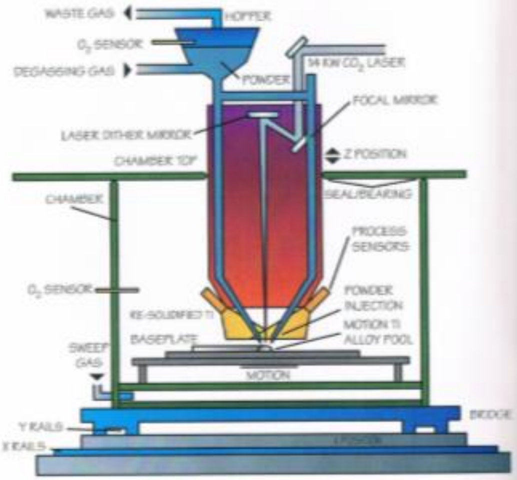
6. Analyze the Best Ideas

Conduct a comparative analysis of your three best ideas.

- Sketch each idea, approximately to scale. The sketch should show all of the parts for the design.
- Study the sketch to ensure that the design can be assembled.
- List all the parts you will need.
- Carefully compare the three designs for ability to function, ease of assembly, ease of making the parts, and cost of the parts.



A technical illustration shows how a design functions. This is an example of how power metallurgy transforms ground metal powder into strong and lightweight metal parts.

7. Select the Best Idea

Your analysis of the three alternative ideas will lead to the "best" idea. The best idea is the one that most closely matches the project requirements of No. 2. Briefly describe in writing why you selected this design as the best of the three alternatives.

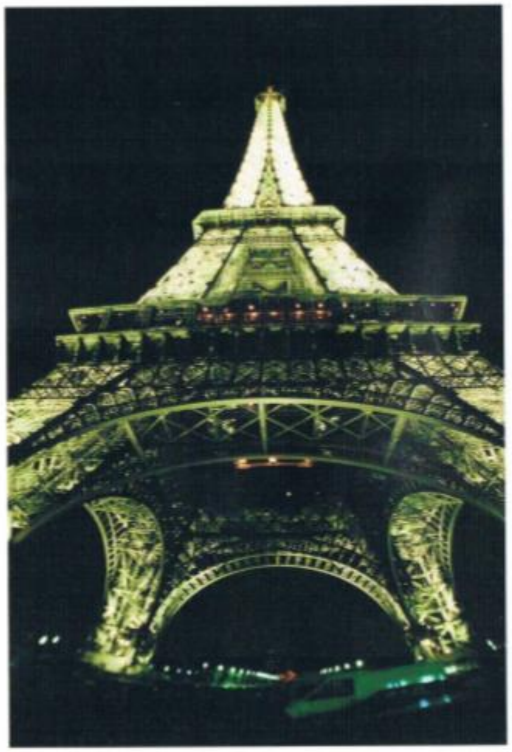
8. Perform the Construction or Solution of the Project

For a design project, make your parts using the resources you identified when you established your systems engineering operation. Sketch the parts on paper, with dimensions. Buy the necessary materials, or use materials you already have on hand. Assemble the design.

9. Check the Solution

Verify that your design (problem solution) works as described in the project statement. Whether it is a wooden skill game, a patrol box, or something else, try it out. See how you like it—this is your creation.

As you have progressed through this process, you have established your systems engineering operation, made the appropriate entries on your milestone chart, and conducted a project. Congratulations! You have played the systems engineer's role of documenting every step of the project and have made changes in planning, scheduling, and production, as required.



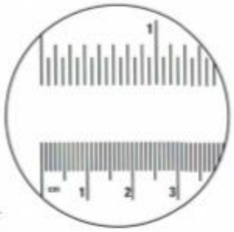
Basic Engineering Concepts

Understanding engineering takes some knowledge about the importance of measurements and a grasp of other basic concepts including velocity, acceleration, force (in action), power, and energy.

Measurements

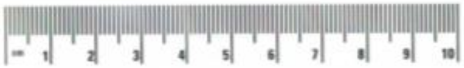
An engineer must understand four basic types of measurements or quantities: length, time, mass, and force. All physical measurements can be related to these quantities or to a computation using them (called *derived measurements*).

Two common systems that measure these basic quantities are the English system and the metric system. In both systems, human beings, rather than nature, have determined the size of the basic units, such as the foot (English system) or the meter (metric system).

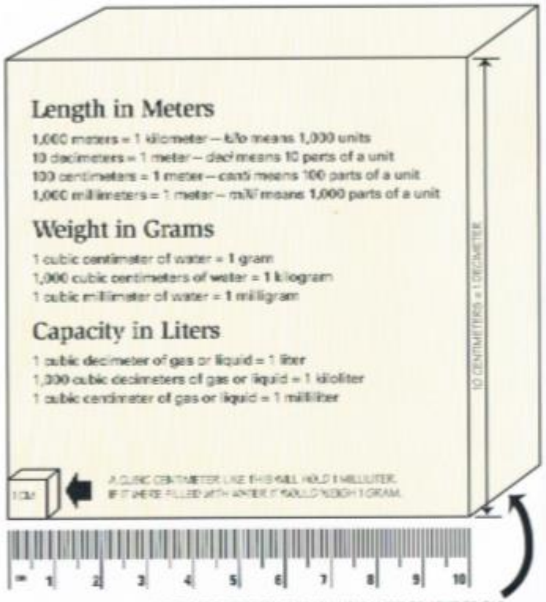


One inch on an English-system ruler equals approximately 2.5 centimeters or 25 millimeters on a metric ruler.

Metric scale



This scale is 10 centimeters long. It will take 10 of these scales to equal 1 meter. The marks between the numbers are millimeters. Ten millimeters equal 1 centimeter.



Length in Meters

1,000 meters = 1 kilometer — *kilo* means 1,000 units
10 decimeters = 1 meter — *deci* means 10 parts of a unit
100 centimeters = 1 meter — *centi* means 100 parts of a unit
1,000 millimeters = 1 meter — *milli* means 1,000 parts of a unit

Weight in Grams

1 cubic centimeter of water = **1 gram**
1,000 cubic centimeters of water = **1 kilogram**
1 cubic millimeter of water = **1 milligram**

Capacity in Liters

1 cubic decimeter of gas or liquid = 1 liter
1,000 cubic decimeters of gas or liquid = 1 kiloliter
1 cubic centimeter of gas or liquid = 1 milliliter

A CUBIC CENTIMETER LIKE THIS WILL HOLD 1 MILLILITER.
IF IT WERE FILLED WITH WATER IT WOULD WEIGH 1 GRAM.

A CUBIC DECIMETER LIKE THIS WILL HOLD 1 LITER OF LIQUID OR GAS.
IF IT WERE FILLED WITH WATER IT WOULD WEIGH 1 KILOGRAM.

Abbreviations

CM—CENTIMETER
DM—DECIMETER
G—GRAM
KG—KILOGRAM
KL—KILOLITER
KM—KILOMETER
L—LITER
M—METER
ML—MILLILITER
MM—MILLIMETER

This chart lists the units each system uses for each quantity. Research these systems of measurement on your own to learn more about them and other measurement systems. The units in boldface print are "basic" units that refer to a standard. The other units are derived from the basic units.

	SYSTEM	
Measurement	*English*	*Metric*
Length	**foot (ft)**	**meter (m)**
Time	**second (s)**	**second (s)**
Mass	Slug (lbf x s^2/ft)	**kilogram (kg)**
Force	**pound force (lbf)**	Newton (kg x m/s^2)

Basic units

In the English system, the basic units (boldface) are length, time, and force. Mass is derived from them. In the metric system, the basic units are length, time, and mass, with force being the derived unit.

