HANDS-ON ACTIVITY

Design Step 4: Select a Promising Solution Using Engineering Analysis

Quick Look

Grade Level: 9 (9-12)
Time Required: 1 hour
Expendable Cost/Group: US $0.00
Group Size: 4
Activity Dependency:
Design Step 3: Brainstorm Possible Solutions
Subject Areas: Science and Technology
NGSS Performance Expectations:

HS-ETS1-2

Summary

Selecting a promising solution using engineering analysis distinguishes true engineering design from "tinkering." In this activity, students are guided through an example engineering analysis scenario for a scooter. Then they perform a similar analysis on the design solutions they brainstormed in the previous activity in this unit. At activity conclusion, students should be able to defend one most-promising possible solution to their design challenge. (Note: Conduct this activity in the context of a design project that students are working on; this activity is Step 4 in a series of seven steps that guide students through the engineering design loop.)
This engineering curriculum aligns to Next Generation Science Standards (NGSS).

Various types of engineering analysis guide the development of product design.

Engineering Connection

Using engineering analysis to select a promising solution is the internal guidance of a project. It can be described as the breaking down of an object, system, problem or issue into its basic elements to get at its essential features and their relationships to each other and to external elements. It is an important part of the engineering design loop that occurs many times during the completion of real-life engineering product or system design. Often, a thorough and varied analysis of a design prior to implementation leads to increased safety and efficiency in using the product.

Learning Objectives

After this activity, students should be able to:

- Describe the role of analysis in engineering.
- Evaluate alternatives using an interaction matrix analysis.
- Compare and contrast design alternatives to select the most promising idea.

Educational Standards

- NGSS: Next Generation Science Standards - Science
- Common Core State Standards - Math
- International Technology and Engineering Educators Association - Technology

Materials List

Each group needs

- Famous Failures Case Studies, one per student or pair of students

- Example Evaluating Alternatives Rubric
- Evaluating Alternatives Rubric

Worksheets and Attachments

Famous Failures Case Studies (docx)
Famous Failures Case Studies (pdf)
Famous Failures Case Studies Answer (docx)
Famous Failures Case Studies Answer (pdf)
Example Evaluating Alternatives Rubric (docx)
Example Evaluating Alternatives Rubric (pdf)
Evaluating Alternatives Rubric (docx)
Evaluating Alternatives Rubric (pdf)

Visit [www.teachengineering.org/activities/view/cub_creative_activity4] to print or download.

Introduction/Motivation

Analysis is the essence of being an engineer; it is what distinguishes an engineer from a technician. Engineering analysis helps us make decisions and guide the design process. A design project without analysis is like a softball team without a coach, a ship without a sail, or a class without a teacher — imagine that! So what is engineering analysis, exactly? Basically, it is the breaking down of an object, system or problem, into its fundamental parts to understand their relationships to each other and to outside elements.

For example, let's say you are a part of a team of engineers working to reduce the number of car accidents that occur during rush-hour traffic. You might start by generating a set of design alternatives to this problem: *Expand the roads and highways? Build more bike routes? Design a new subway system?* Let's say your team determines the best alternative is the expansion of roads and highways. Now another design analysis is needed: *How many new stoplights should be constructed? How many lanes do we need? How much money will it cost to maintain these new roads? Will many trees need to be cut down? If so, will this displace birds and other wildlife?*

Do you see how the engineering analysis includes much more than the object or system being designed? Even in the case of building a new road, engineers must analyze the impacts of the new road on the city budget and the surrounding environment and impacted wildlife.

Our history has many examples of engineering projects that either succeeded or failed because of the type of engineering analysis used to evaluate the design. One "success story" in engineering is the development of modern aircraft. A century ago, the first flying machines were very unsafe. Their designs were based more on bird flight than on fundamental engineering concepts. The designers of these flying machines often tested them by jumping off great heights — sometimes meeting their death in the process.

Fortunately, over many years, engineers have developed a much better approach to engineering analysis for airplanes. Today, engineers use computer programs to design and build models of airplanes and see how the models respond to elements and forces such as weather patterns and wind shear.

Now, can anyone think of an engineering "failure?" It's hard to call an unsuccessful engineering project entirely a "failure" because we usually learn the most from failed attempts. In any case, let's take a look at some "famous failures" in engineering and see how the role of analysis played a part in the project. (Hand out the Famous Failures Case Studies to students, one per student or pair of students.)

