SUMMER INSTITUTE FOR ENGINEERING AND TECHNOLOGY EDUCATION

ENGINEERING DESIGN

INTRODUCTION TO ENGINEERING DESIGN AND PROBLEM SOLVING

OBJECTIVES

This module will expose readers to the fundamental elements of a good engineering design, and to the creative problem solving methods practiced by engineers.

INVITE THE LEARNER

- Ask students if they remember the scientific method.
- Ask students to list the steps of the scientific method.
- Accept free responces from students.
- Relate scientific method to real world application of engineering.

INTRODUCTION

Engineering design is the creative process of identifying needs and then devising a solution to fill those needs. This solution may be a product, a technique, a structure, a project, a method, or many other things depending on the problem. The general procedure for completing a good engineering design can be called the Engineering Method of Creative Problem Solving.

Problem solving is the process of determining the best possible action to take in a given situation. The nature of problems that engineers must solve varies between and among the various branches of engineering. Because of the diversity of problems there is no universal list of procedures that will fit every problem. Not every engineer uses the same steps in their design process, but Wright (1) following list, which includes most of the steps of the design method that engineers use.

In order to address lower grade levels, an alternate list has been developed and is included in the *Teacher Notes* section of this module.

1. Identifying the problem.
2. Gathering needed information.
3. Searching for creative solutions.
4. Overcoming obstacles to creative thinking.
5. Moving from ideas to preliminary designs (including modeling).
6. Evaluating and selecting a preferred solution.
7. Preparing reports, plans, and specifications. (**Project Planning**)
8. Implementing the design. (**Project Implementation**)

It is important to keep in mind as the steps are briefly described, that in many instances, one or more steps may not appear.

IDENTIFYING THE PROBLEM

Evaluating the needs or identifying the problem is a very important step in finding a solution. An improper definition of the problem will cause the engineer to waste time or arrive at an incorrect solution. It is important that the stated needs be real needs. A great design may be worthless if it duplicates other known designs or doesn't benefit many people.

Broadly define the needs and distinguish them from possible solutions. An example of not distinguishing the needs from a possible solution is seen when looking at the problem of motor vehicle fatalities. Traffic safety specialists defined the problem in terms of *accident prevention* rather than *loss reduction.* By focusing on accident prevention, which is a possible solution to the actual problem of loss reduction, they focused their solutions on driver behavior: driver education, traffic enforcement, and "Drive Safely" campaigns. They overlooked possible benefits from more crash worthy vehicles and a safer roadway environment. (1)

The problem and needs should be stated in objective terms or specific terms as much as possible. Here is an example of a *problem definition* in objective terms.

> Design an energy absorption system that will control the energy of a crash of a 2500-pound car traveling 60 miles per hour. The device should be no longer than 10 feet and should cost no more than $10,000 per unit. The deceleration should not exceed 6 g's.

Contrast this definition with the following definition that is very unspecific:

> Design an energy absorption system that will control the energy of a car traveling at a fast speed at impact. The device should be short and inexpensive to build. The deceleration should not be harmful to the driver.

The first problem definition, is specific and gives the design team specifications that they may work towards. The second definition might be okay for some situations, but it might give too much leeway to the design team. The finished product may not accurately meet the needs of the customer, but might still fit the problem definition because it was too vague or inaccurate.

The engineer should also be careful not to make the problem unnecessarily bound. Placing too many constraints on the problem may make the solution extremely difficult or impossible. A careful examination of the first example definition above, will show that it is over constrained. It is impossible to meet the proposed problem limitations. The laws of physics will not allow it to function at those specifications. The device would have to be longer than 10 feet to stop a 2500 lb. car with only 6g's of deceleration.

GATHERING NEEDED INFORMATION

After defining the problem, an engineer begins to gather all the information and data necessary to solve the problem. It could be physical measurements, maps, results of laboratory experiments, patents, results of opinion surveys, or any number of other types of information.

Engineers should always try to build on what has already been done before. Information on related problems that have been solved or unsolved may help engineers find the best solution.

SEARCHING FOR CREATIVE SOLUTIONS

There are several techniques to help a group or individual to produce original creative ideas. The development of these new ideas may come from *creativity*, a subconscious effort, or *innovation*, a conscious effort.