In your daily life, you already use some of these quantities and the systems used to measure them.

Length is a measurement of distance. We can describe objects with three dimensions: width, height, and depth.

Time is simply a measurement of how long something takes to happen.

Mass is a measurement of the resistance of an object to a change in motion. In one sense, it is a measurement of how much "stuff" something consists of. Whether you are on Earth, floating in space, or standing on the moon, your mass is the same. While you are "weightless" in space, you still have your body and you are definitely not "massless."

Force is an action that can cause a mass to change its motion. A mass (such as a car) will not change its velocity or direction of motion (whether at rest or moving) unless a force is acting on it. Forces will be discussed in more detail later.

Accuracy, Precision, Tolerance, and Validity

No measurement is perfect, and the exact or "true" measurement of a quantity can never be known. But we do use standards to represent the "true" measurement. The terms accuracy, precision, tolerance, and validity are often confused and used interchangeably. However, in engineering, these terms have exact meanings.

Accuracy is how good the measurement is compared to the actual or true value of the quantity being measured. Some devices are very accurate and some are not. A tape measure is much more accurate than an odometer in a car for measuring distance. A caliper is more accurate than a tape measure. A tape measure may be accurate to 0.001 meter, an odometer to 100 meters, and a caliper to 0.00001 meter.

Precision indicates the consistency of measurements. If four people each measure the width of a playing field, and each measurement differs by several inches, the measurements are more precise than if they had differed by several feet.

Tolerance is a range of acceptable sizes. If a fence post is to be made between 149 centimeters and 152 centimeters long, then the tolerance on its length is 3 centimeters. Engineers use tolerance to determine if parts will fit together after they are made. When you buy a replacement part for a bike, it will fit if it was made using the right tolerance.

Validity means that the measurement gives us the information we need to know. Invalid measurements can result from using the wrong measuring tool, measuring the wrong thing, or using the right tool incorrectly. What else could make a measurement invalid?

A measurement may be accurate and precise, but out of tolerance. Or, it may not tell us what we need to know and, therefore, might not be a valid measurement.

Other Basic Concepts

To do engineering, you need to know about a few more basic concepts.

Velocity. Velocity is an object's speed in a particular direction. When you ride a bike in a straight line, we can measure your velocity. If you speed up, slow down, or change direction, you change velocity.

Acceleration. Acceleration is the rate of change in velocity. Technically, it refers to both speeding up and slowing down. To experience acceleration, try this. Sit in a car and close your eyes while someone drives. As the car begins to move faster (accelerates), feel your body pushing against the seat. When the car brakes (decelerates, a type of acceleration), feel your body trying to move forward out of the seat. When the car turns a corner, feel your body sliding toward the outside of the turn.

Acceleration, Force, and Mass

Recall that **force** can cause a **mass** to change its motion and that **acceleration** is a change in motion. Now, we can relate all three concepts.

Ride a bike on a smooth, level area such as a sidewalk. As you pedal, your rear tire pushes against the ground with some force. When you start out, you are changing the velocity of (accelerating) yourself and the bike (the mass) from zero to some speed. You can now coast without any additional force. But, you will eventually decelerate due to the friction forces in the bicycle mechanisms, in the wheels against the pavement, and in your body moving through the atmosphere (especially if you are cycling into a headwind).

Weight. Weight is the gravitational force exerted on an object. It differs from mass in that weight changes if gravity changes, while mass remains the same. For example, a bowling ball that weighs 12 pounds on Earth will weigh only 2 pounds on the surface of the moon, where the gravity is one-sixth as strong as Earth's gravity. And yet, the mass of the ball remains the same in both places.

Moment (or Torque). A moment is a force operating at a distance from a pivot point. When you open a door, you are exerting a moment about the door hinge, causing the door to rotate about that point.

Work. Work is done by a force acting on a body, so that the body moves in the direction of the force.

Power. Power is the time rate at which work is done. Pushing your bike slowly takes less power than pushing it fast. This is important, because much of engineering is about moving things or keeping things from moving (like keeping the roof from collapsing).

Newton's Three Laws

Scientist Isaac Newton (1643–1727) discovered three laws related to motion that will help you understand the concept of force.

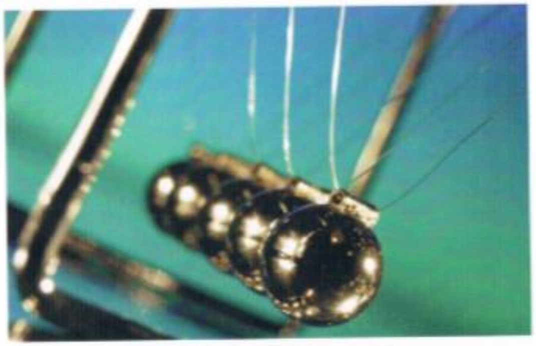
1. An object (or "body") in a state of rest or uniform motion will continue in its state forever unless a force acts on it to change that state. In other words, nothing is going to move or stop moving unless forced to do so.

2. If a force acts on a body, the body will accelerate in the direction of the force. The acceleration will be proportional to the magnitude of the force. That is, if the force is doubled, so is the acceleration.

3. To every force, there is an equal and opposite reaction. When you hit a baseball with a bat, both the ball and the bat experience the same force, but in opposite directions.

Energy

Energy is the ability to do work. It is classified in a number of ways. Let's look at common forms of energy and then consider how one form gets transferred into another.

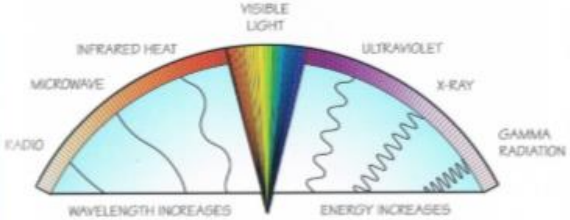


Kinetic Energy. Kinetic energy is the energy something has because it is moving. Drop a ball and see how high it bounces. Now throw it on the floor. The ball has enough energy to bounce higher the second time. Why? A moving object has more kinetic energy if it has more mass or is going faster. When you threw the ball, it was going faster than when you simply dropped it, so it had more kinetic energy.

Potential Energy. Potential energy is the energy something has while at rest after some energy has been put into it. Lift a book up to rest it on a chair. Push it off the chair. It will not reach a high speed before it hits the floor. Now, lift the book higher to rest it on a table; you have increased the book's stored energy. Push the book off the table. It will be going much faster when it hits the floor than when you pushed it off the chair. The book had more potential energy relative to the floor when it was on the table than when it was on the chair. The source of the potential energy is Earth's gravitational field.

Electrical Energy. Electrons flowing through a wire can transfer energy from one place to another. In homes, offices, and factories, it is converted into light (in lightbulbs), heat (in toasters, stoves, etc.), and mechanical energy (in motors, power tools, etc.). Electron flow is easiest to see in a lightbulb. As electrons flow through the filament of the bulb, the wire heats up and gives off light.

Electromagnetic Energy. Electromagnetic fields can best be demonstrated with a magnet. Hold a magnet close to a steel surface. You can feel the force of the attraction even though nothing is moving.

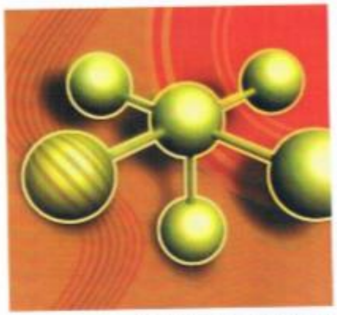


Electromagnetic radiation includes what we "see" as light. It is pure energy that moves in waves at a range of frequencies (the number of waves per second). If the frequency is fast enough, our eyes become sensitive to it, and we call it light. If it is slower, we can still feel it as heat. If it is even slower, we call it *radio waves* and use it to transmit music to your radio. If the frequency is faster than what we see as light, it moves into the categories of ultraviolet, X-rays, gamma rays, and cosmic rays, which are measured along a continuous spectrum. The energy is related to the frequency.

