EngrTEAMS

EngrTEAMS: Engineering to Transform the Education of Analysis, Measurement, and Science in a Team-Based Targeted Mathematics-Science Partnership

Shake It Up

Grades 4-5

University of Minnesota
STEM Education Center
NSF
INSPIRE Research Institute for Pre-College Engineering
Purdue University

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About EngrTEAMS

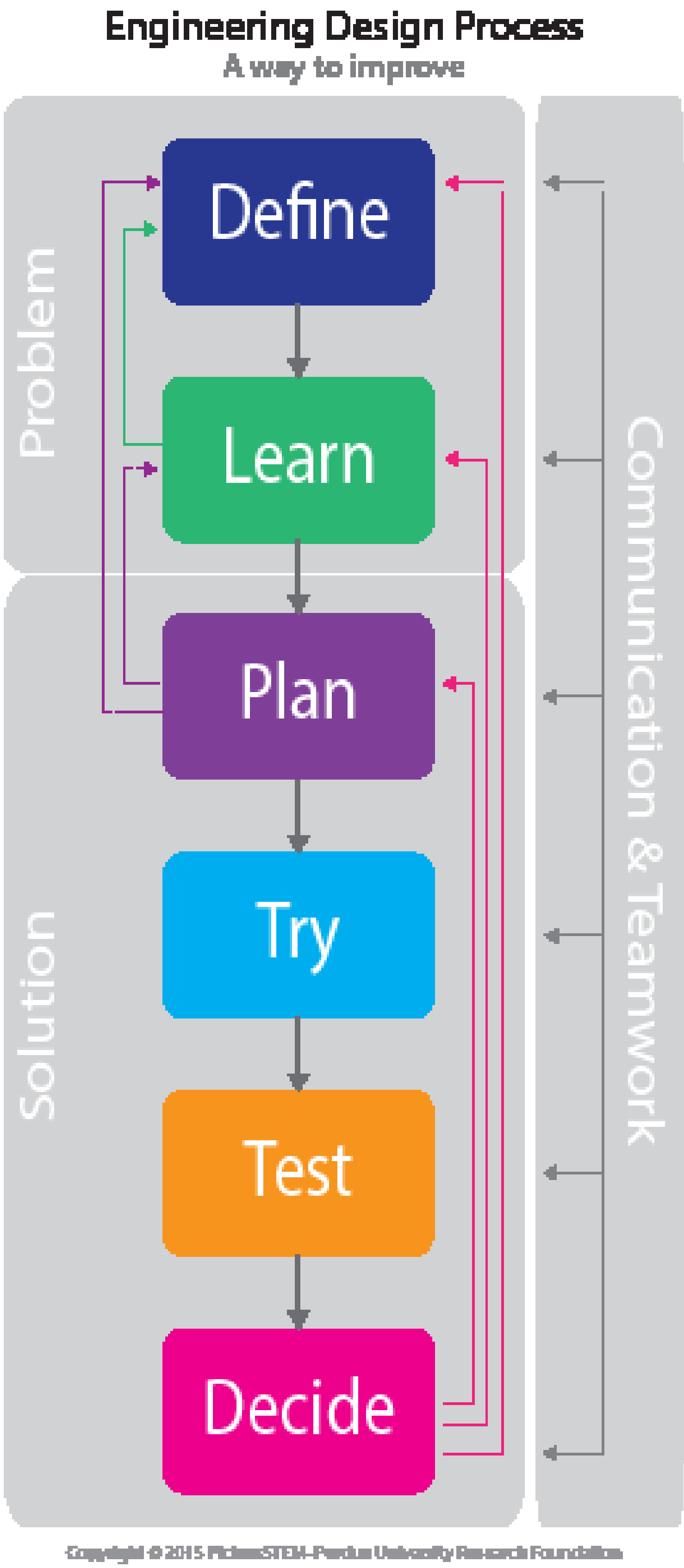
Purpose

The project is designed to help 200 teachers develop engineering design-based curricular units for each of the major science topic areas within the Minnesota State Academic Science Standards, as well as data analysis and measurement standards for grades 4-8.

With a focus on vertical alignment and transition from upper elementary to middle-level, this project will impact at least 15,000 students over the life of the grant.

To learn more about the project and find additional curricular units go to www.engrteams.org.

