these days?

Jack Kilby, Inventor of the Integrated Circuit

Jack Kilby (1923–2005), an electrical engineer, invented the integrated circuit in 1958 while working for Texas Instruments. Before then, electronic devices such as computers were made from individual transistors wired together to form circuits. Kilby had the idea of manufacturing multiple electronic components together on the same piece of semiconductor material, with all the connections built in—no soldering required. His invention paved the way for the development of modern computers and the Information Age of today.

Computers have also revolutionized how we communicate. In the 1960s, a network of computers was born that evolved into the Internet. Then, in 1990, a physicist named Tim Berners-Lee created the World Wide Web. His main innovations were the Uniform Resource Locator (URL), a form of address that can be used on any Web page or other file on the Internet, and hypertext markup language (HTML), a form of computer language that creates Web pages and links them to other Web pages.

Engineering in Our Daily Lives

Let's look at the automobile. Thanks to the use of lighter and stronger materials and changes to engine designs, engineering improvements have made cars more fuel-efficient. In the 1950s and 1960s, the average car got 8 to 10 miles per gallon. Today's automobiles go two or three times as far on the same amount of fuel.

Besides being more fuel-efficient, cars today are much "cleaner" —they release fewer hazardous emissions into the air than those of years past.

Another significant engineering contribution is in automobile safety. Antilock brakes use speed sensors and hydraulic valves to slow each wheel independently to prevent skidding when the driver applies the brakes. A global positioning system (GPS) and cell-phone technology are combined in the OnStar tracking service offered by General Motors. If a car is in an accident, the system automatically signals service representatives who can summon ambulance and police responders. Improvements to car bumpers have reduced damage and injury by absorbing shock at low speeds.

In the home, programmable electronic thermostats automatically adjust heat and cold, saving hundreds of dollars in energy costs. Ovens with computerized timers automatically shut off the heating coils after the cooking time has elapsed. Electronic smoke sensors, wired together into one system, alert the whole family if a fire or smoke is detected. In some homes, security services will call for emergency assistance. Through the use of the Internet and small cameras installed in the home, people can check up on their homes or loved ones from thousands of miles away.

Hybrid Cars: What Was Old Is New Again

Back in 1905, an American engineer named H. Piper filed the first patent application for a gas-electric hybrid car. Piper's hybrid, and others like it, never caught on—that is, until the mid-1990s. Suddenly, worries about oil shortages and air pollution made hybrids attractive again. Modern hybrids get far better gas mileage than conventional cars. They use batteries to store electric power, and sometimes get by on the electric motor alone. What's more, they cleverly capture the car's kinetic energy (the energy of motion) through regenerative braking. Every time you apply the brakes, energy goes to the batteries to be stored.

Making Work Easier

As important as engineering is in the home, it is even more important in the workplace. Advances in engineering increase productivity, the amount of product that results from a given amount of energy or cost. Shaving just a few pennies off the cost of making a product—through better design or cheaper materials—could make the difference between profit and loss.

In factories, engineers can design systems and operating methods to reduce waste. They can devise specialized software to control production processes and manage inventory. They can help plan the best use of salespeople in the field and can design layouts for retail stores. They can even help set up storefronts on the Internet, figure out how much product to keep in inventory, and decide how best to ship products.

Making Play More Fun

If you enjoy computer games, you can thank the software engineers for writing the code that makes those games possible. Likewise, hardware engineers design ever more advanced graphics chips and processors that make computer games appear sharper, more colorful, and more realistic.

Engineering has also affected the sports world. Bicycle engineers have developed better gear shifting for easier riding up hills, and lighter and stronger materials for bicycle frames and components. Tennis has also benefited from engineering improvements. Recent developments in racquet designs are resulting in a faster and more exciting game for tennis enthusiasts.

Understanding Electricity

Consumer electronics products like cell phones and portable music players have become so popular that they are the basis of multibillion-dollar industries. These products demonstrate advanced electronics engineering, fitting sophisticated technology into very small packages.

The typical cell phone consists of a circuit board containing the electronic brains of the device, keyboard, antenna, liquid crystal display, speaker, microphone, and battery, all of which fits inside a sturdy plastic case no bigger than the palm of your hand.

Portable music players are somewhat simpler but still sophisticated. They typically contain a circuit board, compact hard drive or flash memory chip for storing music files, liquid crystal display screen, a scroll wheel or buttons for operating the software that runs the device, and earphones or ear buds that contain speakers.