Chemical Energy. Matter is made of atoms and molecules (combinations of atoms). The atoms bind together in various ways to form solids, liquids, and gases. That binding is a form of stored energy. When these bonds are broken, energy may be released or absorbed, depending on the material.

Chemical energy includes the energy stored in batteries.

There are all kinds of examples of chemical energy around us every day. When gasoline is joined with the oxygen in the air, chemical energy is released in our automobile engine to make it run. The chemical energy of wood burning in a fireplace releases heat and keeps us warm. The chemical energy in dynamite is released to clear construction sites for new buildings and roads.



Nuclear Energy. Individual atoms are made up of electrons surrounding a nucleus of protons and neutrons. The type of atom is determined by the makeup of the nucleus, which has a binding energy keeping it together. Splitting a "heavy" atom (fission) releases enormous amounts of energy—the energy source for nuclear power plants and nuclear bombs. Combining two "light" atoms (fusion) can produce even more energy. To this day, no one has been able to make a working power plant based on fusion.

Thermal Energy. Thermal energy is best demonstrated by an example. Put water in three bowls—hot water in the first bowl (not too hot for your hand), warm water in the second bowl, and cold water in the third. Put one hand in the hot water and your other hand in the cold water. After a few minutes, put both hands in the warm water. Does the "cold" hand feel warm and the "hot" hand feel cool?

The flow of thermal energy from one place to another is called *heat*. In this case, heat is being transferred between your hands and the water. Heat will flow from the hot hand to the water, and from the water to the cold hand. Both hands and the water will eventually reach the same temperature (thermal equilibrium—the temperature is balanced).

Remember the lightbulb? The flow of electrical energy causes the wire to heat up (thermal). The thermal energy is then converted to electromagnetic radiation (light).

Energy Conversion

Engineers make use of energy by converting it—from stored to transitional, from one transitional state to another, or from one classification to another.

Some air conditioners make use of latent heat. Warm air is forced through a stream of water or through wet filter pads, causing some of the water to evaporate (changing the state of the water, or latent heat transfer). The evaporation process takes energy from the air, cooling the air. This type of air conditioner is called an evaporative cooler.

Other increasingly popular methods of energy conversion use solar energy. The heat of the sun can be used to heat a fluid, and that heated fluid can be used to drive a turbine. Solar energy can also be used to create electricity directly, in solar cells.

Let's Do Engineering

In this chapter you will find ideas for ways to fulfill requirement 6, whether you are interested in transforming motion, using electricity, using materials, converting energy, or moving people. There is also information about competing in a science or engineering fair.

Transforming Motion

Engineers, particularly mechanical engineers, are often interested in things that move to make life or work easier. That includes all forms of transportation (bicycles, cars, trains, planes, etc.), machinery, tools, satellites, computers, and many other things.

There are two forms of movement: straight-line and curved. Making one thing move by moving something else is called *transforming motion*. The curved motion of bicycle wheels going around (rotating) transforms the motion of the bicycle to straight-line (linear) motion. Engine pistons moving back and forth in a straight-line motion make a crankshaft go around in a curved motion.

Two basic ways to transform motion are the inclined plane and the lever. You may not know it, but these are simple devices you use every day. Even machines that look highly complex mostly use variations on these two simple ideas.

A screw is an example of an inclined plane wrapped around a shaft. Some automobile jacks use a type of screw to lift a car. Can you think of other examples of inclined planes?

Inclined Plane

An inclined plane is simply a sloping surface. Try to lift a heavy object onto a platform or table. Next, place a board sloping from the table to the floor and slide the object up the board. Which was easier? Why?

Lever

A lever is something such as a metal bar or plank of wood pivoted about a *fulcrum* (a prop or support). A seesaw is a good example of a lever in action. Have you ever tried to balance a seesaw with you on one side and someone else on the other? The *moment* (see "Basic Engineering Concepts") of each person on the seesaw is the person's weight times the person's distance from the fulcrum. For the seesaw to balance, the movements must be equal and act in opposite directions—the lighter person must move farther from the fulcrum.

The lighter person can "lift" the heavier person with just his own weight by moving farther from the fulcrum. Also notice that the weight of both people is down, resulting in movements in opposite directions. Try using a lever to lift or move an object that you normally could not lift or move.

Your arms and legs also act as levers. Your upper arm rotates about your shoulder and your lower arm rotates about your elbow with muscles doing the work. Hold an object in your hand with just your elbow resting on a table. Then extend your arm. Notice how much harder it is to hold the object with your arm extended. What other levers does your body have? What other examples of levers can you find?

Linkages

Linkages use two or more rods or bars to transmit motion. Try doing a push-up. There are four links in this motion—your body, upper arms, lower arms, and the floor. The rotational motion at your toes, shoulders, and elbows allows for the body motion.

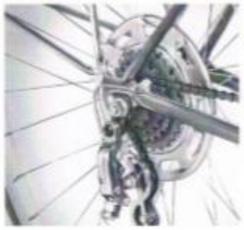
Examine the interaction between you and a bicycle while riding it. Your upper and lower leg pushing on the pedal are two links. The pedal and the gears are another link. Your body and the bike frame are a fourth link. The principle of linkage creates linear motion from a series of rotating motions.

Examine a few common devices that use linkages—an umbrella, folding table legs, a bicycle gear shift. How many links are there? How do the linkages provide the appropriate motion? How is the motion restricted?

Pulleys

Pulleys also use the leverage principle. In this case, the lever is a circular disk and the forces are applied using a rope or cable. Pulleys may include one or more disks of varying diameters to produce the desired effect. Look for examples in and around your home, such as a curtain draw, an automobile fan belt, or a sewing machine.

Gears



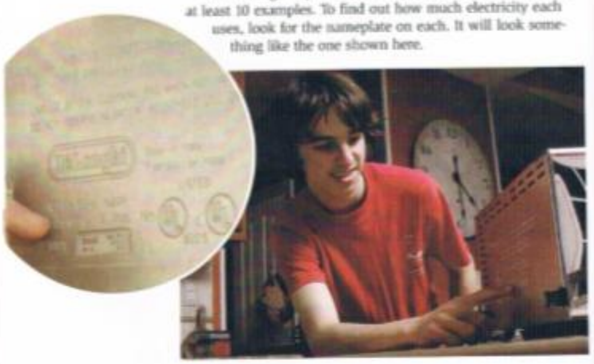
Think of gears as pulleys with teeth. Gears may be circular, cylindrical, flat, or other shapes. All gears have teeth that can mesh with other gears, and frequently with a chain. You can view gears as a series of interacting levers. Take a close look at a bicycle. It will include two or more gears connected by a chain that grabs the teeth to transmit the force from one gear to the other. Where else can you find gears? How do they interact?

If you choose to do requirement 6a, discuss with your counselor a mechanical problem you can solve using the principles of transforming motion. Here is an example problem: Using materials you find around home or at a local store, build a device that will transport a 10 kilogram (minimum) object up a slope at least 2 meters long and 1 meter high, and then stop. It should not use any human power during the operation. Describe to your counselor how you decided on your solution, how it might be improved, and at least one other way it might be done.

Using Electricity

If you choose to do requirement 6b, you can get a taste of what electrical engineering is like by learning how electricity is used in your home. You will find out how much electricity your family uses and how much it costs. This might also lead you to consider how you might conserve electricity, to save money and to help the world.