Some techniques Wright (1) suggests that may aid a group or individual in obtaining a creative solution are brainstorming, checklists, attribute listing, the forced relationship technique, and adopting a different point of view. Each of these will be discussed briefly. The purpose to most of these methods, which can be almost like a game, is to break the set patterns of thought that every individual develops.

Brainstorming

BRAINSTORMING RULES

1. All ideas are encouraged.
2. Record as many ideas as possible.
3. Combine and improve ideas.
4. Delay judgment and evaluation of ideas until end.

A popular technique for group problem solving is brainstorming. Typically, a brainstorming session consists of 6 to 12 people who spontaneously introduce ideas designed to solve a specific problem. In these sessions, encourage and record all ideas, including those that appear completely impractical. Do not allow judgment or evaluation of ideas during the idea generation session. It is important to generate as many ideas as possible, encourage people to build upon the ideas of others. Evaluate the ideas after the session is complete.

Individuals can also use the same techniques to brainstorm without a group.

Checklists

One of the simplest methods for generating new ideas is to make a checklist. The checklist encourages the user to examine various points, areas, and design possibilities. For example to improve a device, you may want a checklist like this:

Ways the device could be put to other uses.
Ways the device could be modified.
Ways the device could be rearranged.
Ways the device could be magnified.
Ways the device could be reduced, etc.

Attribute Listing

With attribute listing, all the major characteristics or attributes of a product, object, or idea are isolated and listed. Then, for each attribute, list ideas as to how each of the attributes could be changed. Again, as in brainstorming, all ideas are listed no matter how impractical. After all the ideas are listed, evaluate each idea bringing to light possible improvements that can be made to the design of the product. For example, how can we improve a telephone design?

Attribute	Ideas
1. Color	Could be any color
	Could be transparent
	Could utilize designs such as plaid
	Could have a personalized design
2. Material	Could be metal
	Could be glass
	Could be wood
	Could be hard rubber
3. Dial	Could be 10-push-button design
	Could be lever system
	Could use abacus-type system
	Could be push buttons arranged in a line
4. Handset and base	Make it square
	Make it round
	Make it oval
	Use higher base
	Use lower base
	Eliminate handset by using microphone and speaker

Forced Relationship Technique

The forced relationship technique takes a fixed element, such as the product or some idea related to the product, and forces it to take on the attributes of another unrelated element. This forms the basis of a free flowing list of associations from which hopefully new ideas will emerge. As before, judge the value of the ideas after the process is complete.

For example, suppose we wish to design a weed-cutting device. This will be the forced object. Suppose we randomly choose an automobile wheel as the other element. Some of the ideas that may occur based upon the automobile wheel are:

A round weed cutter.
A rubber weed cutter.
A weed cutter that rolls.
A weed cutter that has spokes.
A weed cutter that has air in its tires.
A weed cutter that has brakes.
A weed cutter that will not break.

Different Point of View (2)

People sometimes stretch their minds by adopting different points of view. Imagine a similar problem located on a strange planet or in free fall. Try to identify with the stone that is to be crushed, or the fruit that is going to be peeled. Pretend that common materials or components are not available or that certain exceptional ones are. Try to project how nature would do it. The methods are endless.

OVERCOMING OBSTACLES TO CREATIVE THINKING

Here are some specific actions and attitudes that can be employed to overcome obstacles to creative thinking:[1]

1. Avoid placing unnecessary constraints on the problem being solved.
2. Search for different ways to view the problem, avoiding preconceived beliefs and stereotypical thinking.
3. Recognize that there are non-engineering solutions to many problems. Consider approaches that other disciplines might use.
4. Look for relationships that are remote and solutions that are unusual and nontraditional. Most creative thought involves putting experiences and thoughts into new patterns and arrangements.
5. Divide complex problems into manageable parts and concentrate on solving one part at a time.
6. Allow time for incubation, after periods of intensive concentration.
7. Be open to a variety of problem-solving strategies.

