

INTRODUCTION TO ENGINEERING DESIGN

For Instructors

Introduction

Think of all the things you have in your classroom: desks, computers, clocks, and calculators. Where did all of these things come from? Who built them? The answer to both questions is engineers. Engineers have existed for centuries in all cultures around the world. They are creative people who use their imaginations and knowledge of math and science to improve human lives. They have changed the way humans communicate and the way we travel. Their inventions have allowed us to search for life on Mars and save lives here on Earth. Imagine riding a horse to school instead of the bus, or walking five miles just to talk to a friend. Engineers developed cars and telephones to make these tasks easier.

Instructor:

The Infinity Project recommends using this module in Grade 6, after the first 6-week grading period. It can be used, however, at any grade level after the scientific method has been taught, in order to introduce students to engineering.

UNIT 1: INTRODUCTION TO THE ENGINEERING DESIGN PROCESS

SECTION 1: THE WORK OF ENGINEERS

Engineers do not work alone to develop the products we use every day. Some businesspeople do research to identify the new products people want. Scientists and mathematicians perform research and collect data that engineers use to build prototypes, or samples of their designs. Artists often design advertisements to sell the finished products. There are many people involved in the engineering process, but we will focus on scientists and the engineers themselves.

The Role of Scientists in Engineering

Scientists try to understand and describe the world around us. Scientists have answered questions such as “What causes the flu?” and “How do clouds form?” To answer questions like these, scientists use the scientific method. The scientific method is a sequence of steps that a scientist can follow to discover why something happens in nature. The sequence of steps is shown below.

1. Make an observation about nature.
2. Develop a question or problem related to the observation, and a tentative answer, or hypothesis, to the question.

3. Perform an experiment to attempt to answer the question.
4. Collect data and analyze the results.
5. Draw conclusions. If the results support the original hypothesis, then it is confirmed as the answer to the question. If the results differ from the original hypothesis, then the answer to the question is different from what was expected. In many cases, this can lead to additional hypotheses and experiments to study variations on the original question.

Instructor:

Review the following diagram and make sure that students have a firm grasp of the scientific method before introducing the engineering design process.

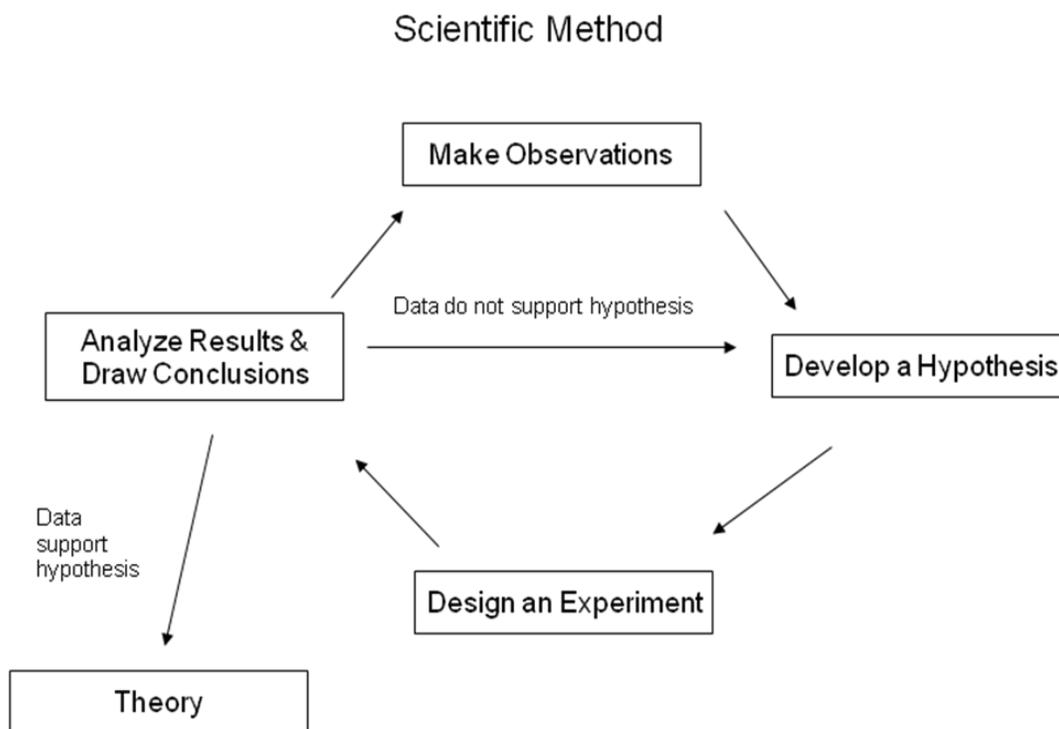


Figure 1.1: The Scientific Method

Did You Know?