What things in your home are powered by electricity? List at least 10 examples. To find out how much electricity each uses, look for the nameplate on each. It will look something like the one shown here.



Volts refers to the required operating voltage. *Cycles* is usually 60 hertz for North America. *Phase* is usually 1, for "single phase," but may be 3 for three-phase power appliances. *Amps* is the operating current. *Watts* is the power consumption. (Watts = voltage x amperes.) (For more about these terms, see the *Electricity* merit badge pamphlet.)

Some appliances, such as refrigerators, air conditioners, water heaters, or furnaces, may also have a label that tells you how much electricity the appliance typically will use in a year. It will usually be in *kilowatt-hours* (kwh). If the appliance in the example used in the chart were always on for an entire year, it would use 100 watts x 24 hours a day x 365 days a year ÷ 1,000 watts = 876 kwh/year.

For this study, the figure you are interested in is watts, the measure of power consumption. Every day for a month, keep a record of how long a particular appliance is used. Some of your figures will have to be estimates to the nearest half-hour or 15 minutes. Make your estimates as accurate as you can.

At the end of the month, you can make a record in a chart like the one shown here. Perhaps you will find, in keeping your record, that some of the appliances seem to use a lot of power. Ask yourself why. Watch the appliance in use.

Appliance	**Watts rating**	**Hours used per month**	**Kilowatt-hours** (Watts rating × hours ÷ by 1,000)	**Cost**
Toaster				$
Iron				
Refrigerator				
Humidifier				
Dehumidifier				
Furnace				
Air conditioner(s)				
Clothes dryer				
Washing machine				
Dishwasher				
Television(s)				
Lights				
Living room				
Bathroom(s)				
Total				$

Cost per month equals the total kilowatt-hours times the cost per kilowatt-hour. Ask your parent to let you look at your home's latest electric bill to find the cost per kilowatt-hour. Or, you can find this out by calling your local electric utility company.

What ways can your family conserve electricity? Some methods might just call for breaking poor habits; others take a more active approach (with your parent's permission, of course).

- Turn off the lights when no one is in the room.
- Turn off the TV when no one is watching it.
- Before you run the dishwasher, make sure it is full.
- Don't linger in front of the refrigerator door when you are looking for a snack.
- Use ceiling fans to help circulate the air. (Remember to reverse the direction of the fan blades in wintertime.)
- Use a 7-watt nightlight in the bathroom at night instead of a 60-watt regular bulb.
- Use compact fluorescent bulbs in lamps instead of regular incandescent bulbs.

Think of more ways your family could conserve electricity. Talk them over with your merit badge counselor. If you are interested in other electrical engineering problems, consider earning the Electricity, Electronics, Energy, and Computers merit badges.

Contact your local power company and ask how much electricity you could save if you raised the temperature of your air conditioner by 1 degree in the summer, or if you lowered the thermostat for your home-heating system by 1 degree during the winter. Find out how much electricity is saved, on average, when homeowners switch to a programmable thermostat, which automatically adjusts the temperature setting for different times of the day, such as when family members are not home or are sleeping at night. Afterward, share this information with your parent. Discuss how these small changes can result in big savings—both energy and money—for your family.

Using Materials

Engineers design and build things out of many different materials. Different materials behave differently when put under a load. There are several important concepts: stress, strain, stiffness, and strength. If you choose requirement 6d, you will do experiments that demonstrate these ideas.

Stress is the load placed on the material by area. If the load is spread over a large area, the stress is small. If concentrated on a small area, it is high. Push the blunt end of a pen or pencil against your skin. Now push with the same force using the pointed end. The cross section of the blunt end is much greater than the pointed end. You can definitely feel the higher stress with the point.

Strain is how much the material changes when under stress. Stretch a rubber band. As you pull it, you are putting a load on the material and stressing it. That results in a strain, or change in length. All materials change dimension under load, even the hardest steel. However, special instruments are needed to measure the strain.

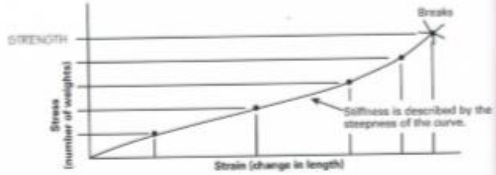
Stiffness combines stress and strain to describe how a material changes over a range of loads. It tells us how rigid or flexible something is. A steel bar is rigid. Licorice is flexible. Does the material behave the same way in all directions? How about a steel wire? It is rigid when you pull it, but flexible when you bend it. Why?

Strength is the stress at which the material breaks (ultimate strength). Engineers also consider the stress at which a material deforms and stays deformed (yield strength). When you blow up a balloon a little, it will come back to its original shape. If you blow it up all the way and let the air out, it will "yield" and not come back to quite the same shape when you let the air out. Keep blowing and it will reach its ultimate strength—but watch out! The material strength is often confused with structural strength. The strength of a structure is the load at which it will break, not the stress. We will look at that later.

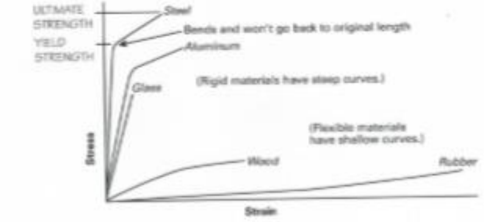
Describe different parts of your body in terms of strength and stiffness. Also, look at various plants and trees. How do they use stiffness and strength to function?

In the book *The New Science of Strong Materials,* author J. E. Gordon puts it this way: "A biscuit is stiff but weak, steel is stiff and strong, nylon is flexible and strong, raspberry jelly is flexible and weak."

Let's take some measurements to tie the concepts together. Hang a rubber band from a hook or paper clip. Hang a paper cup from the rubber band using another paper clip and string. Measure the length of the rubber band. Add weights to the cup in even amounts (for example, marbles, fishing weights, or pennies). As you add each weight, measure the new length of the rubber band. Take at least four measurements and plot them on a graph. That will be the stress/strain curve. What factors, such as the thickness of the rubber band, might skew your results?



The stiffness determines how steep the curve is. For a rubber band, the slope of the curve will change. If you were to use steel or aluminum in the same experiment, the curve would be very steep and straight until it reached the yield strength. The slope of the curve describes the stiffness of the material. If the curve is shallow, the material is flexible (rubber band). If the slope is steep, it is stiff. For brittle materials such as glass, the stiffness is the same for the entire curve. For materials such as steel and aluminum, the curve is straight until the material permanently bends.

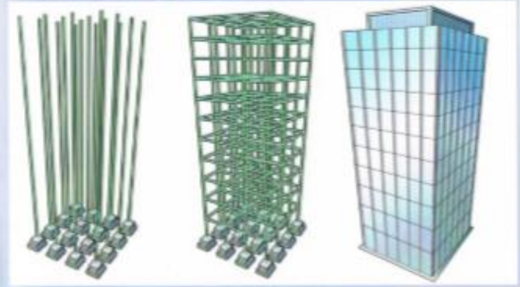


Try bending pieces of different materials such as steel, aluminum, wood, and plastic with your hand. How do you think their stress/strain curves would look?

Now let's take a look at structural strength (as opposed to material strength). Take a sheet of paper and try to stand it on its edge without bending it. The sheet won't support its own weight, let alone something else. Paper is not very strong or stiff. Now roll the paper so it forms a tube and tape it together. Stand the tube on its end and see how much weight (for example, how many DVDs) it will support. Engineers combine the material properties with structural shapes to make very efficient structures. What types of shapes do you see in skyscrapers and machines? How about in nature?

