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# ENGINEERING PROBLEM SOLVING AND SOLUTION DESIGN PROCESS

The engineering design process is a series of steps that engineers follow to come up with a solution to a problem. Many times the solution involves designing a product (like a machine or computer code) that meets certain criteria and/or accomplishes a certain task. This process is different from the [Steps of the Scientific Method](https://www.sciencebuddies.org/science-fair-projects/science-fair/steps-of-the-scientific-method), which you may be more familiar with. If your project involves making observations and doing experiments, you should probably follow the Scientific Method. If your project involves designing, building, and testing something, you should probably follow the Engineering Design Process. If you still are not sure which process to follow, you should read [Comparing the Engineering Design Process and the Scientific Method](https://www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-compare-scientific-method). This diagram shows the steps of the engineering design process, and the table below describes each step in more detail:



Engineers do not always follow the engineering design process steps in order, one after another. It is very common to design something, test it, find a problem, and then go back to an earlier step to make a modification or change to your design. This way of working is called **iteration**, and it is likely that your process will do the same!

Most engineering designs can be classified as inventions-devices or systems that are created by human effort and did not exist before or are improvements over existing devices or systems. Inventions, or designs, do not suddenly appear from nowhere. They are the result of bringing together technologies to meet human needs or to solve problems. Sometimes a design is the result of someone trying to do a task more quickly or efficiently. Design activity occurs over a period of time and requires a step-by-step methodology. We described engineers primarily as problem solvers. What distinguishes design from other types of problem solving is the nature of both the problem and the solution. Design problems are open ended in nature, which means they have more than one correct solution. The result or solution to a design problem is a system that possesses specified properties.

**THE DESIGN PROCESS**

 The basic five-step process usually used in a problem-solving works for design problems as well. Since design problems are usually defined more vaguely and have a multitude of correct answers, the process may require backtracking and iteration. Solving a design problem is a contingent process and the solution is subject to unforeseen complications and changes as it develops. Until the Wright brothers actually built and tested their early gliders, they did not know the problems and difficulties they would face controlling a powered plane. The five steps used for solving design problems are:

 1. Define the problem

 2. Gather pertinent information

3. Generate multiple solutions

4. Analyze and select a solution

5. Test and implement the solution

The first step in the design process is the problem definition. This definition usually contains a listing of the product or customer requirements and specially information about product functions and features among other things. In the next step, relevant information for the design of the product and its functional specifications is obtained. Once the details of the design are clearly identified, the design team with inputs from test, manufacturing, and marketing teams generates multiple alternatives to achieve the goals and the requirements of the design. Considering cost, safety, and other criteria for selection, the more promising alternatives are selected for further analysis. Detail design and analysis step enables a complete study of the solutions and result in identification of the final design that best fits the product requirements. Following this step, a prototype of the design is constructed and functional tests are performed to verify and possibly modify the design. When solving a design problem, you may find at any point in the process that you need to go back to a previous step. The solution you chose may prove unworkable for any number of reasons and may require redefining the problem, collecting more information, or generating different solutions. This continuous iterative process is represented in the following Figure.

1. **DEFINE THE PROBLEM**

You need to begin the solution to a design problem with a clear, unambiguous definition of the problem. Unlike an analysis problem, a design problem often begins as a vague, abstract idea in the mind of the designer. Creating a clear definition of a design problem is more difficult than, defining an analysis problem. The definition of a design problem may evolve through a series of steps or processes as you develop a more complete understanding of the problem.