Airbags are commonly filled with nitrogen gas. The gas enters the airbag with a speed of 200 mph (322 kph). It only takes about 0.05 seconds to fill the airbag.

The Role of Engineers

Engineers design new products to solve some problem or to meet some human need. For example, in older cars airbags were placed only in the front of the car. Safety experts noticed that these airbags protected drivers when they were struck from the front or the rear. However, the airbags were not very effective when drivers were

struck from the side. To solve this problem, engineers built new airbags into the sides of the car to provide more protection.

Like scientists, engineers follow a series of steps to design products. The steps of the engineering design process are:

1. Identify a problem or need.
2. Identify design constraints.
3. Gather information necessary to design and build the product.
4. Develop several possible designs.
5. Analyze the solutions to determine which will work.
6. Choose the best solution based on your analysis.
7. Build a prototype of the selected design.
8. Test the prototype and evaluate its design.
9. Repeat any or all steps as needed.

Constraints are requirements that limit how engineers design their products.

Let's look more closely at each step to find out what the process really involves.

Step 1: Identify a problem or need

It is hard to solve a problem without knowing what the problem is, so the first thing an engineer does is define the problem that needs to be solved. He or she may be given information about a potential problem that comes from business and consumer research—that is, businesspeople will find out if users have identified a problem with an existing product, or if people have expressed a wish for a new product, and share this information with engineers.

From here, the engineer has to identify the exact problem or objective in order to develop a useful product. It is not always easy to identify the exact problem. For example, if an engineer is presented with an existing device that has a malfunction—such as a cell-phone battery that loses its charge quickly—the engineer must work to find out exactly what is causing the problem before he or she can determine how to fix it.

Step 2: Identify design constraints

The engineer must also develop a list of criteria, or *constraints*, that the design must meet in order to be useful. For instance, if an engineer plans to develop an inexpensive MP3 player, he or she will probably have to limit the number of functions the player can perform, because the extra time and materials required for extra functions would increase the cost of the player.

It is also important to know that there is no right answer to an engineering design problem. The solution, in the form of the design developed in response to the problem, is variable and limited only by the design constraints and the creativity of the engineer.

Step 3: Gather information necessary to design and build the product

Before building or even dreaming up possible solutions, engineers have to do their research. They use every print and electronic resource available to make sure their problem is specific, but not limiting, and that it expresses a real need, and to find out if a solution has already been developed. Even if someone else has already worked on the problem, an engineer can learn from the mistakes of others or improve on the solution already developed. Research will also help engineers learn more about the science behind their problems, the materials they might use, and the costs that may be involved. Engineers take all this information with them into the brainstorming phase of the process, in which they develop as many potential solutions to the problem as they can.

Step 4: Develop several possible designs

In this step, an engineer uses his or her problem, constraints, research, and creativity to generate as many ideas as possible for the solution to the design problem. Analysis and testing of the ideas will come later—for now, the engineer can be inventive and take risks. He or she might bring together a group of engineers from his or her own branch of engineering or from other branches to expand the possibilities. The ideas are recorded for later analysis and testing.

Step 5: Analyze the solutions to determine which will work

Once the brainstorming phase has ended, the engineer will go back over the list of ideas, select a handful of the best ideas, and carefully evaluate them to figure out how they will work and whether they will be functional, safe, cost-effective, and valuable to consumers.

Safety testing is generally important for any product or design. If a product injures a consumer, the consumer may hold responsible the producer and designer of the product. Any design will be considered for safety and either modified or thrown out if it is not safe.