Reaching for the Skies

The first steel-framed building called a skyscraper was designed by William Le Baron Jenney (1832–1907). Built in Chicago in the late 1800s, the Home Insurance Building was initially nine stories high. By 1910, New York had its first 50-story building, and by the 1930s, the Empire State Building claimed an unprecedented 102 stories. What makes skyscrapers so amazing is how engineers must design their structures to withstand the elements, like gravity and wind.



Examine some items you have around your home such as fingernail clippers, vise grips, clocks, tape measures, and so on. Think about how the different materials are used and why.

Heat and Materials. How materials behave with temperature is extremely important. Different materials conduct heat differently. Changes in the temperature of a material can also change its dimensions.

Temperature can affect a material's stiffness. Put a rubber band in the freezer for 30 minutes. Does it behave the same as it did at room temperature?

Experiment: Heat Transfer

Bring a pot of water to a boil. Drop a metal tablespoon, a piece of wood, and a piece of plastic into the boiling water. After a minute, use tongs to remove the pieces from the water, one by one. Touch each one lightly with your fingers, taking care not to burn yourself.

What are your conclusions about the heat conductivity of metal, wood, and plastic? If you wanted to insulate something, which material would be best? If you wanted to transfer heat quickly, which material would you choose? Discuss your conclusions with your counselor.

Materials can also change dimension with temperature. Most will contract (shrink) when cold and expand when hot. Some do just the opposite, and some change very little.

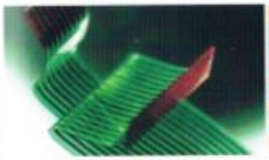
In space, the temperatures on parts of a satellite can change 100 degrees or more over a short time as the satellite moves in and out of the sunlight.

Experiment: Changing Dimension

Glue a strip of aluminum foil to a piece of paper the same size (a glue stick will work fine). Make sure the combined strip is flat; put it in a freezer for 15 minutes. What happens to the strip? Now carefully take it out and let it reach room temperature. What happens to the strip? What is happening to the aluminum and paper combination to cause the strip to change shape?

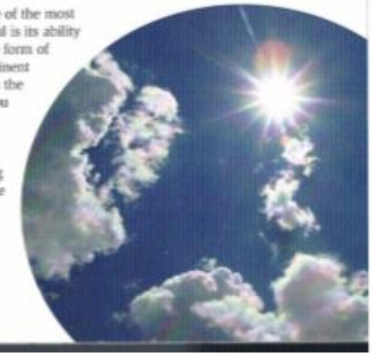
Sometimes you can hear a house creak at night when there is a big change in temperature. Also, doors in your house may close easier in one season than in another. The materials are expanding and/or contracting because of temperature. Engineers have to be very careful when connecting different materials.

Electrical Properties. Just as materials respond differently to heat and cold, so do they respond differently to electricity. Materials that carry electricity are called *conductors*. Materials that resist carrying electricity are called *insulators*. Copper, used extensively in electrical circuits and wiring, is a good conductor. Rubber, used to encase the copper in electrical wiring, is a good insulator. Can you think of another example of an insulator and where it is used? What about a conductor and its use?



Optical Properties. Why do we use glass instead of plywood for windowpanes in a house or for windows in an automobile? The question is not as silly as it seems. The answer lies in the *optical properties* of the material. Why do doctors and nurses use lead-lined aprons when they take an X-ray, rather than standing behind a plywood door? Because the optical properties of a material must be matched with the type of radiation it will encounter. Visible light, such as passes through a windowpane, is only one type of radiation. X-rays are a completely different type. You can't see them, but they are there.

Radiation and Absorption. One of the most fascinating properties of a material is its ability to *radiate* or *absorb* energy in the form of waves. The sun is the most prominent radiator of energy. If you stand in the sun, it feels a lot hotter than if you stand in the shade because your body absorbs the heat from the sun's radiation. Wearing white clothing feels cooler than wearing black clothing in the sun, because the black material absorbs more of the sun's heat-energy waves than the white material does.



Similarly, using different types of waves, we turn on a TV set with a remote control. The remote control radiates invisible light waves that are picked up, or absorbed, by a device in the TV set. If you point the remote control at yourself, you don't feel anything. If you look at it, you don't see anything coming out when you push the button. Try using your remote control on your neighbor's or friend's TV. It may not work. That is because your TV and someone else's use slightly different waves.

Chemical Properties. When engineers study how a material interacts with other materials and external stimuli (stimulants), they are studying the material's chemical properties. Fire-resistant construction requires materials that do not burn easily. The liquids and solids in batteries are chosen because of their *chemical properties*. What kinds of chemical properties would you want in your materials if you were designing a match to light a fire?

Another important chemical property is *resistance to corrosion*. Materials can react with oxygen, water, salt, or just about any substance. What is important is the rate of reaction and how long the material must survive. A bridge over salt water may be expected to last 100 years, but a resealable plastic bag might be expected to last for only a year. How long would you expect the steel body of an automobile to last in Miami, Chicago, or Phoenix? Why might you expect any differences? (Hint: Consider temperature, humidity, salt air, and the road salt used to melt snow.)

Think of some liquids that you encounter in your daily activities and identify the ones with high or low viscosity.

Properties of Liquids. Liquids are sensitive to temperature and have a freezing point and a boiling point. Water turns to ice (a solid) when the temperature goes below 32 degrees Fahrenheit and becomes steam (a gas) when the temperature goes above 212 degrees Fahrenheit. Liquids can also evaporate (turn to gas), just by sitting long enough. Another important property of liquids is their resistance to motion, which is called *viscosity*. You can swim in water, but why would it be difficult to swim in a pool of honey? Because honey has a high viscosity.

Classifications of Materials

We have discussed the characteristics of materials that an engineer must consider. Now let's look at other considerations, including the type of material and the manufacturing method.

Materials are classified into metals, composites, ceramics, polymers, electronic materials, and other groups. For each class of materials, the method of manufacturing is important. Questions about how a material can be made into a given shape must be addressed. Engineers also must know how to model a material all the way from raw material to finished product. To do this, the engineer develops equations and computer programs to describe the material and its characteristics.

Imagine that you are an engineer with a company that makes all sorts of different products. The chief engineer has given you and the other engineers the task of developing new and superior versions of those products. Specifically, you want to improve the following.

- **Fishing rods:** In the past, they have been made from materials including bamboo, steel, and composites. What material might make a better rod?
- **Bicycles:** What might you look for in a material to build a better bike?
- **Shoes and sneakers:** What properties of a material would allow you to make a better sole and heel on a shoe?
- **Automobile bodies:** We are very cost-conscious in our imaginary corporation, because we still use gasoline in the engines. What properties of a material are important for building a better car body?

Structures

Structures are the most common "engineered" devices around. They include all buildings, chairs, tables, signposts, bridges, dams, frameworks for automobiles, airplanes, satellites, etc.

A structure's capability depends upon the materials used, the shape of the materials, their position (or *orientation*), and how they are interconnected.

The primary responsibility of a structure is to transmit loads. When the wind blows, the rain falls, the earth quakes, or someone is on the roof, you don't want your home to collapse.

Review the example demonstrating paper's structural strength from page 71. Using materials such as straws, toothpicks, string, glue, etc., build a bridge across a 1-meter span. Add weights (pennies, paper clips) to the middle and observe the deflections (in this case, the curvature) the weights cause. How could you strengthen the bridge? How might you make it simpler or lighter and keep the same strength? How is the load of the added weight transmitted by the different parts to the ends? Which are in tension? Which are in compression?

An engineer must consider a structure's strength, stiffness, weight, and cost. These elements often conflict with one another. Reducing the weight and/or cost may affect the strength and stiffness. Sometimes the structure needs to be able to *flex* (be less stiff), but still be strong and light. Consider a bicycle wheel. The wheel needs to be strong enough to support your weight and handle the bumps it encounters. However, it also needs to "give" to provide a comfortable ride and it needs to be lightweight for ease of handling.