Overview



Engineering Design Process
A way to improve
Problem
Solution
Define
Learn
Plan
Try
Test
Decide
Communication & Teamwork

DEFINE THE PROBLEM

- Who is the client? What does the client need? Why does she or he need it? Who are the end-users?
- Why is the problem important to solve? What are the criteria (requirements) of the solution? What are the constraints (limits)?
- Problem Scoping: WHO needs WHAT because WHY

LEARN ABOUT THE PROBLEM

- What kind of background knowledge is needed to solve the problem? What science/mathematics knowledge will be needed? What materials will be needed?
- What has already been done to solve the problem? What products fill a similar need?
- How should we measure improvement?

PLAN A SOLUTION

- Continue to specify the criteria and constraints
- Idea generation
- Develop multiple possible solution paths
- Consider trade-offs and relative constraints
- Choose a solution to try
- Develop plans (blueprints, schematics, cost sheets, storyboards, notebook pages)

TRY A SOLUTION

- Put the plan into action
- Consider risk and how to optimize work
- Use criteria, constraints, and trade-offs from problem/plan to build a prototype (a testable representation of a solution), model, or product

TEST A SOLUTION

- Consider testable questions or hypotheses
- Develop experiments or rubrics to know if the solution is meeting the stated criteria, constraints, and needs
- Collect and analyze data

DECIDE WHETHER SOLUTION IS GOOD ENOUGH

- Are users able to use the design to help with the problem?
- Does your design meet the criteria and stay within the constraints?
- How could your design be improved based on your test results and feedback from client/user?
- Iterative nature of design: Consider always which step should be next!

COMMUNICATION & TEAMWORK

- Good oral and written communication and teamwork are needed throughout the entire design process.
- The client should be able to create/follow the solution without ever speaking to you. Include claims and use evidence to support what you believe is true about your solution so that the client knows why they should use it.

Overview

Grade Levels: 4-5

Approximate Time Needed to Complete Unit: Ten 50-minute class periods

Unit Summary

Earthquakes are a natural phenomenon that can have detrimental impacts on the daily lives of humans. Students will learn how engineering can reduce the impact of earthquakes. In addition, students will develop background knowledge on the cause of earthquakes and different types of anchors. Presented with the context of a renewable energy company seeking a way to stabilize their wind turbines in an earthquake prone area, students will design anchors that take into consideration the client's criteria and constraints. Students will test their designs with shake tables and analyze the results to determine the anchors effectiveness at stabilizing the wind turbines.

Science Connections	Technology & Engineering Connections	Mathematics Connections
Earthquakes, plate tectonics, substrate, faults, and environmental impact	Anchors, shake table, and engineering design process	Collect and graph data from experiments, line plots, cost analysis, analyze data and make a data driven decision

Unit Standards

Next Generation Science Standards

- 4-ESS3-2 Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

Common Core State Standards - Mathematics

- 4.MD.B.4 "Make a line plot to display a data set of measurements in fractions of a unit (½, ¼, ⅛). Solve problems involving addition and subtraction of fractions by using information presented in line plots.
- Builds off 3rd grade standard: 3.MD.B.4 Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch. Show the data by making a line plot, where the horizontal scale is marked off in appropriate units— whole numbers, halves, or quarters.

Overview

Unit Assessment Summary

- Throughout this unit, each student will maintain an Engineering Notebook to document their engineering design processes. In this, students will make observations, collect data, and plan for their design. Part of the Engineering Notebook will include answering specific questions related to that day's activities. You may choose to post the questions in your overhead/PowerPoint slides, or give the students printed versions to tape into their Notebooks. Students will also use their Notebooks as a reference – a place to maintain the information they are learning through design. Additionally, students will reflect on their work throughout the design process. This is important for modeling what real-life engineers do. **Collect the Engineering Notebooks at the end of each class.** You will use the Notebooks to assess student learning and their design process. Read the Notebooks and provide feedback to students. You are encouraged to assign points for responses in the engineering notebooks.
- The notebook pages are often set up as handouts in each lesson. If you prefer to use notebooks without having students paste copied pages in them, there is an appendix at the end of this unit that includes notebook prompts and how to have students title each entry.
- The final summative piece of this unit requires students to provide a letter for their client.

Overview

Lesson Summaries

Lesson 1: Earthquake Science

Exploring the cause of earthquakes and how they affect structures. Introduction to the problem from the client.