It is also important to consider how the product will work, or if it will work, when it is built. If a design for a heavy-duty plastic is made of materials that shatter easily, the plastic will not likely work as it should, and so the design would be thrown out.

A design may also be evaluated for comfort of use, strength, conformity to product requirements set by the government, and ease of construction. Some factors are more important than others, depending on the design problem and proposed solution. The importance of each factor is determined by the engineers developing a particular design or product.

Step 6: Choose the best solution based on your analysis

After studying the analyses of each of the possible designs, the engineer will consider all data gathered and use the data to choose the final design. The design will still have to be built and tested, but the engineer makes a preliminary choice about how the product will look based on the performance, safety, cost, and sales factors determined by the analysis.

Step 7: Build a prototype of the selected design

At this stage, engineers will build a model of the chosen design, called a prototype. If the prototype is successfully assembled, it will proceed to Step 8, where it will be put through tests that simulate the exact use of the product when it is sold to the public.

Step 8: Test the prototype and evaluate its design

Now that the engineer has built a prototype of his or her design, it is time to test that design and see how well it stands up to real-world conditions. A newly designed car, for example, will be tested against real road conditions to ensure that it performs well, and crashed in simulated traffic accidents to assess damage to the car and its human occupants. The test stage is where engineers work out any problems in the design before it is produced and sold.

Step 9: Repeat any or all steps as needed

Rarely does a design solution go straight through the engineering design process into the market. Design solutions may be revisited one or many times before the engineer is satisfied. Prototypes may be refined and redeveloped many times over before they are ready to be produced and sold. Engineers may go back to any part of the process to refine their designs or start again to make sure that the final product is as good as it can be.

**THE WORK OF ENGINEERS****EXERCISE 1.1**

In Exercise 1.1, you will follow a scenario to understand how the engineering design process works on a specific project.

**WHEELCHAIR RAMP SAFETY****ACTIVITY 1.2**

“Safety first” is a good motto, especially for engineers. In Activity 1.2, you will design an experiment to identify the safest way to build a wheelchair ramp at school.

Instructor

Assign Exercise 1.1. After students have presented their answers, ask them to describe the advantage of working in groups on an engineering project.

Complete Activity 1.2: Wheelchair Ramp Safety. Divide students into groups of 3 or 4, and

allow them 2–3 days to complete the activity. Select ramps that are at least 6–8 inches (15–20 cm) long with a slope of 10° or less. Objects will roll faster down ramps with steeper slopes, making it more difficult for students to collect data.

Show students several different types of business letters and allow them to select the format they would like to use.