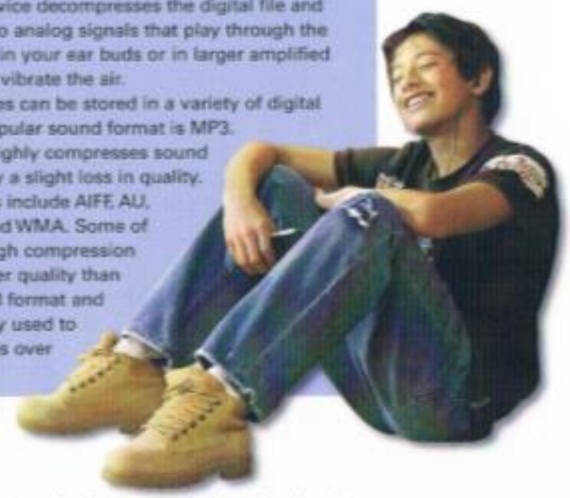
Cell phones and music players both use computer technology to handle the transmission of sound. Sound is made up of vibrations, which travel through the air by passing from one molecule to the next. These vibrations are called waves—if you could see them they would look like the waves at the beach. The height, or amplitude, of the wave determines the volume, or how loud the sound is. How close the waves are together determines the frequency, or pitch—how high or low the sound is to your ear.

The voice of a caller enters your cell phone as a digital signal transmitted through the air over radio waves. When the call reaches your phone, the data is sent through a digital-to-analog converter chip, which rebuilds the shape of your friend's voice wave and sends that information to the earpiece speaker, which

vibrates the air, recreating your friend's voice. When you speak into your cell phone microphone, the opposite happens: An analog-to-digital chip converts your voice into a digital signal that can be transmitted back over the airwaves to your friend.

Portable music players also make use of digital-to-analog conversion. They store digital music files on a tiny hard drive or flash memory chip. Often, the files are in a highly compressed format to save storage space. When you select a file to listen to, a computer chip in the device decompresses the digital file and converts it into analog signals that play through the tiny speakers in your ear buds or in larger amplified speakers that vibrate the air.

Sound files can be stored in a variety of digital formats. A popular sound format is MP3. This format highly compresses sound data with only a slight loss in quality. Other formats include AIFF, AU, WAV, AAC, and WMA. Some of these have high compression but even better quality than the older MP3 format and are commonly used to sell music files over the Internet.



Your Turn

Give some thought to the above examples of engineering feats. Jot down a few of your own and see if you can suggest what might be possible in the future. Think about Scouting and the technological and engineering advancements that have affected it. There are many examples, such as camping gear and advances in first aid.

The Different Fields of Engineering

Each field of engineering applies different sciences, formulas, and techniques. Designing a bridge takes different knowledge than creating a fire hot enough to refine iron ore. The way an engineer figures out how to make large batches of chemicals is quite different from how another engineer plans to manufacture automobiles or computer chips.

The special scientific ideas and mathematical formulas needed by each type of engineer can be collected and made available to all the people doing that kind of work. These include information such as

- Tables that show how materials behave when cooled, heated, or melted
- Mathematical formulas that describe how air, water, or electrons flow
- Computer programs to help engineers understand how these things will happen

The First Engineering Specialties

Five early fields of engineering emerged to meet the growing needs of society that were brought about by the industrial revolution in the 1800s. These engineering fields were civil, mining and metallurgical, mechanical, chemical, and electrical.

Civil engineering specialties include structural engineering, transportation engineering, environmental engineering, hydraulic engineering, and surveying.

Civil Engineering

Civil engineers meet society's needs for infrastructure—things like roads, railways, bridges, dams, water supply systems, and sewage systems. A critical part of designing these structures is making sure they will stay where they are put—that they will not tilt, shift, or sink into the soil over time. Therefore, civil engineers often apply knowledge of geology and physics in their work.

The World's Largest Dam

In 2006, the largest dam in the world built to produce electricity was completed in China. The Three Gorges Dam stretches 1.4 miles across the massive Yangtze River. At 607 feet tall and constructed of some 21 million cubic yards of concrete, it is nearly five times as large as the famous Hoover Dam on the Arizona-Nevada border. The Three Gorges Dam will create a 410-mile-long reservoir up to 574 feet deep, eventually producing 18.2 gigawatts of power—about nine times as much as the Hoover Dam. The dam is expected to protect 15 million people from periodic flooding of the Yangtze River.

Brooklyn Bridge

John Roebling (1806–1869) developed a machine to create thin, flexible wire ropes that were twisted together to produce lengths up to 30,000 feet. These ropes were used to build New York City's Brooklyn Bridge and in projects such as the Panama Canal and San Francisco's Golden Gate Bridge.

Mining and Metallurgical Engineering

Mining and metallurgical engineers work to make mining and refining metals more predictable, safer, and less expensive. They do this by applying the principles of materials science—the study of the properties and behavior of solids, liquids, and gases.

Metallurgical engineers have advanced the ore refining processes by creating new mixtures (alloys) tailored to meet specific needs. Examples are hard metals that can hold a sharp edge, soft metals that can be stamped with artistic patterns, noncorrosive and weather-resistant metals, and metals that can withstand very high or very low temperatures. The metallurgist strives to meet the project's goals by delivering alloys with just the right properties in such areas as cost-effectiveness, weight, durability, and strength.