 **Identify and establish the need**

Before you can develop a problem definition statement for a design problem, you need to recognize the need for a new product, system, or machine. Thomas Newcomen saw the need for a machine to pump the water from the bottom of coal mines in England. Recognizing this human need provided him the stimulus for designing the first steam engine in 1712. Before engineers can clearly define a design problem, they must see and understand this need. Although engineers are generally involved in defining the problem, they may not be the ones who initially recognize the need. In private industry, market forces generally establish the need for a new design. A company's survival depends on producing a product that people will buy and can be manufactured and sold at a profit. Ultimately, consumers establish a need, because they will purchase and use a product that they perceive as meeting a need for comfort, health, recreation, transportation, shelter, and so on. Likewise, the citizens of a government decide whether they need safe drinking water, roads and highways, libraries, schools, fire protection, and so on. The perceived need, however, may not be the real need. Before you delve into the details of producing a solution, you need to make sure you have enough information to generate a clear, unambiguous problem definition that addresses the real need. The following example illustrates the importance of understanding the need before attempting a solution. Example: Automobile Airbag Inflation - How Not to Solve a Problem A company that manufactures automobile airbags has a problem with an unacceptably high rate of failure in the inflation of the bag. During testing, 10 percent of the bags do not fully inflate. An engineer is assigned the job of solving the problem. At first the engineer defines the problem as a failure in the materials and construction of the inflation device. The engineer begins to solve this problem by producing a more robust inflation device. After considerable effort, the engineer discovers that improving the inflation device does not change the failure rate in the bags. Eventually, this engineer re-examines the initial definition of the problem. The company investigates the airbag inflation problem further and discovers that a high degree of variability in the tightness of folds is responsible for the failure of some bags to inflate. At the time the bags were folded and packed by people on an assembly line. With a more complete understanding of the need, the engineer redefined the problem as one of increasing the consistency in tightness of the folds in the bags. The final solution to this problem is a machine that automatically folds the bags. Often the apparent need is not the real need. A common tendency is to begin generating a solution to an apparent problem without understanding the problem. This approach is exactly the wrong way to begin solving a problem such as this. You would be generating solutions to a problem that has never been defined. People have a natural tendency to attack the current solution to a problem rather than the problem itself. Attacking a current solution may eliminate inadequacies but will not produce a creative and innovative solution. For example, the engineer at the airbag company could have only looked at the current method for folding airbags-using humans on an assembly line. The engineer might have solved the problem with inconsistent tightness by modifying the assembly line procedure. However, the final solution to the problem proved to be more cost effective and reliable, in addition to producing a superior consistency in the tightness of the folds.

**Develop a Problem Statement**

The first step in the problem-solving process, therefore, is to formulate the problem in clear and unambiguous terms. Defining the problem is not the same as recognizing a need. The problem definition statement results from first identifying a need. The engineer at the airbag company responded to a need to reduce the number of airbag inflation failures. He made a mistake, however, in not formulating a clear definition of the problem before generating a solution. Once a need has been established, engineers define that need in terms of an engineering design problem statement. To reach a clear definition, they collect data, run experiments, and perform computations that allow that need to be expressed as part of an engineering problem-solving process. Consider for example the statement "Design a better mousetrap." This statement is not an adequate problem definition for an engineering design problem. It expresses a vague dissatisfaction with existing mousetraps and therefore establishes a need. An engineer would take this statement of need and conduct further research to identify what was lacking in existing mousetrap designs. After further investigation the engineer may discover that existing mousetraps are inadequate because they don't provide protection from the deadly Hantavirus carried by mice. Therefore, a better mousetrap may be one that is sanitary and does not expose human beings to the Hantavirus. From this need, the problem definition is modified to read, "Design a mousetrap that allows for the sanitary disposal of the trapped mouse, minimizing human exposure to the Hantavirus." The problem statement should specifically address the real need yet be broad enough not to preclude certain solutions. A broad definition of the problem allows you to look at a wide range of alternative solutions before you focus on a specific solution. The temptation at this point in the design process is to develop a preconceived mental "picture" of the problem solution. For example, you could define the better mousetrap problem as "Design a mousetrap that sprays the trapped mouse with disinfectant." This statement is clear and specific, but it is also too narrow. It excludes many potentially innovative solutions. If you focus on a specific picture or idea for solving the problem at this stage of the design process, you may never discover the truly innovative solutions to the problem. A problem statement should be concise and flexible enough to allow for creative solutions. Here is one possible problem definition statement for our better mousetrap problem. A Better Mousetrap: Certain rodents such as the common mouse are carriers and transmitters of an often fatal virus, the Hantavirus. Conventional mousetraps expose people to this virus as they handle the trap and dispose of the mouse. Design a mousetrap that allows a person to trap and dispose of a mouse without being exposed to any bacterial or viral agents being carried on the mouse.