All materials, such as paper, have some amount of strength that will allow them to carry a load before failing. All shapes have properties that allow them to carry loads. The ways in which structural elements fit together also have properties to carry loads. The engineer's task is to find an appropriate combination of material, shape, and interconnection for a particular task.

Shapes

One common solution for increasing strength and stiffness, while reducing weight and cost, is designing with the simple triangle. Take four boards of equal length and join them. Use one nail at each corner to form a square, but keep the joints a little loose. How stable is it? Does it want to collapse? Can you twist it?

Now take out one of the boards and join the three remaining boards. Is this structure stable? Does it collapse or twist as easily? The square is not stable because there are an infinite number of positions (solutions) a four-sided square can assume between a square and the collapsed position. However, there is only one solution to any given three-sided shape (triangle).

Go back to the four-sided square and add a fifth board from one of the corners to the opposite corner. Does this improve the stability? Does it twist as easily? Why? Look at a bicycle again. How is it framed to make it strong and stiff, but lightweight? Can you find examples of triangles used in other structures?

Take a look at natural things such as trees, plants, animals, and hills. How are they structured? What loads must they carry? How do these structures "behave"?

Another thing to consider is the cross section of a structural member. The most common shapes for structural members include circles, squares, rectangles, L's, and I's. The I beam is often used because it is stiff in the direction that is needed but is relatively lightweight and inexpensive—it makes efficient use of materials. Take a look at a board with a rectangular cross section, such as a two-by-four. Does it bend as easily in both directions? Look at the boards used to support the roof of a house. How are the boards oriented? What would happen if the boards were turned 90 degrees?

Out on a Limb

If having a hideout of your own sounds appealing, a treehouse can fit that bill perfectly. Before you get started, you should know that building a treehouse takes a lot more than a hammer and a few nails. Yep, constructing a structurally sound treehouse is tricky business.

Not All Trees Are Created Equal. You will need to find out whether the tree you have in mind can endure the stress and alterations that may be in store. A certified arborist, or tree expert, can examine the tree's health and condition from the roots to the tip-tops. The inspection will reveal whether the tree can support the weight of the house you want to build.

It's All About the Tree. The tree's structure will help determine the height and size of the treehouse. Find a spot that is not so high that your structure will twist along with the tree's movement in the wind—10 feet up usually is about right. The arborist may be able to provide some direction here and can also tell you how to care for the tree once the structure is in place.

For added convenience, check out ready-made plans that give step-by-step instructions to build a structurally sound treehouse. Be sure you have your parent's permission before you attempt to plan a treehouse.

Planning Your Retreat. This is where the systems engineering approach to problem solving comes into play. Start by making a list of your available tools and materials and those that need to be obtained. Keep in mind that a project of this scope takes a lot of resources—including money.

Look for ideas to incorporate in your treehouse. When you are ready to sketch your dream house, make sure to adapt the design to the structure of the tree. Once your sketch is refined to a workable plan, start gathering the materials you will need to build and go for it!

You can see that building a fort in the sky is not something that can be done on impulse. Making a treehouse takes careful planning from start to finish. Yet a project like this presents an excellent opportunity for you to explore how engineering touches our lives day-to-day.

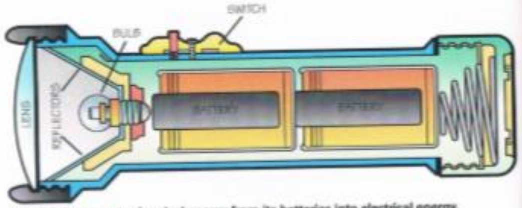
For more details about designing and building a treehouse retreat, get your parent's permission to visit The Treehouse Guide on the Internet at *http://www.thetreehouseguide.com*. This site is just one of many helpful online resources.

Converting Energy

Many of the machines that make our lives comfortable depend on the conversion of energy from one form to another. How does a car move? Oil (chemical energy) is pumped (mechanical energy) from the ground. It is then processed (by heat, chemical, mechanical, and electrical energy) into gasoline (chemical energy). The car then converts the gasoline to mechanical and heat energy by using mechanical, heat, and electric energy.

Examples of such energy conversions are all around. Your body is an excellent example. You eat food (stored chemical energy) and convert it to heat, plus other forms of chemical energy stored in your muscles. Your muscles convert chemical energy to mechanical energy to move your legs to ride a bike. Your body also converts chemical energy to electrical energy in the neurons and synapses of your brain when you are thinking about how to ride the bike. When you sweat while riding, thermal energy is releasing heat, allowing your body to cool.

A common example of energy conversion that you could research is how a car or flashlight battery converts chemical energy into electrical energy. Check at your school or public library for books on electricity. Look in the indexes under "battery." (If you use the Internet, be sure you have your parent's permission first.) Study the explanations and be prepared to tell your merit badge counselor what happens when a car battery is used or a flashlight is turned on.

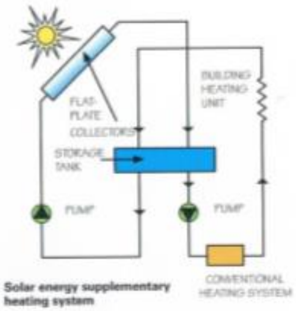


A flashlight converts chemical energy from its batteries into electrical energy.

Solar Energy

Solar energy is virtually unlimited, and the sun's rays fall everywhere on the face of the Earth. But solar energy has one serious disadvantage: You can't turn it on or off. At night and on cloudy days, there is little solar energy to catch. This means that for heating a house, you need another source of energy part of the time.

Some homes have simple solar energy systems for heating. The sun's heat is collected by flat-plate collectors and heats the circulating water. The hot water goes to a storage tank and then passes through the house's heating system. As the water cools, it is pumped back to the collectors where the sun reheats it.



Solar energy supplementary heating system

Experiment: Solar Energy

Try this experiment on a sunny day.

Step 1—Fill a cake pan or pie tin with water.

Step 2—Measure the water's temperature.

Step 3—Place the pan in the sun.

Step 4—Measure the water temperature every two hours for six hours.

Step 5—Measure the water temperature at sundown and again at sunup the next morning.

Step 6—Repeat step 4 on a cloudy day.

What do your findings tell you about the value and potential of solar energy? Why does a house heated by solar energy need another energy source for continuous heating?

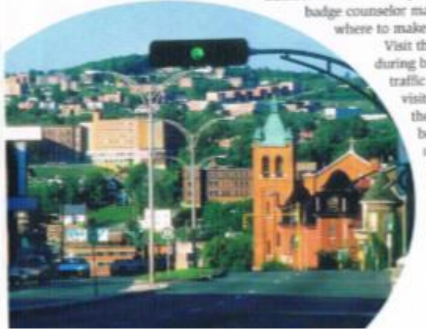
Moving People

Americans are always on the go. Most people have to travel to work or to school, to shop, and to their place of worship. Because we travel so much, and most of what we buy must travel from manufacturers to stores, we depend heavily on transportation systems. These systems include roadways, railways, bus lines, trucking companies, airlines, pipelines, and waterways.

Engineers are called upon to plan, design, and manage these systems. Engineers who work for your city or region probably have studied the existing transportation systems. Their aim is to find ways to improve or expand the systems to make travel easier, faster, safer, and cheaper. You can find out about their plans in the office of your city, town, or village engineer. Your merit badge counselor will also help you.

Making a Traffic Study

If you decide to do requirement 6f, you can find some of the data you will need from the city, town, or village engineer. The engineer can tell you about predictions for population and number of cars in five years or more. Your merit badge counselor may be able to suggest where to make your traffic study.