Presidential Engineers

Two U.S. presidents were engineers before they entered the White House. Herbert Hoover (1874–1964), the 31st president, had been a mining engineer and managed mines in Colorado, Australia, and China. He started his own engineering firm in 1908. In 1977, an engineer was elected as our nation's 39th president. Jimmy Carter (1924–) studied nuclear physics at the U.S. Naval Academy in Annapolis, Maryland. Later, while serving in the Navy's nuclear submarine program, he became a qualified nuclear engineer.

Mechanical Engineering

Mechanical engineers apply the principles of physics to design, build, and maintain mechanical systems. That can mean anything from designing a collapsible cardboard box for holding doughnuts to constructing the most advanced jet engines.

Potential energy is harnessed at hydroelectric power plants, where water drives a turbine and generator to create electricity.

Some mechanical engineers specialize in converting energy into more useful forms. Boilers and generators convert heat to electricity in coal-fired, gas-fired, and nuclear power plants. The energy in falling water can be used to generate electricity. Heat from the sun can be collected and used to heat water or even generate electricity.

Many mechanical engineers specialize in moving heat to where it is wanted and away from where it is not wanted. They design boilers, gasoline engines, and gas turbines (jet engines) that can operate for long periods without overheating, or fans to cool the microprocessors in computers.

Other mechanical engineers take the converted energy and devise machines to do useful things with it: Automobiles, lawn mowers, microengineered medical equipment, aircraft landing gears, and machines to mold plastic toys or fill soda bottles are all examples. These engineers learn how to use shafts and bearings, pulleys, gears, and mechanisms (collections of levers) to make things move around or back and forth or in special patterns, at specified speeds.

Mechanical engineers understand how hard you can push on a part before it will bend or break, and how to design the shape of a part so that the lightest possible part will support the most force possible.

Two-Wheeled Marvel

The Segway® Personal Transporter (PT), a battery-powered, two-wheeled "human transporter," is a marvel of engineering. What is amazing about the Segway PT is that it reacts to the rider's movements, adjusting the speed of its wheels to maintain balance at all times. The rider leans forward to move the Segway PT ahead and backward to move in reverse. This ability to self-balance is accomplished by a combination of computers, motors, and gyroscopes.

Chemical Engineering

Chemical engineers develop useful things based on the newest advances in chemistry. In the process, they harness their knowledge of chemicals, chemical reactions, and raw materials. When chemists create a new medicine, plastic, fiber, fabric, or glue, they normally make only a small amount in the laboratory. Chemical engineers devise ways to adapt these small laboratory experiments into full-scale productions in processing plants that can efficiently make tons of the new substance every day.

Electrical Engineering

Electrical engineers discover how to harness electricity to do more for people. They study and apply electronics and electromagnetism (the physics of electricity and magnetism).

Electrical engineering had its start during the latter part of the 19th century. The original focus was on generating and distributing electricity widely, to replace steam and water as sources of power and gas as a fuel for lighting. Along the way came inventions like electrically powered trains, microwave ovens, and other modern conveniences that have dramatically changed our lives, as well as communication devices that have brought people around the world closer together.

Electrical communications started with the telegraph before the Civil War, followed by the telephone (1876) and the radio (late 1800s). Television was first demonstrated in the United States in 1927. The transistor was invented in the late 1940s and showed up in portable radios by the late 1950s. Some of the earliest electronic computers were developed during World War II. The first modern digital computer, the ENIAC, was a giant machine that used vacuum tubes. The integrated circuits that make possible desktop computers were invented in the late 1950s, followed by the microprocessor and the first personal computers in the 1970s.

Inventing a Better Lightbulb

Believe it or not, a new marvel of engineering may replace the lightbulb. In 2006, engineering professor Shuji Nakamura was awarded the Millennium Technology Prize in part for inventing a type of solid state lighting that gives off light without generating heat. His light-emitting diodes use a fraction of the energy needed to brighten the filament inside Thomas Edison's incandescent lightbulb.

The specialties of modern electrical engineering include:

- Power generation and distribution
- Electrical machinery (motors and things run by motors)
- Communications (telephones, radio, TV, and data)
- Computer systems, sometimes called information systems
- Control systems (like those that guide robots)
- Electronic devices (integrated circuits, microprocessors)

Power Extremes

Some electrical engineers specialize in power: generating electricity, moving it across great distances to where it is needed, and delivering it to end users. They work with huge amounts of electricity, often at extremely high voltages.

Other electrical engineers work with low amounts of power. They design the microchips that go into computers and portable electronic devices. They can see the details of their work only under microscopes. Many of these fields are closely allied with other branches of science and engineering. For example, the turbines used to generate electricity are designed by mechanical engineers. The design of integrated circuits depends on materials scientists and engineers.

Today's Many Fields of Engineering

As technologies have become more complex and the products based on them more complicated, more modern engineering specialties have developed.

A horticulturist inspects the size and quality of hydroponically grown strawberries.