 **Establish Criteria for Success**

 Criteria for success are the specifications a design solution must meet or the attributes it must possess to be considered successful. You should include criteria in the problem statement to provide direction toward the solution. At this point in the design process, the criteria are preliminary. As the design solution develops, you will most likely find that the initial criteria need to be redefined or modified. Preliminary criteria must not be too specific so they allow flexibility through the design process. The criteria that apply to a particular design problem are based on your background knowledge and the research that you've conducted. Since each problem or project is unique, the desirable attributes, or criteria, of the solution are also unique. Some criteria are unimportant to the success of the design. The list of criteria is developed by the design team. The design team is made up of people from various engineering backgrounds that have expertise pertinent to the problem. This team may also include people from backgrounds other than engineering, such as managers, scientists, and technicians. The design team must evaluate each criterion and decide if it is applicable to the design effort. Later in the design process, value judgments must be applied to the list of criteria. Therefore, it makes little sense to include those criteria that will be of relatively low priority in the evaluation of design solutions. For example, if you were designing a critical life support system, you would not include the criterion of "must be minimum cost," because cost is not an important factor in evaluating this design. The following is a list of preliminary criteria for a better mousetrap design. This list would be included in the problem definition statement.

• The design must be low cost.

• The design should be safe, particularly with small children.

 • The design should not be detrimental to the environment.

 • The design should be aesthetically pleasing.

 • The design should be simple to operate, with minimum human effort.

 • The design must be disposable (you don't reuse the trap).

 • The design should not cause undue pain and suffering for the mouse.

1. **GATHER PERTINENT INFORMATION**

Before you can go further in the design process, you need to collect all the information available that relates to the problem. Novice designers will quickly skip over this step and proceed to the generation of alternative solutions. You will find, however, that effort spent searching for information about your problem will pay big dividends later in the design process. Gathering pertinent information can reveal facts about the problem that result in a redefinition of the problem. You may discover mistakes and false starts made by other designers. Information gathering for most design problems begins with asking the following questions. If the problem addresses a need that is new, then there are no existing solutions to the problems, so obviously some of the questions would not be asked.

• Is the problem real and its statement accurate?

• Is there really a need for a new solution or has the problem already been solved?

• What are the existing solutions to the problem?

• What is wrong with the way the problem is currently being solved?

• What is right about the way the problem is currently being solved?

 • What companies manufacture the existing solution to the problem?

 • What are the economic factors governing the solution?

 • How much will people pay for a solution to the problem?

 • What other factors are important to the problem solution (such as safety, aesthetics and environmental issues)?

Search for Information Resources As an engineering student in the 2000s you have many more sources of information available to you than engineers did only 20 years ago. This section discusses some of the most current resources available, but because our world is witnessing an information explosion, by the time you read this many more resources will be available that are not mentioned here. Traditional publications are still an essential source of information to engineers and scientists. However, electronic information transfer and retrieval are quickly becoming a standard source for engineers and scientists. When you begin a search for information relating to a design problem, you must be prepared to go to many different sources. The library is still the primary source of information for an engineering student. Your success as an engineer and student will be enhanced if you are able to use the library effectively. For specific help on using our library, you should consult the library staff at the college; they probably offer courses or seminars on library usage.

**GENERATE MULTIPLE SOLUTIONS**
 The next step in the design process begins with creativity in generating new ideas that may solve the problem. Creativity is much more than just a systematic application of rules and theory to solve a technical problem. You start with existing solutions to the problem and then tear them apart-find out what's wrong with those solutions and focus on how to improve their weaknesses. Consciously combine new ideas, tools, and methods to produce a totally unique solution to the problem. This process is called synthesis. Casey Golden, age 13, did this when he invented the BIOtee. Casey noticed that discarded and broken wooden golf tees littered golf courses, damaging the blades and tires of lawn mowers. He decided to design a new biodegradable tee. After experimenting with different mixtures, he devised a recipe made of recycled paper fiber and food byproducts coated with a water-soluble film. When the film is broken, moisture in the ground breaks down the tee within 24 hours. As a result of his creative efforts, Casey's family started a company to manufacture BIOtees producing several million tees per year. Psychological research has found no correlation between intelligence and creativity. People are creative because they make a conscious effort to think and act creatively. Everybody has the potential to be creative. Creativity begins with a decision to take risks. Listed below are a few characteristics of creative people. These are not rigid rules to be followed to experience creativity. You can improve your creative ability by choosing to develop these characteristics in yourself.

• Curiosity and tolerance of the unknown. Creative people have a positive curiosity of the unknown. They are not afraid of what they don't understand.

• Openness to new experiences. Creative people have a healthy and positive attitude toward new experiences.

 • Willingness to take risks. Creative people are not afraid to take risks and try new experiences or ideas, knowing that they may be misunderstood and criticized by others. They are self-confident and not afraid to fail.

 • Ability to observe details and see the "whole picture." Creative people notice and observe details relating to the problem, but they also can step back and see the bigger picture.