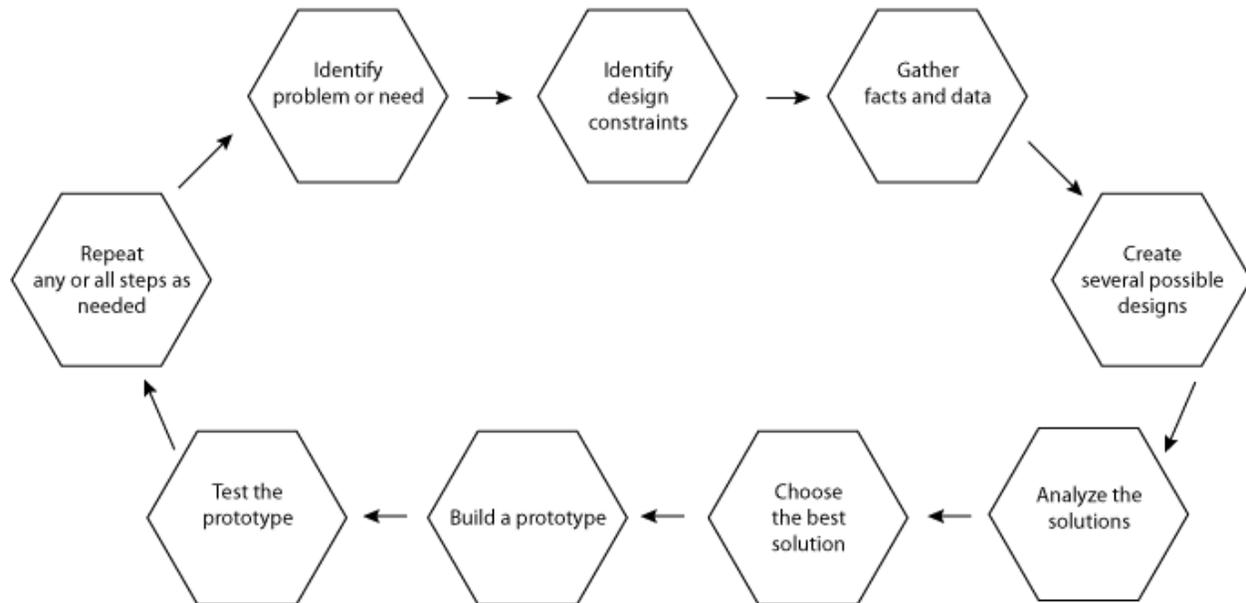


Figure 1.2: The Engineering Design Process

The example below shows how the engineering design process can be applied to meet a need.

EXAMPLE 1.1: DEVELOPING LAPTOP COMPUTERS

- **Identify a problem or need.** The goal was to build a computer that people could carry with them and that worked just like a desktop computer.
- **Identify design constraints.** Some constraints for the laptop may have included:
 - Make it lightweight and small enough so that it is easy to carry and will sit comfortably on a person's lap
 - Make it large enough to have a standard keyboard, a screen that is easy to read, and a CD-ROM drive
 - Develop a battery that can last for 2–3 hours before being recharged
 - Keep the computer cool enough so it does not burn the user's skin
 - Make the laptop relatively inexpensive so that people will purchase it
- **Gather information.** Engineers researched ways to address each of the constraints listed above. They identified the best materials to use to make the laptops sturdy, lightweight, and inexpensive. They determined what size the laptop should be so that it was easy to use but not too big to carry. Engineers also developed batteries that would last for a few hours before they had to be recharged.

- **Build and test designs.** Several possible designs were developed and discussed by a team of engineers. Some of the designs were built and tested to see if they met the design constraints listed above. The best designs were produced in large numbers and sold.

Instructor

Emphasize the fact that the engineering design process is cyclical, as shown, and that engineers often enter the process at various stages. Many engineers base their work on problems that others have identified, or try to improve other's designs. The same is true for the scientific method; scientists may base their research on observations made by others.



DON'T SCRAMBLE THE EGGS!

ACTIVITY 1.3

In Activity 1.3, you will use the engineering design process to build a bungee cord to let a little egg take a big bounce.

Instructor

Complete Activity 1.3: Don't Scramble the Eggs! Allow two days to complete the activity. Show students images or samples of real bungee cords so they can see firsthand how they are designed.

Try to avoid leading students in a particular direction regarding bungee cord design. Allow them the freedom to try different designs on their own. Emphasize the importance of taking good notes and making sketches. Draw students' attention to Part E, where they will record their findings.

Science and Engineering are Interdependent

Did You Know?

In the future, drones may be used to monitor forest fires and melting of the polar ice caps. They may also be used to track migrating animals.

Scientists and engineers do not work independently; rather, they are interdependent. They rely on each other to achieve their goals. Scientists use the technology developed by engineers to perform their experiments. As scientists make new discoveries, engineers often use these discoveries to build new products.

For example, scientists wanted to collect data from inside hurricanes so they could make better weather predictions. However, it was incredibly dangerous for humans to enter hurricanes in airplanes. Engineers helped solve this problem by building small remote-controlled airplanes called drones. The drones could measure wind speeds, temperatures, and air pressures inside hurricanes and send the data back to Earth using satellites.

Instructor

Ask students to define interdependent. Then, have students pair up and ask them to explain how the following are interdependent: flowers and bees, students and teachers.

Discuss student answers. Then, have them use media or Internet resources to research inventions (such as drones) that required engineers to collaborate with scientists.

SECTION 2: BLOCK DIAGRAMS IN ENGINEERING DESIGNS

Most products are made of several different parts that all must work together. Before engineers begin building a product, they draw a block diagram to see how the product will be assembled. Block diagrams show pictures of the parts in a product and how the parts work together. A block diagram can be simple or complex. An example of each is shown below.