Aerospace Engineering. Aerospace engineers are specialized mechanical engineers that study the way airplanes and rockets interact with the air to fly; develop lightweight structures for airplanes and space vehicles; and design the high-powered engines needed to propel airplanes and lift space vehicles clear of Earth's gravity and atmosphere. Aerospace engineers specializing in aerodynamics design specially shaped wings, tails, and airplane bodies to move through the air with the least possible resistance.

Agricultural Engineering. Agricultural engineers design farm and food-processing equipment and develop systems for irrigation, drainage, and waste disposal. Some experiment with new ways to grow crops more efficiently, like hydroponics (growing plants without soil).

Architectural Engineering. Architectural engineers work with architects on the systems that make buildings functional, such as elevators and escalators, heating and cooling systems, and ventilation and air-conditioning systems. They also work with earth scientists to understand when, how, and at what strength natural forces—such as wind, rain, and earthquakes—will affect buildings.

Bioengineering. Bioengineering combines biology and engineering and also relies on the principles of biomechanics—the study of the mechanics (or workings) of living organisms. Bioengineers work with medical doctors to design surgical instruments, artificial organs like heart valves and hearts, implants to replace weakened bones, and prosthetics like artificial legs to help people who have been hurt in accidents.

World's First Bionic Man

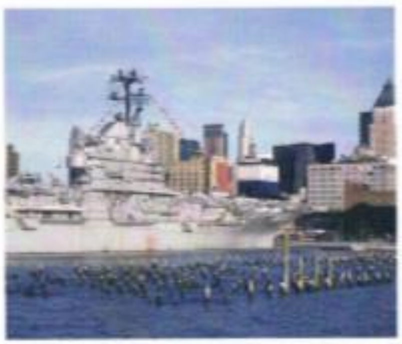
Jesse Sullivan of Dayton, Tennessee, lost both of his arms in a terrible accident involving an electric power line. After recovering from his injuries, Mr. Sullivan was selected to receive a new type of artificial arm. This "bionic" arm is an improvement over earlier artificial limbs because the wearer can control it with his thoughts (a neural control) rather than by flexing certain muscles (a mechanical control). Now, when he thinks "close hand," for example, impulses from his chest signal motors in his artificial limb, and his new hand closes.

Ceramic Engineering. Ceramic engineers work with processes that convert clay and nonmetallic minerals into ceramic products such as dishes, protective tiles for the space shuttle, and solar panels. During production, ceramic products are heated in very hot ovens, making them among the best materials for parts that will be exposed to high heat—such as inside a jet engine, or on the surface of a spaceship that must fly through the atmosphere to return to Earth.

Computer Engineering. The amazing rate at which computers have progressed is due in large part to computer engineers, who continue to find ways to make memory storage devices smaller, to fit more circuits on a microchip, and to move data faster and faster through the circuits. Devices for holding data and software programs, as well as media files such as photographs and movies, have exploded in capacity while their physical size has gotten smaller. The computer that controlled the lunar lander when Apollo astronauts landed on the moon in 1969 cost more than a million dollars. Today, the cheapest home computer has far more power than the Apollo computer—and costs a fraction of the price.

Environmental Engineering. Environmental engineers study the quality of the air, water, and land and develop systems to reduce pollution and help restore Earth to good health. Increasingly complex computer programs now allow environmental engineers to create computer models of the movement of air and pollutants. This lets engineers pinpoint the worst sources of pollution and how to improve air quality for the entire area. Once environmental engineers identify which polluting chemicals are coming out of the exhaust stack of a particular factory, for instance, they can design special equipment to clean up the exhaust and improve the air quality around that factory.

Industrial Engineering. Industrial engineers are concerned with how manufacturing plants are organized: what machinery there is, how materials and the things being made flow through the factory, and how people are organized to make the factory as effective as it can be. They often are involved in managing warehouse operations such as tracking inventory, routing conveyors, and overseeing materials handling. They use the branch of mathematics called statistics to design efficient systems.



Manufacturing Engineering. Mass-producing large quantities of products requires special knowledge of high-speed machinery (including automated machines and robots) to make sure the parts and finished products really are identical. This is the task of manufacturing engineers. They understand how machine tools cut metal, how tools wear out, and how assembly robots can consistently make good products day after day.

Marine or Naval Engineering. Just as special skills are needed to create vehicles that move through the air, designing ships also requires unique knowledge and mathematical tools. Marine or naval engineers design equipment for a structure that is constantly moving, twisting, and being slammed by environmental factors such as weather, salt water, current, and marine life.

Materials Engineering. Materials engineers work with all kinds of materials, natural and synthetic, to create new materials that meet specific needs for strength, flexibility, durability, and resistance to corrosion. Composites are excellent examples of what materials engineers are capable of creating. Composites can be strong enough for use as I beams or flexible enough to be formed into just about any shape, from airplane parts to bicycle frames.

A Comeback for Nuclear Power?