• No fear of problems. Creative people are not afraid to tackle complex problems, and they even search for problems to solve. They seek solutions to problems with their own abilities and experience if possible. They have the attitude of "if you want something done, you'd better do it yourself."

 • Ability to concentrate and focus on the problem until it's solved.

Creative people can set goals and stick to them until they're reached. They focus on a problem and do not give up until the problem is solved. They have persistence and tenacity. Solutions to engineering design problems do not magically appear. Ideas are generated when people are free to take risks and make mistakes. Brainstorming at this stage is often a team effort in which people from different disciplines are involved in generating multiple solutions to the problem.

1. **ANALYZE AND SELECT A SOLUTION**

Once you've conceived alternative solutions to your design problem, you need to analyze those solutions and then decide which solution is best suited for implementation. Analysis is the evaluation of the proposed designs. You apply your technical knowledge to the proposed solutions and use the results to decide which solution to carry out. You will cover design analysis in more depth when you get into upper-level engineering courses. At this step in the design process, you must consider the results of your design analysis. This is a highly subjective step and should be made by a group of experienced people. This section introduces a systematic methodology you can use to evaluate alternative designs and assist in making a decision. Analysis of Design Solutions Before deciding which design solution to implement, you need to analyze each alternative solution against the selection criteria defined in step l. You should perform several types of analysis on each design. Every design problem is unique and requires different types of analysis. The following is a list of analysis that may need to be considered; bear in mind that the importance of each varies depending on the nature of the problem and the solution.

 • Functional analysis

 • Industrial design/Ergonomics

 • Mechanical/Strength analysis

• Electrical/Electromagnetic

• Manufacturability/Testability

 • Product safety and liability

• Economic and market analysis

• Regulatory and Compliance

1. **TEST AND IMPLEMENT THE SOLUTION**

 The final phase of the design process is implementation, which refers to the testing, construction, and manufacturing of the solution to the design problem. You must consider several methods of implementation, such as prototyping and concurrent engineering, as well as distinct activities that occur during implementation, such as documenting the design solution and applying for patents.

**Prototyping.**

 The first stage of testing and implementation of a new product, called prototyping, consists of building a prototype of the product-the first fully operational production of the complete design solution. A prototype is not fully tested and may not work or operate as intended. The purpose of the prototype is to test the design solution under real conditions. For example, a new aircraft design would first be tested as a scale model in a wind tunnel. Wind tunnel tests would generate information to be used in constructing a full-size prototype of the aircraft. Test pilots then fly the prototype extensively under real conditions. Only after testing under all expected and unusual operating conditions are the prototypes brought into full production.

**Concurrent Engineering**.

 Traditional design practices are primarily serial or sequential: Each step in the process is completed in order or sequence only after the previous steps have been completed. The implementation of the design occurs after a prototype or model is created from engineering drawings. A machinist working from the engineering drawings generated by a drafter, or an engineer, makes the prototype. Only after creating a prototype of the design would the engineer discover that a hole was too small, parts didn't mate properly, or a handgrip was misplaced. The part would have to be redesigned and the process completed until a satisfactory solution was reached.

Concurrent engineering is the ability to implement parallel design and analysis in which safety, manufacturability, serviceability, marketability, and compliance issues are considered early on and during the process. Concurrent engineering is however possible through the application of modern computer-aided design (CAD), analysis, and manufacturing software. A designer starts with an idea of a new product in which the above factors are considered and uses the CAD software to create a preliminary design. With the appropriate software, the preliminary design can also be analyzed for functionality as the design is being created. Using the results of this analysis, the designer then makes any necessary modifications and reanalyzes the computer model. An engineer designing a bicycle frame, for example, would use concurrent engineering to minimize the weight and maximize the supported loads in a new frame design. The engineer would first create a design and model the physical behavior of the frame on the computer before actually manufacturing the frame. The next stage in concurrent engineering is called rapid prototyping or sometimes called "art to part." Here the three-dimensional computer model of the finished design is used with computer-aided manufacturing (CAM) software to drive appropriate machinery to physically create the part. The entire design cycle therefore becomes nearly paperless. Engineers can go from design to prototype in a matter of days, instead of weeks or months as with earlier serial design practices. Since design is an iterative process, concurrent engineering significantly shortens the time between iterations. A product can therefore get to market much quicker, at a lower cost, and with a higher quality.