MOVING FROM IDEAS TO PRELIMINARY DESIGNS

For engineers to move from ideas to a preliminary design, they must sort through the possible solutions and determine which ones are unworkable and which might have promise. The promising ideas are then molded and worked into plans. Preliminary designs evolve through *analysis* and *synthesis*. Analysis is breaking apart the whole and studying its individual components. Synthesis involves putting together many facts, laws, or principles into a whole idea that will accomplish some result or solve a problem.

There are many techniques an engineer might use to determine if an idea has promise. Preliminary sketching or analysis may show that the idea is a bad one. Laboratory tests may need to be run on a component to see if it will work in a given situation. Perhaps a large research project may need to be undertaken to examine the validity of a process, or its consequences if used as a solution. The engineer must critically examine and study possible solutions, and constantly eliminate poor or inappropriate solutions.

To facilitate the design process, engineers often rely on models. A model simplifies a system or process so that it may be better studied, understood, and used in a design. There are three common models used in engineering: mathematical, simulation, and physical.

Mathematical models usually consist of one or more equations that describe a physical system. Many physical systems can be described by mathematical models. Such models can be based on scientific theories or laws that have stood the test of time, or they may be based on empirical data from experiments or observations. Mathematical models are usually employed for simple systems. The difficulty in deriving the equations for complex systems out weighs their usefulness.

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[1]Wright (1) obtains this partial list from VanGundy (3).

Computer simulation models allow engineers to examine complex systems. Such models may incorporate many empirically based mathematical models as part of the total simulation model. A computer program is developed to describe a system, and this model may then be subjected to many different simulated operating conditions.

Physical models have long been used by engineers to understand complex systems. They probably represent the oldest method of structural design. Physical models have the advantage in that they allow an engineer to study a device, structure, or system with little or no prior knowledge of its behavior or need to make simplifying assumptions. Full scale models are sometimes built, but most often they have been scaled down anywhere from 1:4 to 1:48. Examples of studies made with physical models include:

1. Dispersion of pollutants throughout a lake.
2. Behavior of waves within a harbor.
3. Underwater performance of submarines of different shapes.
4. Performance of aircraft by using wind tunnels to simulate various flight conditions.

EVALUATING AND SELECTING A PREFERRED SOLUTION

There are many criteria that engineers use to evaluate the value of a solution or design, which may depend on the nature of the problem. If the solution involves a product, great importance may be placed on safety, cost, reliability, and consumer acceptability.

Many designers use prototypes to test the operation of the design. The designer could then identify any weak areas of the design and attempt to improve upon them. No idea should be discarded solely on the basis of one prototype or one test. Many great designs have been discarded prematurely and many working prototypes have failed to give acceptable products.

Indirect evaluation can be used as well, to evaluate a design. Scale models can be used to test aircraft design at a fraction of the cost of building a prototype. Computer simulations and mathematical models may not be accurate enough to allow understanding of all the complexities of component interference or turbulence, but they still may be used to approximate the design of the first scale model for wind tunnel testing.

PREPARING REPORTS, PLANS, AND SPECIFICATIONS

After selection of the preferred design, it must be communicated to those who must approve it, support it, and translate it into reality. This communication may take the form of an engineering report, or a set of plans and specifications. Plans and specifications are the engineer's means of describing to a manufacturing division or to a contractor sufficient detail about a design so that it can be produced or constructed. Engineering drawings, written and oral communications, and scheduling and planning a design project are very important in implementing a design smoothly and efficiently.

Engineering Drawings

Engineers create detailed technical drawings that show what the design looks like, what parts are necessary, how to assemble it, and how to operate it once constructed. These *graphical* *specifications* are probably the most important type of documentation for engineering design problems. They communicate visually to the technical team what verbal communications cannot adequately convey. The drawings must be done clearly and according to standards and conventions accepted by the team.

Written Communications

Memorandums, often called memos, are a brief and effective way to keep everyone involved aware of the design's progress. Memos can be distributed to one person or to a list of people within the organization who have an interest in the subject.