Nuclear power reactors generate electricity to run our homes, factories, and businesses. Interest in building new nuclear plants has grown with the rising cost of oil and natural gas and public concerns about air pollution caused by coal-burning power plants. Nuclear engineers are working to develop a new generation of reactors that would run at higher temperatures, drawing more power from the same amount of fuel—and also creating less radioactive waste.

Nuclear Engineering. Nuclear engineers design systems that operate in the presence of nuclear radiation, from power plants to medical instruments to weapons. They specialize in applying materials that are not weakened by radiation, and in making the systems safe. Handling nuclear materials must be done safely and surely, whether the materials are tiny "seeds" to be implanted under the skin of a cancer patient, or new fuel supplies for a power plant. One task of nuclear engineers is to design containers that will safely shield the radiation under normal use, and will not break open if they are involved in an accident while they are being shipped.

Ocean Engineering. Some engineers say it is harder to work in the ocean than in outer space. Oceanic pressures are extremely high, temperatures vary greatly, unusual materials are found, and the wildlife ranges from Earth's tiniest animals to the largest known mammal. Ocean engineers design ways to harvest food from the ocean or harness the energy in waves. Some engineers are developing new methods and machines to make it possible to work and live beneath the sea for long periods.

The giant oil-drilling and pumping platforms that operate near America's Gulf Coast and in the stormy North Sea of northern Europe are complex and exciting ocean engineering projects. Engineers must design steady platforms that can withstand storms and occasional collisions by ships.

Today, we rely on petroleum for fuel as well as many nonfuel products, such as asphalt for roads, paint thinners, candy and chewing gum, and skin creams.

Petroleum Engineering. Petroleum engineers are specialized chemical engineers who develop efficient ways to extract crude petroleum from the ground. Near the coast of Southern California, oil-drilling rigs on the land actually branch out under the sea to find oil deposits. It is difficult and complex to drill more than a mile straight down into the earth. Can you imagine the extra engineering problems of drilling sideways?

Software Engineering. Software engineers apply the findings of computer science to design complex software systems and products—from the systems that control airplanes in flight, to the systems that watch over our money in banks, to exciting new computer games. They learn or create different programming languages to do different kinds of tasks. The fast-moving graphics action of a computer game is quite different from carrying out a detailed mathematical analysis. Creating photographlike images, complete with shadows and reflections, is different from searching a huge database for related items of information.

Systems Engineering. Complex systems like an airplane or a power plant require the expertise of many kinds of engineers. Systems engineers figure out how all the many parts of a complex system work together, so that a plane will fly safely or a power plant will generate power steadily, safely, and cleanly. Systems engineers often are the first engineers on a new project. They translate the customer's needs (like high-quality surround sound for a home-theater system) into requirements and specifications that other engineers can follow as they design the product. They then design tests to ensure that the finished product actually does what it was designed to do.

Besides the fields described above, there are other, more highly specialized fields of engineering. Engineers must be able to work in teams because many problems or projects are highly complex. Several specialties may be required to complete the project, and no one engineer may have all the necessary knowledge.

The Engineer's Work

Besides specializing in particular fields, different engineers have different responsibilities.

Design. The design engineer uses a combination of new and existing ideas to solve a new problem or to solve an old problem in a new way. These engineers find solutions that work according to the project's requirements, stay within the budget, and are easy and safe to use. The solutions must be doable, long-lasting, practical to maintain or repair, and environmentally safe.

Analysis. The analytical engineer is mainly responsible for creating mathematical models of physical problems. Analysis is the process of using the methods and tools of mathematics to simulate (mimic) how a physical object will behave in response to the forces acting upon it. The goal of analysis is to understand the object's behavior without the time and expense of building and testing physical models. Computer-aided engineering tools are used for simulation and analysis.

Testing. The test engineer develops and carries out tests of a new product to make sure it meets the design requirements for structural integrity, reliability, and performance under all expected conditions. Test engineers also perform quality checks on existing products.

Computer Tools

Many engineers today use computer tools to help them with their work. These computer-aided programs allow engineers to draw their design and then simulate how the design will work in many situations. CAD (computer-aided design) and CAE (computer-aided engineering) programs also allow engineers to make quick design changes without having to actually build the equipment.

Research. Research engineers conduct research and seek out new materials, methods, and tools for other engineers to use. Together with research scientists, they explore advanced ideas and opportunities. Innovative products such as microrobots to help medical doctors in surgery, improved car aerodynamics (streamlining) to reduce drag and increase fuel efficiency, and computer microchips are direct results of research done by research engineers.

Sales. The sales engineer is a liaison (or go-between) between the company or organization that creates a product and the customers who use it. The sales engineer must understand the customer's needs as well as how the product or process works and why it will satisfy the customer's requirements. An outgoing personality and solid technical knowledge are important to be a successful sales engineer.