Visit the location at least once during both its heavy and light traffic periods. Two or three visits on different days of the week would be even better. You will get a more accurate count of the average number of cars, trucks, and other vehicles using that roadway.

If you find that population and number of vehicles are expected to increase over the next five years, be prepared to suggest ways to handle the heavier traffic. Talk with your counselor. Your solution will depend on the particular location. You might recommend widening or straightening the road. Or, the answer might be to build a thoroughfare or tunnel, install a traffic light or turn lane, make the street one-way, or implement some other idea for improving the traffic flow. Some communities have installed roundabouts, which are common in Europe. Research the pros and cons of roundabouts.

Share your data and your proposed solutions with your counselor.

Creating a Science Fair Project

Science fairs and engineering-team competitions are sponsored by a variety of organizations. Many schools, colleges, universities, and professional engineering societies sponsor engineering fairs and competitions every year.

How to Pick a Project or Competition

There are many ways to pick a project or competition and also meet requirement 6g. Remember that the project or competition that you choose should be related to examining an engineering question, rather than gathering pure scientific research. For ideas, just look at the world around you or at recent news events. Consider how scientific principles may have influenced them. Look at your personal interests (sports, bicycling, or skateboarding, for example). How might they be improved upon or studied?

For another example: How can the effects of low rainfall be minimized? Think of ways to prevent or reduce the effects of a drought. What water conservation efforts work in your community, and how can they be improved? Asking some of these questions, and performing experiments to find possible answers, can form the basis of a good science fair project.

As you consider the different types of subjects and projects that interest you, begin to research and assemble information in your area of interest. Your research tools should include the World Wide Web, libraries, and related industries.

Ask your science teacher and merit badge counselor for guidance. Planning, developing, organizing, and building your entry into a project that will meet the particular requirements of a fair or competition can be complicated. Some competitions may require both a scientific investigation and a demonstration concerning the subject you have chosen (such as designing the most structurally sound miniature-bridge design using specified materials, and then building the miniature bridge).

Remember that another way to meet the requirement is to become a member of an engineering-project team. Project teams enter local competitions, and often the winners can go to national competitions.

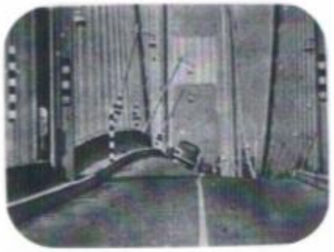
The Joy of Engineering

For any given engineering problem, there are many solutions. It would be great if we could always find the "best" solution. Engineers, however, must work within limitations imposed on them by available materials, supplies, money, and tools. They must be sensitive to environmental concerns, politics, and the culture of their company and the community. There is tremendous satisfaction in solving a problem when faced with such challenging constraints.

Learning From Our Mistakes

It has been said that engineering advances one failure at a time. With every failure comes the chance to learn how to improve design and technique. The engineer seeks the proper balance of quality of construction and acceptable cost, while not compromising function or safety. A constant danger is becoming overconfident, believing that failure can't happen. Here are some examples of famous engineering mistakes that also led to engineering improvements.

The *Titanic*. The RMS Titanic was the largest passenger ship in the world when it sank on its maiden voyage from England to the United States in 1912. Shipbuilders had dubbed the ship "unsinkable." The ship was built with 16 compartments and could stay afloat even if up to four of them were flooded. A fatal design flaw, however, was that the compartments were not sealed at the top. When the ship brushed a giant iceberg, water rushed into forward compartments, spilling over the top of the bulkheads into adjacent compartments, sinking the ship and costing 1,523 people their lives.

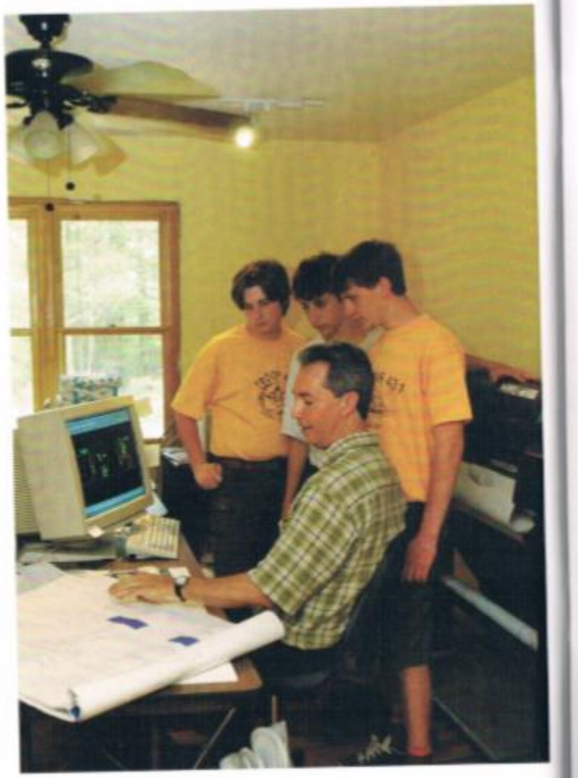


Tacoma Narrows Bridge collapse

Tacoma Narrows Bridge. This two-lane, mile-long bridge over Washington state's Puget Sound collapsed four months after it opened in 1940. The cause? A 42 mph wind that caused the bridge deck to buckle and twist and finally break apart and fall into the water. During design of the bridge, to reduce costs, engineers had decided to stiffen the roadway with 8-foot girders instead of the original plan to use 25-foot supports. The bridge's collapse, which caused no loss of life, has been used as a lesson in civil and structural engineering classes ever since.

Space Shuttle Challenger. The space shuttle Challenger broke apart 73 seconds after launch on January 28, 1986, killing all seven crew members onboard. The cause of the disaster was the failure of a seal, or O-shaped ring, at the joint of two parts of a solid rocket booster. Because of cold temperatures at launch, the ring was stiff rather than flexible, allowing hot gases and flames to blow out of the seal, destroying the shuttle's external fuel tank and causing the breakup of the spacecraft.

Hubble Space Telescope. The Hubble Space Telescope (HST) was launched into Earth's orbit in 1990. Situated far above Earth's soupy atmosphere, the HST was expected to deliver much clearer images than any telescope located on the ground. But as soon as astronomers looked at the first Hubble images, they knew something was drastically wrong. The pictures of deep space were blurry. The problem: The huge main mirror that the HST used to gather light from deep space had been ground to the wrong measurements. The result was blurry pictures. To correct the problem, NASA sent a repair team into orbit to fit the HST with corrective lenses that worked like eyeglasses to sharpen the focus. Since then, the Hubble has returned thousands of images of deep space that were never before possible.



Engineering as a Career

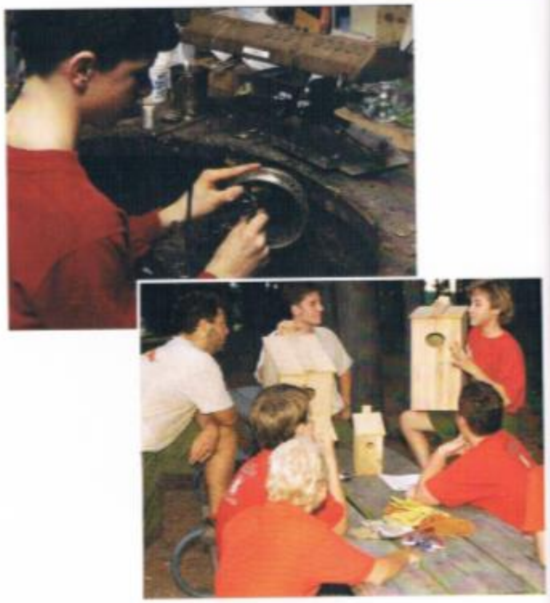
Let's look again at what engineers do. These statements may help you decide if you might like to become an engineer.