A technical report is a much longer and complete record of the design process. It should include everything that was done to solve the problem. As with any communication the technical writing should be clear, direct, and readable by the intended audience. There are many types of reports written by engineers, but in general they all include the following information: (4)

- Cover page, stating title of project, company name, author, and date
- Abstract, giving a short overview and summary of the work
- Table of Contents
- Body of the report, which elaborates on the problem solved, presents background material, procedure used, results and significance of work.
- Conclusions and recommendations, which summarize the results and significance of work.
- Appendices, for the reader who wants to know everything about the work.

Oral Communication

At different stages during the design process an engineer may be called upon to give an oral progress report to the design team, the supervisor, or management and marketing people. The objectives of an oral presentation are the same for a written report: the engineer wants to communicate information and convince the audience. The methods used however are very different. The most important element in for a successful oral presentation is preparation. Here are some pointers for a good oral presentation:

- Be very familiar with the subject of the presentation.
- Know how much time is allotted for the presentation.
- Practice the presentation to cover everything completely within the time limit.
- Know your audience. Match presentation level with audience's understanding level.
- Speak clearly and eloquently.
- Have simple and uncluttered visual materials. Do not put too much information on one visual.
- Have a good summary and conclusion to highlight the important parts of the presentation.
- End the presentation, by asking the audience if they have any questions.

Scheduling and Planning a Design Project

Since a design project is usually much more complicated than finishing physics homework, a complete solution will involve several steps or tasks. Some complex problems will require weeks or months to complete. The design problem solution needs to include a schedule or a plan of when to do the necessary tasks to complete the design. In a good schedule, each task should be completed before its results are needed by another task. The schedule should also make use of all the personnel all of the time. Also since designs frequently are changed and improved throughout the entire process, it is a good idea to schedule design reviews at the end of each project phase.

IMPLEMENTING THE DESIGN

The final stage of the design process is implementation, the process of producing or constructing a physical device, product, or system. Engineers must plan and oversee the production of the devices or products and supervise the construction of the engineered projects. Different engineers may, of course, be involved in this final phase. For the design engineer, implementing the design is the most satisfying stage of all.

TEACHER NOTES

Suggestions for brainstorming activity:

- Students do not write on their worksheet.
- Construct a concept map using the overhead transparency.
- Suggested questions for brainstorming:
    - ♦ What do you think of when you hear the word “design”, “engineer”, etc.?
    - ♦ Why would you need to engineer a design?
    - ♦ In order to meet a need, what should you do or develop? An example to provoke thought might be a need to build an earthquake proof building. A person might solve that need by designing a method to follow, a product to limit shaking, a technique to construction, a structure that would meet the need, etc.

Answers To The Student Worksheet Concept Maps Are:

Engineering Design
- creative
- identifying needs
- solutions to needs
    - method
    - product
    - technique
    - structure
    - project

Engineering Method Of Creative Problem Solving

(for grades 5-8)

1. Think
2. Plan
3. Do
4. Share

(for grades 9-12)

1. Identifying the problem.
2. Gathering needed information.
3. Searching for creative solutions.
4. Overcoming obstacles to creative thinking.
5. Moving from ideas to preliminary designs(including modeling).
6. Evaluating and selecting a preferred solution.
7. Preparing reports, plans, and specifications. (Project Planning)
8. Implementing the design.(Project Implementation)

EVALUATION

Students will include their work as a portfolio entry to be evaluated using the portfolio rubric.