It's important to understand that the types of engineering analysis are many and different throughout the course of every design loop, and through the course of our project development. Right now, because we are more or less in the conceptual phase of our own design challenge, we will use the engineering analysis process to help us evaluate the best design alternative from our brainstorming results. We will do this by using an "interaction matrix" in which we generate criteria for our design (attributes we think are important) and then rank each of our design alternatives according to these criteria. It may sound complicated, but it is quite useful to help guide your team's decision making process.

(Note: After conclusion of this activity, proceed to the next activity in the series, Design Steps 5 and 6: Create and Test a Prototype.)

Procedure

Background

What differentiates engineering design from simple "tinkering until you get it right" is the role of analysis in the design. Engineering analysis is the internal guidance of a project. It can be described as the breaking down of an object, system, problem or issue into its basic elements to get at its essential features and their relationships to each other and to external elements. The process of analysis is different at various stages of the design process. Toward the beginning of a project, engineers might perform an analysis to select the best design alternative. Once the best design alternative has been agreed upon, the team might perform design analyses that focus on the technical details of the design.

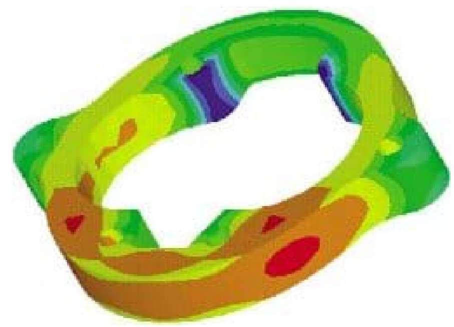
We can learn about the role of analysis in engineering by examining case studies of engineering projects that succeeded — and failed — due largely to the analysis used in the design. First, let's consider the development of airplanes during the past century. Many early flight pioneers died while testing their inventions. These early flying machines were based more on birds and other airborne creatures and less on fundamental engineering equations. However, these early attempts gave birth to the modern field of aeronautics and the fundamental engineering equations used to design modern airplanes.

Another major progression that has helped the aeronautic industry is the development of computer-aided design (CAD) programs. Engineers use these programs to build computer simulations of airplanes and analyze the effects of different materials, forces, weather patterns, and so on. This method of analysis is generally more accurate, cost effective, and safe than testing full-scale physical models.

The design of modern airplanes, such as this Boeing 747, depends on sophisticated engineering analysis techniques.

Computer-aided design analysis is not confined to the aeronautic industry; many automobiles, buildings, and prosthetic devices are designed using advanced computer software.

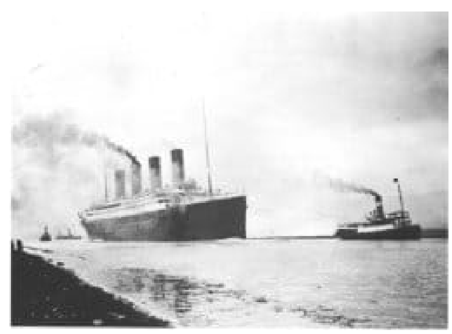
Now, let's look at a famous engineering "failure" of our time. Some past engineering failures have been attributed to following a methodology that seemed to work. However, when scale models or forces were expanded and the designs subjected to external elements, the results were catastrophic.



Computer-aided analysis applied to the design of an automobile gearbox.

The Titanic is one example. Although the Titanic was thought to be the most robust and elaborate ship of its time (in the early 1900s), it sank when its starboard side was punctured by an iceberg, causing the starboard side of the hull to fill with water and tip the giant ship. Unfortunately, the engineering analysis of the ship had been a purely static one, meaning that engineers had analyzed the ship as if it were not moving. This static analysis accounted for the weight of the passengers, cargo and wind forces, while a dynamic analysis would have taken into account external forces such as the unbalancing movement of a collision with an iceberg.

Many advanced analytical tools are needed to perform thorough engineering analyses; hence, it is often difficult for beginning design students to carry out adequate analysis. A good point to make with students is that in the "real world," engineers are continually called upon to learn and apply new engineering concepts in analysis. It is truly a lifelong learning process.



The Titanic – the most elaborate ship of the early 1900s – shown in a sea trial. Thorough engineering analysis is crucial to ensure human safety.