- Engineers apply the concepts and methods of science for the benefit of people.
- Engineers are creative, solve problems, and make decisions based on their solutions.
- Analyst engineers help the design engineers solve their most complicated problems, usually by applying complex mathematical methods, often using computers.
- Project engineers and systems engineers coordinate the work of a group of engineers, often from different fields, to complete a big, complex project.

All sorts of engineers work together on teams, which often include nonengineers as well (marketers, purchasers, manufacturers). Engineers also work alone, using their specialized skills to solve pieces of the team's problem. Though other people, such as factory workers or construction crews, actually make the things engineers design, engineers often make simplified models to better see how their ideas work together.

Many engineers (design engineers) dream up new things for people to use, and then figure out how to make them.

Do you like technology? One compelling reason to become an engineer is that they get to use the newest gadgets, most current computers, and most up-to-date software programs. As new technology emerges, interesting new engineering projects appear—everything from designing robotic spy planes to unraveling the mysteries of genetics to cure disease.



Other Things to Ask Yourself

You have read that engineers create new things to meet needs and solve problems. Do you enjoy doing the kinds of things engineers do? Ask yourself these questions.

- Do I try to figure out how things like toys, appliances, and machines at home work? Do I take them apart (with my parent's permission!) to see how they work? Can I put them back together without help?
- Do I like to try to fix household items that break, even though I may need help?
- Do I build or make things like roads and castles at the beach?
- Do I build things from model kits, sometimes customizing them by modifying the basic model and adding extra details?
- Do I use computer programs to solve special problems that interest me, or to create simple games?

Engineers use the principles of mathematics and science to do their work. Ask yourself:

- Do I do well in math in school? Do I enjoy it?
- Do I like science in school, especially the experiments?
- Do I do optional extra assignments the teachers give?
- Do I seek ways to use the ideas I learn in science?
- Have I ever entered a school science fair?

If you answered "yes" to some of these questions, then you may want to consider engineering as a career.

Are You Creative?

Creativity is the ability to bring new ideas or objects into being. It involves playing with imagination and possibilities, and seeing possible connections. Creativity is an ability that is vital to engineers, whether they design products, figure out how to analyze complicated parts, develop tests that determine how well things work, research new kinds of plastics, or figure out how to keep classes interesting for students. So if you like to question, explore, invent, discover, create, and help people solve problems and find new ways of doing things, then engineering may be for you.

Preparing for an Engineering Career

If you think you might like to become an engineer, then here are some things to start thinking about and doing now that will help you along the path to an engineering career.

Engineering College Entrance Requirements

Engineering colleges have entrance requirements—courses you must have taken in high school in order to be admitted to study engineering. Clearly, you will need math and science. It is best to take all the "college prep" math and science courses your high school offers. Don't neglect English, either. Engineers must be able to clearly describe their work to others, from their bosses to the people who will build the things they design. You will also need to know what special tests they want you to take during high school, such as the Scholastic Aptitude Test (SAT).

Every college and university publishes a catalog that describes the school's admission requirements and lists all its programs of study. Review the sections for the engineering fields (majors) that interest you. These will mention any special requirements or suggested courses.

If you are able to take electives during high school, you may want to consider courses that relate to the field of engineering that most interests you. Here are some examples.

- **Architectural engineering:** art, drafting
- **Bioengineering:** advanced biology, advanced chemistry
- **Chemical engineering:** advanced chemistry
- **Civil engineering:** art, drafting
- **Computer engineering:** advanced computers, electronics shop
- **Electrical engineering:** advanced computers, electronics shop
- **Materials engineering:** advanced chemistry, metal shop
- **Mechanical engineering:** art, automotive shop, drafting, metal shop
- **Software engineering:** advanced computers

The Professional Engineer

Engineering qualifies as a profession because it requires specialized knowledge and often long and intensive academic preparation. Engineers are also professionals because they make their living in an activity that conforms to the technical and ethical standards of a profession.

Ethics

Ethics are an important part of the engineering profession, especially as science and technology continue to evolve rapidly. An engineer's ethical standards are similar to those expected of other professionals in the well-established areas of medicine, business, and law.

Engineers have the responsibility to act ethically in the research and problem-solving part of their position as well as in dealing with the people directly affected by their work. Their work is for the good of the public and the clients they represent, and in no way should result in harm to people or the environment.

A Scout who commits to the Scout Oath and the Scout Law already has some understanding of ethics and is practicing them in his everyday life. These are the same principles that guide the careers of engineers and other professionals.

The Engineer's Code of Ethics has three fundamental principles that guide the work of the engineering profession. Engineers uphold and advance the integrity, honor, and dignity of their profession by

1. **Using their knowledge and skill for the enhancement of human welfare**
2. **Being honest and impartial, and faithfully serving the public, their employers, and their clients**
3. **Striving to increase the competence and prestige of the engineering profession**

Professional Registration

Qualified engineers may become licensed to practice engineering in their state. It isn't always necessary to get a Professional Engineering (PE) license to be hired as an engineer, but it may be required to perform certain governmental work and to review and approve designs. Some firms require engineers to be licensed before they can move up to engineering management positions.

Requirements vary from state to state, but for most engineers, obtaining a license is a four-step process. The applicant must:

1. Earn a four-year engineering degree in a program approved by the state engineering licensure board.
2. Complete four years of qualifying engineering work experience.
3. Pass the Fundamentals of Engineering exam. (Also called the Engineer-in-Training exam, this test can usually be taken by students in the final years of an undergraduate engineering curriculum, or any time after graduation.)
4. Pass the Principles and Practice of Engineering (PE) exam. The PE exam is hard, and it is not unusual for an applicant to fail it the first time (failed examinations may be retaken). The PE license must be renewed periodically.

Engineering Resources

Scouting Literature

Architecture, Automotive Maintenance, Chemistry, Composite Materials, Computers, Drafting, Electricity, Electronics, Energy, Inventing, Model Design and Building, Nuclear Science, Space Exploration, and *Surveying* merit badge pamphlets

For more information about or to order Scouting-related resources, see *http://www.scoutstuff.org* (with your parent's permission).

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Organizations and Web Sites

American Indian Science and Engineering Society
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Telephone: 505-765-1052
Web site: *http://www.aises.org*

American Institute of Chemical Engineers
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Web site: *http://www.aiche.org*

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Web site: *http://www.asce.org*

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Web site: *http://www.ksc.nasa.gov*

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Acknowledgments

The Boy Scouts of America is grateful to Scott S. Stuckey for updating this edition of the *Engineering* merit badge pamphlet. Mr. Stuckey is a senior editor at *National Geographic Traveler* magazine and is the former editor of *Boys' Life* magazine.

Thanks also to the Convergence Education Foundation, whose members provided assistance with revising the Engineering merit badge requirements. The Foundation strives to expose young students to the wonders of science, mathematics, and engineering to pique their interest in a possible career for the future.

We appreciate the Quicklist Consulting Committee of the Association for Library Service to Children, a division of the American Library Association, for its assistance with updating the resources section of this merit badge pamphlet.

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If a Scout has already started working on a merit badge when a new edition for that pamphlet is introduced, *he may continue to use the same merit badge pamphlet to earn the badge and fulfill the requirements therein.* In other words, the Scout need not start all over again with the new pamphlet and possibly revised requirements.

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American Labor	2006
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Archery	2004
Architecture	2008
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Astronomy	2004
Athletics	2006
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Basketry	2003
Bird Study	2005
Bugling (see Music)	
Camping	2005
Canoeing	2004
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Citizenship in the Nation	2005
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