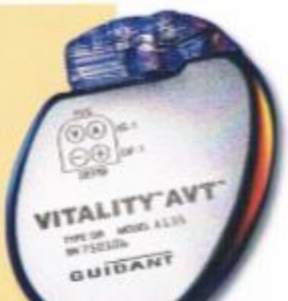
Management. Successful engineers with strong communication and leadership skills often become managers—project managers, department managers, chief engineers, engineering vice presidents—even presidents of companies and organizations. The role of the engineering management staff is to supervise the work of engineers assigned to them and ensure that projects are completed successfully, on time, and within budget.

Consulting. A consulting engineer is an independent, self-employed engineer who provides services to companies, organizations (including the government), or individual clients on a contract basis. A contract may be for one specific project or for long-term services. Consulting engineers serve in all fields of engineering, including management.

Teaching. An engineering professor is involved in teaching, research, and service. Teaching includes classroom teaching, supervising student research projects and papers, and developing courses for colleges and universities.

A Steadying Experience

Engineers often combine their training in one discipline with experience in other fields. One example is Wilson Greatbatch, who invented the heart pacemaker. Trained as an electrical engineer, Greatbatch worked in the areas of medicine, agriculture, and chemistry. He was building an oscillator to record heart sounds when he accidentally installed a resistor with the wrong resistance and it began to give off a steady electrical pulse. From this came the first implantable cardiac pacemaker, which has helped millions of people to live.



How Does an Engineer Solve Problems?

Think of problem solving as a complex, challenging game. As you solve the problem, you will find that several things must be done, and each of these things involves a new problem. We often call the main engineering problem to be solved a *project*.

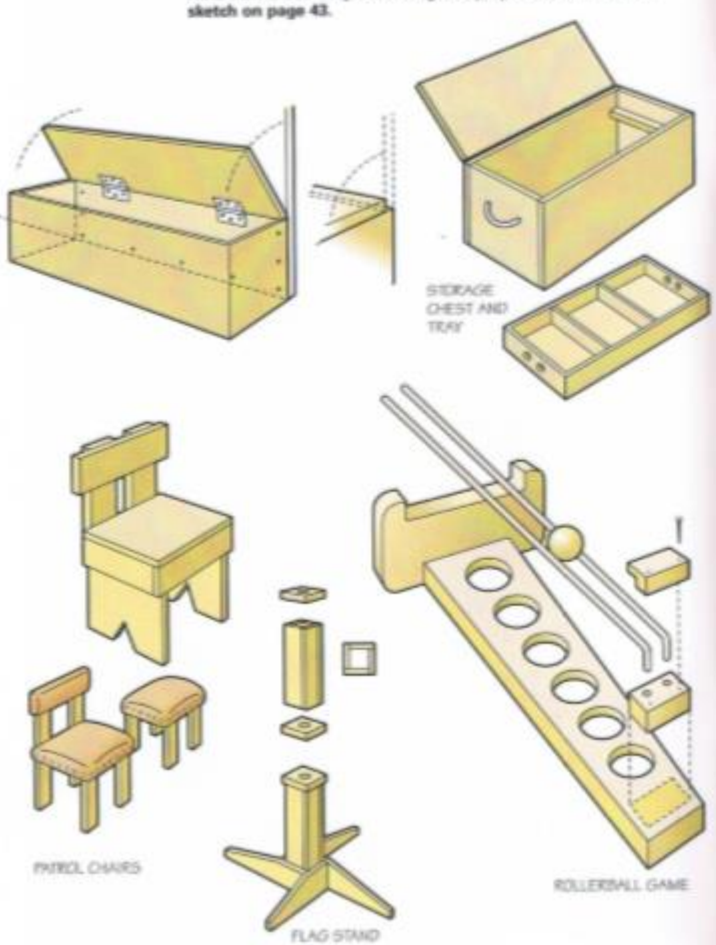
Systems Engineering Approach to Problem Solving

You will use a systematic (planned or orderly) approach to accomplish your project. We call this approach *systems engineering*. There are nine steps to follow.

1. Establish a Systems Engineering Operation

As you set up your systems engineering operation, you will get an overview of the next eight steps of this approach. You will decide what items you will need to use, how you will make sketches or drawings, how you will analyze alternative designs, how you will make the parts you need, and how you will assemble and test the project.

Note how these simple drawings for projects differ from the sketch on page 43.



Safety note: Use only power tools you are thoroughly familiar with and only under the direct supervision of a responsible adult who knows how to properly and safely operate those tools. The adult must always be present and aware of your task while you are operating a power tool.

List items you might need, such as a computer for computer-aided drafting, drafting tools, voltmeter, measuring scale, or hand tools. For example, let's assume you have the following items that you may use for projects:

- A set of wrenches for nuts and bolts
- Two or three each of straight-head and Phillips-head screwdrivers
- A socket wrench set
- A hammer and handsaw for wood
- A hacksaw for metal or plastic
- A ruler and a measuring tape
- Pencils, plastic triangles and templates, and a drafting compass for making drawings and sketches
- Electrical multimeter (ammeter and voltmeter) for electrical measurements
- A workbench with a vise for holding pieces
- Two C-clamps
- Various power hand tools, such as a drill motor (with a few drill bits) and a sander

The tools listed above are the physical assets available to you for the manufacturing phase of your project. This project might be a freestanding patrol box for base camping. If the base camp has electrical power available, you might add a light to the design project. You have the multimeter to check the electrical system.