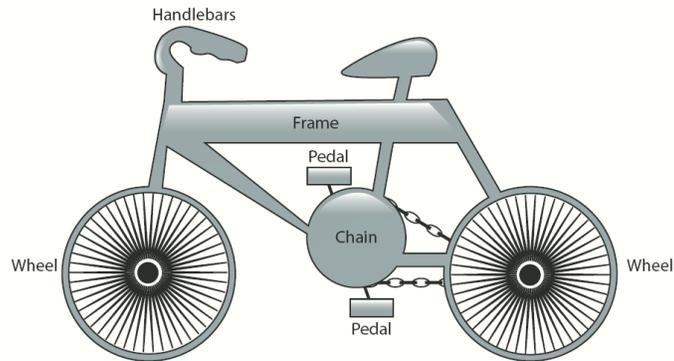


Figure 1.3: Block Diagram of a Bicycle

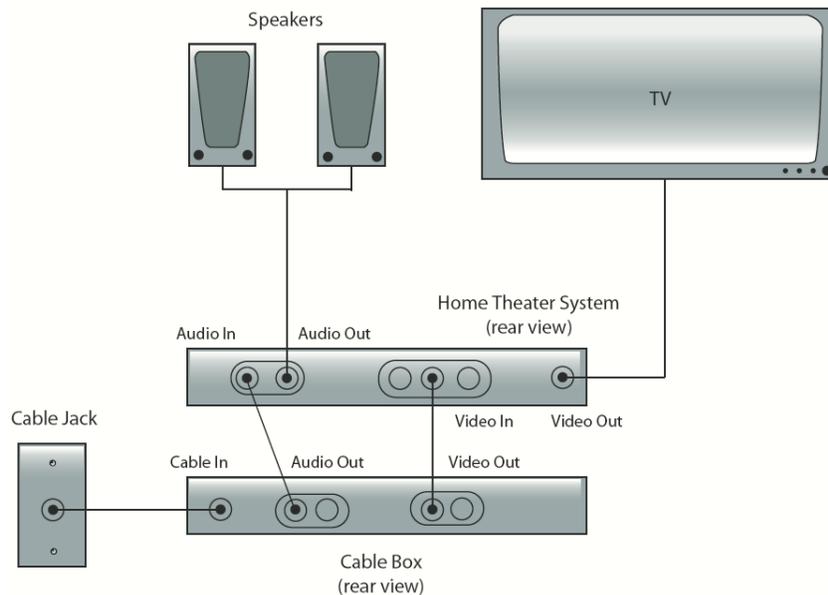


Figure 1.4: Block Diagram of a Home Theater System

Different engineers or teams of engineers often design only one part of the product shown in the block diagram. Another set of engineers makes sure all of the parts fit together correctly and that the final product actually works.

Block diagrams can be used to build a *prototype*—an original model of the design. Prototypes are built to verify that the design actually works. Engineers can use the prototype to identify any flaws in the design and make corrections. Engineers often have to build many prototypes until they correct all the flaws. It can take many years of prototyping before a product is ready to be sold in stores.



BLOCK DIAGRAMS IN ENGINEERING DESIGN

EXERCISE 1.4

Get your pencils ready—in Exercise 1.4, you become the engineer as you draw your own block diagrams.

Instructor

Use the diagrams above to illustrate that block diagrams can be fairly simple or more complex. Remind students that a block diagram may not show all the details for each component of a product. The diagram may show only how the components fit together. Also, emphasize the importance of building prototypes and why it may take years to develop a final product.

Assign Exercise 1.4. To help students with question 1.c., put a simple lamp (without its shade) on display so students can see its parts. Before starting question 2, consider showing students a newspaper article, or an evening news clip, about a recalled product, or having them research recent recalls.

UNIT 2: CAREERS IN ENGINEERING

Many people think engineers work only with machines. However, these are only a few of the things that engineers build. Today, there are many different types of engineers building a variety of products. Some of the many types of engineers are described below.

Mechanical Engineers: When we hear the word *engineer*, we commonly think of mechanical engineers. Mechanical engineers design things such as automobiles, refrigerators, and machines used in factories.

Electrical Engineers: Electrical engineers design products that use or produce electricity. They design circuits used in TVs, computers, and cell phones. These engineers also build power plants and monitor electricity production.