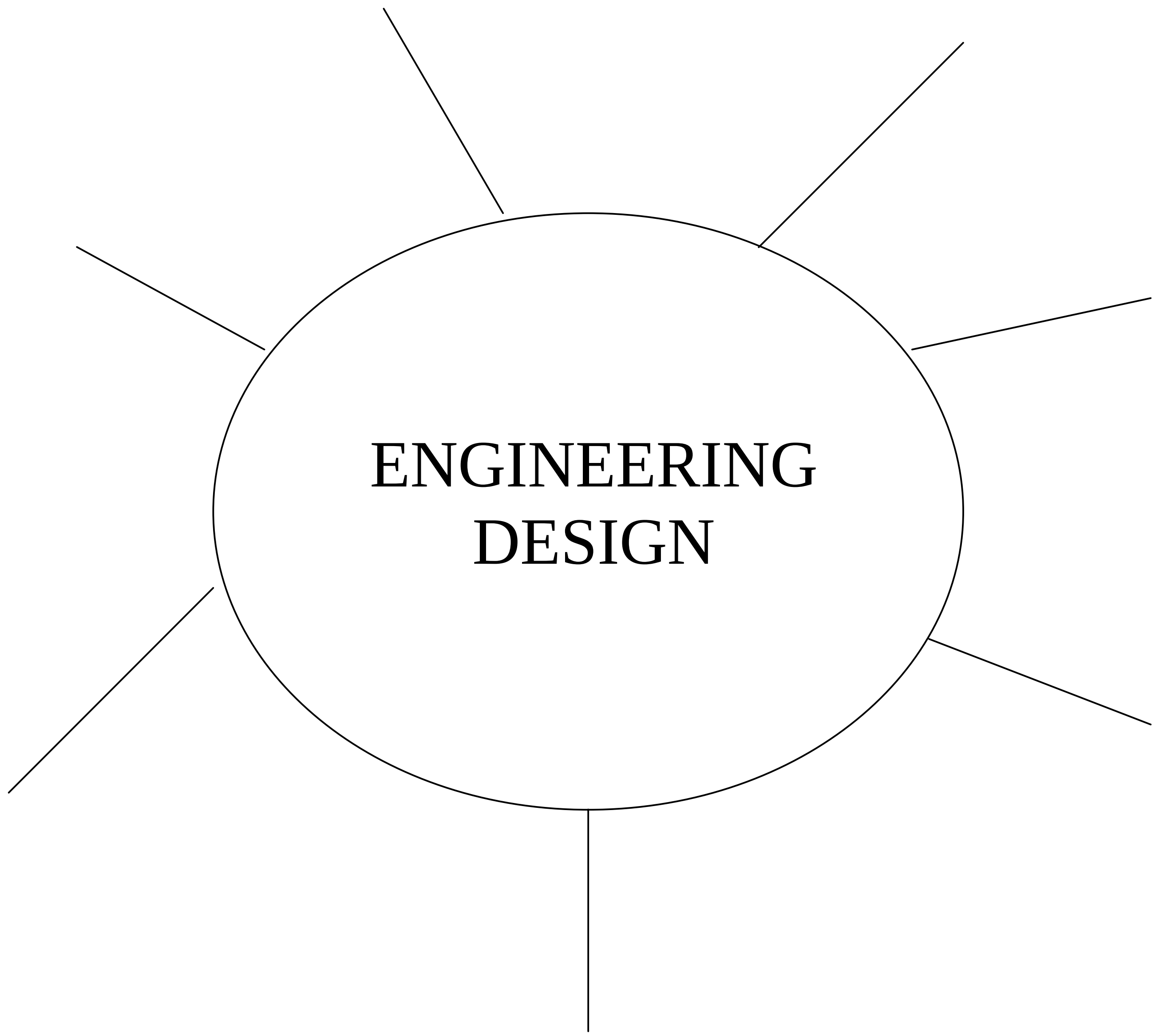
REFERENCES

1. WRIGHT, PAUL H., *Introduction to Engineering, Second Edition.* New York: John Wiley & Sons, Inc., 1994, p.p. 91-117.
2. SIMON, HAROLD A., *A Student's Introduction to Engineering Design.* New York: Pergamon Press Inc., 1975, p.p. 100-101.
3. VANGUNDY, ARTHUR B., *Training Your Creative Mind,* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1982.
4. HOWELL, STEVEN K., *Engineer's Toolkit, A First Course in Engineering: Engineering Design and Problem Solving.* The Benjamin/Cummings Publishing Company, Inc., 1995, p.p. 65-70.

OTHER RESOURCES

BEAKLEY, GEORGE C. AND H. W. LEACH, *Engineering: An Introduction to a Creative Profession, 4th Edition.* New York: Macmillan Publishing Co., Inc., 1982.

HOWELL, STEVEN K., Engineer's Toolkit, A First Course in Engineering: Engineering Design and Problem Solving. The Benjamin/Cummings Publishing Company, Inc., 1995.



Transparency for Brainstorming