Before the Activity (Teacher Prep)

- Read and review the four attachments (case studies and answer, example rubric, blank rubric).
- Make copies of the Famous Failures Case Studies handout (one per student or pair of students), Example Evaluating Alternatives Rubric (one per team), and Evaluating Alternatives Rubric (one per team).
- Student teams should continue with the same 3-5 members each, as determined in the first activity of this unit, Design Step 1: Identify the Need.

With the Students

1. To introduce the concept of engineering analysis and provide relevant examples, lead the Introduction/Motivation section with the students.
2. (optional) Use the Investigating Questions to discuss the role of analysis in engineering problem solving.
3. Conduct the pre-activity assessment (described in the Assessment section) to help students understand the role of analysis in engineering. This asks students to read the two Famous Failures Case Studies and answer the discussion question at the end, "What factor(s) did the engineers of both the Titanic and the Tacoma Narrows Bridge fail to include in their engineering analysis?"
4. Start the main activity with the students by giving each design team a copy of the Evaluating Alternatives Rubric. (Note: This would be a good time for teams to take out the design challenge project work they have completed in previous activities [defining the problem, background research and brainstorming ideas].)
5. Review the rubric instructions with the students. This is called interaction matrix analysis. It may be helpful to show and refer to the example rubric.
6. Have teams begin their rubric by making lists of all the criteria they can think of to help rank their design alternatives.
7. Next, have teams assess the relative importance of each criterion relative to all the other criteria.
8. Have teams normalize the values by calculating each value as a proportion of a total that equals 1.
9. Teams can now analyze alternative designs according to how well each design satisfies each of the identified design criteria.
10. Lastly, have the teams analyze their results. The design alternative with the highest value is the "best" idea—meaning that it best meets the criteria.

Vocabulary/Definitions

computer-aided design: The use of computer technology for the design of objects; CAD design can also include symbolic information such as materials, processes, dimensions and tolerances.

dynamic analysis: An analysis of an object that accounts for interactions and uncertainties in the environment.

engineering analysis: The breaking down of an object, system or problem, into its basic parts to understand its essential features and their relationships to each other and to outside elements.

rubric: A scoring tool that lists the criteria against which to evaluate a design.

static analysis: An analysis of an object as if it was not moving.

Assessment

Pre-Activity Assessment

Famous Failures: Give each student (or pair of students) a copy of the Famous Failures Case Studies. Ask them to read the two case studies and answer the discussion question at the end: "What factor(s) did the engineers of the Titanic and the Tacoma Narrows Bridge fail to include in their engineering analysis?" See possible answers in the Famous Failures Case Studies Answers.

Activity-Embedded Assessment

Stepping through the Analysis Process: To make sure that students understand the process outlined in the Evaluating Alternatives Rubric, go through the scenario presented in the example rubric. This step-by-step example shows how a student team used the analysis process to evaluate alternatives for a scooter design.

Post-Activity Assessment

Tell It in Two Minutes: Give each team two minutes to summarize the results of the evaluating alternatives process:

1. What were the team's design alternatives?
2. What criteria did the team use to evaluate these alternatives?
3. What was the outcome of the rubric? (In other words, which alternative received the highest score?)
4. Defend why the most promising idea from the analysis is the one that should move forward in the design process.

Investigating Questions

Use the following discussion questions to help students gain understanding of an important aspect of engineering problem solving: **analysis**.

- **What is a major difference between a technician and an engineer?** (A possible answer would explain how engineers provide analysis in their design work. Engineers figure it out with careful testing, calculations and data analysis to evaluate their design.)
- **What are some types of analysis that an engineer could use to test a design?** (Possible answers may relate to: mathematical calculations; testing of stress, loads or function; or computer-aided analysis.)

Troubleshooting Tips

The rubric can be tricky at first. Make sure to review the process of using this matrix (and the example rubric) before asking students to complete the matrix.

Activity Extensions

Real-Life Project Analysis: As part of the teams' background research (completed in the Design Step 2: Research the Problem activity), students were asked to find examples of "real-life: engineering projects similar to their own design challenge." Now, ask students to look more closely at the analysis process used by the engineers for these projects. Did the engineers use computer simulations, build physical models, or perform another type of engineering analysis?

Additional Multimedia Support

Show students a four-minute video about the failed Tacoma Narrows Bridge including footage of the 1940 collapse, at: https://www.youtube.com/watch?v=3mclp9QmCGs.

References

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