Next, make an outline of a milestone (or Gantt) chart. You will use this to schedule the steps required for the project. Here is a sample Gantt chart.

Example Gantt Chart: Patrol Box

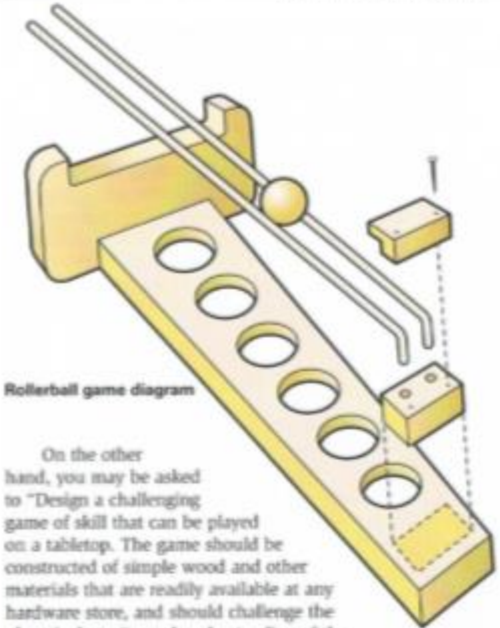
	Time Schedule—Project days from start													
Project Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project statement	—													
Planning	—	—	—	—	—									
Ideas		—	—	—	—	—								
Draw best ideas			—	—	—	—	—							
Analyze ideas				—	—	—	—	—	—					
Select best idea					—	—	—	—	—					
Draw idea with parts shown assembled						—	—	—	—	—				
Obtain materials							—	—	—	—				
Make parts								—	—	—	—			
Assemble design											—	—	—	
Use the patrol box														—

Lastly, estimate the cost of each idea and the financial resources available to you for your project. Engineers must always be aware of the cost of a project.

You have now established the beginning of a systems engineering operation. You have listed your operation's resources (computer, calculator, tools, finances), and you have a means of keeping track of the progress of the scheduled steps of your project. Your systems engineering operation can apply to any project you wish to tackle and is limited only by your available resources.

2. Describe the Project Requirements

Clearly describe the project with a project statement. Your project description might be a statement of a relatively simple problem, such as: "Find the time required to fill a 100-gallon water tank with a constant flow rate of 10 gallons per minute into the tank, and with zero water loss or leakage." However, a problem might be extremely complex mathematically, and still be solved with a clear, brief problem statement.



Rollerball game diagram

On the other hand, you may be asked to "Design a challenging game of skill that can be played on a tabletop. The game should be constructed of simple wood and other materials that are readily available at any hardware store, and should challenge the player's dexterity and understanding of the laws of gravity and physics." This is an example of the design class of problem. The solution is a project because a series of problems must be solved during planning and construction.

You are asked to devise a design solution for this project, which, in your judgment, best satisfies the design requirements. This type of project solution is called an *iterative* (or trial-and-error) solution and is typical of a design project, so you must carefully list all of the positive and negative requirements for the design. List the function (what it does), size, weight, materials, and any other factors that may come into play, such as the physical development of the person playing the game. For example, would your game be appropriate entertainment for a toddler?

For many projects, you may be required to consider environmental factors such as noise, air, or water pollution. Social forces in your community might also be factors, such as the need for ramps for citizens with disabilities.

3. Plan the Project's Activities, With Time Schedules

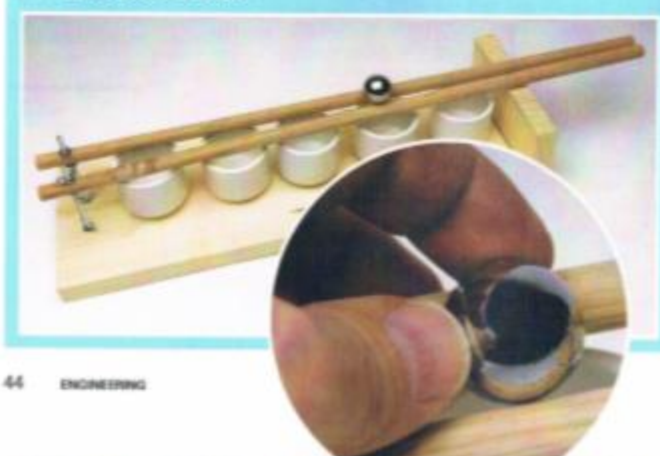
Compare the resources required to accomplish your project with your actual resources. You might need to look for more or different tools, or other pieces of equipment.