**Documentation.**

 One of the most important activities in design is documenting your work, clearly communicating the solution to your design problem so someone else can understand what you have created. Usually this consists of a design or technical report. Communicating the solution to a design problem through language, both written and oral, is a vital part of the implementation phase. Many people you will be communicating with do not have technical training and competence. They may be the general public, government officials, or business leaders. Successful engineers must possess more than just technical skills. The ability to communicate and sell a design solution to others is also a critical skill. You can use graphs, charts, and other visual materials to summarize the solution process and present your work to others. Multimedia techniques, including Power Point presentations, slides, sounds, videos, and computer-generated animations, are often used to clearly communicate the solution to a design problem.

**Applying for Patents.**

If you develop an original and novel solution to a design problem, part of the implementation phase may include applying for a patent on your solution. A patent will not protect you from someone else copying your solution, but it does give you specific rights to make and sell your design for a specified period. A patent is an agreement made between you-the designer or inventor-and the U.S. government. Through a patent document you agree to make public all the details and technology of your invention. You agree to provide an invention disclosure, which provides enough details to allow anyone to build a working model of your invention. Most large libraries now have files of issued patents, which are available for anyone to see. These can be a good source of ideas for engineering design solutions. In return for making your invention or design solution public, the U.S. Patent Office grants you the exclusive right to your invention for a specified period of time. Pursuing a patent is not a trivial process and may take a long time, costing hundreds or even thousands of dollars. Before considering a patent you should have a general understanding of patent requirements and what can be patented. Ideas by themselves cannot be patented. To obtain a patent, you must prove that your idea can be applied to produce a "new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof." These categories include just about everything made by people and the processes for making them. Most engineering design problems fall into the patentable categories of utility patents or design patents. All mechanical and electrical devices fall into the category of utility patent, which is granted for 20 years. At the end of the patent period, your protection expires, and anyone can copy, manufacture, and sell your invention without giving you credit or payment. A design patent is granted to protect the styling or ornamental features of a design. A design patent is only granted for the appearance of an item, not for how it works or is made. For example, if you invent a telephone that looks like a shoe, you might apply for a design patent. The design patent would be granted on the appearance of the phone, not on the electronic and mechanical workings of the phone. Design patents are granted for 3-1/2, 7, or 14 years, depending on the patent fee paid. The fees range from $200 to $600. Patents are only granted to the inventor of a device. However, the inventor can assign the rights to the patent to another party. If you develop an invention while working as an engineer for a company, you will probably be required to assign the patent rights to that invention to your employer. Once a patent is granted, there is no guarantee that someone else will not try to copy the invention. The U.S. Patent Office does not enforce patent rights. It is the responsibility of the patent holder or a patent attorney to police the patent and make sure no one else copies it while it is in effect. Since a patent makes all information about your design public, some people choose not to pursue a patent, but rather keep the details of the invention secret. If no one else learns how the invention works, you will have protection until another inventor figures it out. For example, the formulas for Coca-Cola and Silly Putty have never been patented, and the secrets are only known to selected company officials. To apply for a patent, you need to prepare and include the following items: A written document clearly describing your invention and stating that you are the original inventor. Enough information must be provided so that someone else can make your invention from the information you provide. You must also make claims about your invention which describe the features which distinguish it from already patentable material. Engineering drawings that follow the format documented in Guide for Patent Draftsmen, which is available from the U.S. Patent Office. The filing fee. This is a basic fee of at least $ 150 that must accompany the patent application. If the patent is granted, you will be charged an additional patent issue fee. The total charges for obtaining a patent can be hundreds of dollars. A patent is granted only after an extensive review process of the U.S. Patent Office. The office will first search the nearly 5 million existing patents to determine whether your design has been previously patented or infringes on an existing patent. This process can take several years and be very expensive. Many inventors employ patent attorneys or agents to conduct a preliminary patent search. Most large libraries have records of all the patents filed with the U.S. Patent Office. This information is also available on a CDROM database at many libraries. You can look at this database and read the patent applications filed under the same product category as yours. This will give you a good idea on how an application is written and might help you improve your own design. Before spending more time and money pursuing a patent, it is a good idea to find out if someone else has already patented your invention.

**Testing and Verification.**

Testing and verification are important parts of the design process. At all steps in the process, you may find that your potential solution is flawed and have to back up to a previous step to get a workable solution. Without proper testing at all stages in the process, you may find yourself making costly mistakes later.