Civil Engineers: Civil engineers design and build many different structures that usually benefit our whole society. These engineers build roads, bridges, and buildings.

Chemical Engineers: Chemical engineers typically develop new substances from raw materials. For example, these engineers turn oil into gasoline and plastics.

Biomedical Engineers: Biomedical engineers design products to improve human health. They design artificial limbs and organs, X-ray machines, wheelchairs, and contact lenses.

Aerospace Engineers: Aerospace engineers design objects that fly into the air or outer space. This includes airplanes, space shuttles, and satellites.

Computer/Software Engineers: Computer engineers design the circuits inside parts of computers. Software engineers develop programs that run on computers.

Environmental Engineers: Environmental engineers develop solutions to environmental problems, such as recycling and protecting wildlife from human activity.

Architectural Engineers: Architectural engineers design buildings and often oversee their construction.

Industrial Engineers: Industrial engineers work to improve the way things are done. They identify ways for factories to produce goods faster and cheaper.

Materials Engineers: Materials engineers develop substances with the specific properties required for a product. They develop lightweight, but strong, metals used in airplanes. They design plastic cups that hold hot liquids without melting, and oven-safe glass dishes.

Agricultural Engineers: Agricultural engineers design equipment used for farming and food production. They develop farm equipment, such as tractors and irrigation systems, as well as silos for storing grain.

Automotive Engineers: Automotive engineers design the different components found in cars and trucks.

Transportation Engineers: Transportation engineers design streets, highways, and subway systems that allow people to travel more easily and safely.

Nuclear Engineers: Nuclear engineers design products that safely use nuclear energy. They work on nuclear power plants or create technology using nuclear radiation to diagnose and treat medical problems.

Oceanographic Engineers: Oceanographic engineers design products used in the ocean. They also develop ways to protect the erosion of coastlines and beaches during strong storms.

As you read about the different types of engineers, did you notice that some engineers need to have knowledge of other types of engineering? For example, automotive engineers must understand mechanical engineering to design the moving parts in car engines. Automotive engineers also must understand electrical engineering to develop the electrical circuits in a car. Although an engineer may work in one special area, he or she usually needs to understand other types of engineering too.

Engineers also use math quite frequently. In engineering projects, mathematical theories and concepts are applied directly to real life. If your favorite part of math class is measuring and experimenting with concepts, you will probably enjoy engineering.

Few products are developed by just one type of engineer. For example, many engineers are involved in building a power plant to produce electricity. Architectural engineers may work with industrial and electrical engineers to build a plant that produces electricity safely and cheaply. Environmental engineers may also be involved to make sure the power plant does not generate a lot of air pollution.

Not all engineers design new products. Some make sure new products are manufactured correctly, or repair broken products. Other engineers help businesses decide what products they need and then train employees to use the new products. Some engineers help companies raise money to research and develop new products. Even if engineers do not design products, they still have to understand how the process works. Many engineers start their careers designing products, but then take other jobs, like the ones described above.



CAREERS IN ENGINEERING

EXERCISE 2.1

In Exercise 2.1, you will use a variety of resources to find out what it's really like to be an engineer.

Instructor

Assign Exercise 2.1. Note that the first part of the exercise is an interest survey that will match students' interests with an engineering profession, which they will then research in groups based on the profession that interests them. Assign each student to the profession that corresponds to the group of questions in which they answered Y most. If students have equal interest in multiple professions or no interest in any of the professions, either permit them to choose one or assign the student based on grouping needs.

Before students complete the research portion of Exercise 2.1, discuss the importance of using reliable resources. Help students distinguish reliable Web sites from unreliable ones by showing students a few examples of each type. Students will also need access to computers connected to the Internet and a word processing or spreadsheet program.

When students finish the research, have them present to the class their findings about their type of engineering.

The next time you buy a new video game, use the drinking fountain, or take a photograph, think about how the products you are using were made. Think about the types of engineers that were involved in designing and testing the product. Consider how long the product was tested before you were able to use it. How many different designs did engineers investigate? How many block diagrams and prototypes did they make before selecting the final design? Now that you have explored what engineers do, hopefully you can appreciate their hard work and dedication to improving human lives.