Let's assume that your project is to design a wooden rollerball skill game. The sample list of tools given in No. 1 are appropriate for many projects, such as designing a base camp patrol box, and will do just fine in this situation, as well.

Be sure to take inventory of the materials you will need, too. Because you are tackling a woodworking project, you also will need wood and wood screws, and you might consider adding a lacquer finish, paint, and paintbrushes to your list to put the finishing touches on your game. Sheets of fine sandpaper can be used to give your game a smooth finish. Felt pads for the underside of the game will help protect furniture from being damaged. And don't forget the steel rollerball!

You could choose to make a wooden skill game like this one, in which the challenge is to roll a steel ball along a pair of rods, dropping it into a cup with the highest point value. The rods have a slight uphill slope, and the player's objective is to manipulate the rods and ball to get the ball to roll up the slope. As the ball rolls over the cup with the desired score, the player spreads the rods quickly and the ball drops into the cup.

The trick to mastering the game is to spread the rods apart slowly to start the ball rolling, then work its momentum to roll the ball to the top for the highest possible score.



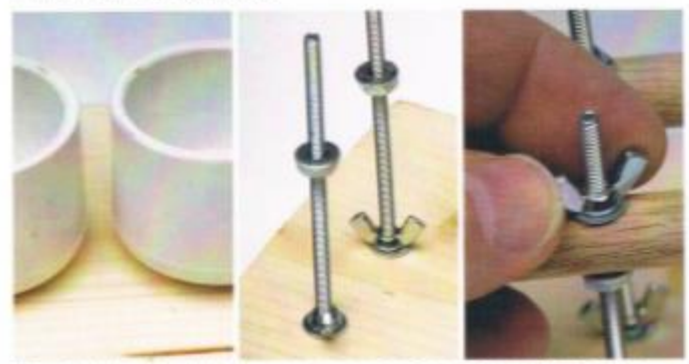
As indicated, you may purchase parts for your design project. Engineers normally buy many of the parts for their projects and perhaps need to make only a few of their own with the manufacturing tools available to them. As you design your project, you will decide which parts of your design to make and which ones to buy.

For our rollerball example, we bought the following parts:

- Long screws
- Steel rollerball
- PVC pipe end caps

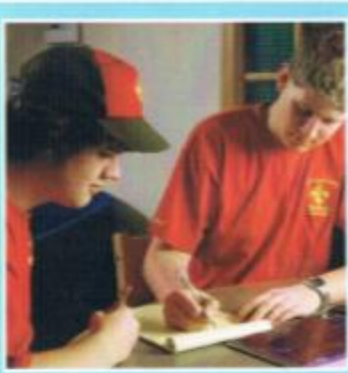
We made the following parts from purchased lengths of plywood and wooden dowels cut to the proper length, as specified on your design drawings:

- The base and sides of the game
- Two half-inch wooden dowels



When designing the rollerball game, many engineering problems will need to be considered, like how far apart to place the cups and how high to place the rods. You also might discover different building materials that work better than the ones we used in this example.

Schedule your project steps on your milestone chart and leave room to describe your actual progress as you accomplish the project steps. If you have overestimated the complexity of a particular phase of your project, you will probably find that it takes less time to accomplish than you have scheduled. As an example, you may have scheduled three weeks for making design drawings or sketches. If it takes only four days, your actual progress will show a faster accomplishment of your project than your scheduled progress. This is why you should allow flexibility in your planning. If you take more time than you had planned, adjust the dates on the time scale. If you discover additional tasks (or steps) to be done, leave room on your milestone chart to add these new steps.



Review your planning at least weekly. Do not be discouraged if your planning requires several changes. This is a feature of the systems engineering approach. Assess your progress and feed information about necessary changes back into your planning system. You will learn a great deal from this and you will do better on your next project. Remember that leadership training in Scouting consistently stresses the importance of planning.

4. Conduct Research—Get Ideas

If your problem is analytical, you can review books and professional engineering journals to find solutions to similar problems. But if you have a design problem—a project—you must also look at similar design solutions (whether you are designing circuit boards, a sprint racer, or a dune buggy). Find out what other people have done. For the rollerball project, you would visit hobby or woodworking shops to see examples of other woodworkers' projects. The goal is to get the most ideas you can, even if you don't use them all.

You can also get ideas by brainstorming. Sit alone for a few minutes and try to clear your mind of outside distractions. Then list all design ideas that come to mind for the next 15 minutes. Look for ways to combine ideas to produce new ones. It doesn't matter if these are all good ideas. You will evaluate your ideas during the next step. Brainstorming with a couple of friends is more fun and can lead to more (and more creative) ideas. Write down all the ideas that are suggested. The wildest idea may eventually lead you to the best solution.

5. Develop the Best Ideas for Alternative Solutions

Now that you have lots of ideas, it is time to take a critical look at them, comparing one against the other. Decide which ideas will work best, which are the easiest to make, and which cost the least. Use your best judgment to narrow your ideas down to three.