Lesson 2: Anchors

Investigate a variety of materials for model anchors to determine which will hold a structure stable during an earthquake.

Lesson 3: Planning Anchor Designs

The students will divide into small groups to plan their initial anchor design, referring to the individual and team problem scoping prompts, and using evidence-based reasoning to support their design decisions.

Lesson 4: Try and Test Anchor Designs

The groups will try and test their anchor design. After the first test, they will plan a redesign. They will then try and test their redesign. Throughout this process, the students will be recording data on the effectiveness of their anchor designs at different earthquake magnitudes.

Lesson 5: Analyzing Anchor Designs

The groups will analyze the effectiveness of the anchoring systems used to attach a model wind turbine in a pea gravel substrate. They will compare their two designs and decide on one design to present to the client based on the data they collected from trying and testing.

Lesson 6: Memo to the Client

The students will continue to work in small groups to prepare a memo to the client about their anchoring design.

Overview

Overview

Lesson	Time Needed	**Objectives** The student will be able to:
1: Earthquake Science	Two 50-minute class periods	• Understand how an earthquake occurs • Explain how earthquakes affect structures • Understand context of design project • Engage in problem scoping with the client letter • Understand the concept of engineering and the types of engineering this challenge draws upon
2: Anchors	Two 50-minute class periods	• Investigate a variety of materials for model anchors to determine which are most effective at stabilizing a structure during an earthquake • Learn about different types of anchors
3: Planning Anchor Designs	One 50-minute class period	• Understand the terms renewable energy and environmental impact • Use evidence-based reasoning to justify their design choices • Draw on science concepts, problem scoping, and client needs to inform their design choices

Overview

Materials * required materials not included in the kit	**Duplication Masters**
• **Per Classroom:** (1) Study Jams Earthquake video*, (1) Poster size Engineering Design Slider • **Per Group:** (1) Problem Scoping Team Prompts • **Per Student:** (2) different colored writing utensils*, (1) engineering notebook*, (1) copy of letter from client*, (1) copy of problem scoping individual prompts*	• 1.a. Client Letter • 1.b. Problem Scoping Individual Prompts • 1.c. Problem Scoping Team Prompts
• **Per Classroom:** (1) roll of cotton 10 ply string, (1) roll of 1" masking tape*, (20) large paper clips*, (20) wooden clothespins, (20) large binder clips, (20) medium binder clip, (20) small binder clip, (20) #16 penny nail, (20) plastic drinking straws, (20) 4mm 12" pipe cleaners, (20) wooden stir stick, (20) round plastic disks, (20) 1.5" carriage bolts, (20) wooden golf tees, (20) plastic golf tees, (1) National Geographic earthquake video*, (3) .5 cu. ft. bags of pea gravel, (1) Poster size Engineering Design Process slider, (1)Pad of grid chart paper • **Per Group:** (1) K'nex® wind turbine, (2) write & wipe lapboards, (4) racquetballs, (3) size 32 rubber bands, (1) heavy duty paper tray, (2) copies of observation recording sheet*, (1) ruler*, (1) sheet of grid chart paper, (1) set of markers, (1) copy of snap sheet • **Per Student:** (2) different colored writing utensils*, (1) engineering notebook*, (1) copy of data recording sheet*, (1) sticky note	• 2.c. Observation Recording Sheet • 2.d. Snap Sheet • 2.e. Materials for Testing • **EDUCATOR RESOURCES** • 2.a. Shake Table Construction • 2.b. Tower Construction
• **Per Classroom:** Material line graphs from lesson 2*, (1) roll of 1" masking tape*, (1) Poster size Engineering Design Process Slider • **Per Group:** (1) completed copy of Problem Scoping Team Prompts*, (1) copy of Material Cost and Environmental Impact sheet*, (1) copy of Design 1 Planning sheet*, (1) copy of Evidence-Based Reasoning Graphic* • **Per Student:** (2) different colored writing utensils *, (1) engineering notebook*, (1) copy of letter from the client*, (1) copy of Evidence-Based Reasoning Graphic*, (1) copy of completed Problem Scoping Individual Prompts*	• 3.a. Design 1 Planning Sheet • 3.b. Materials Cost & Environment Impact Sheet • 3.c. Evidence-Based Reasoning Graphic **FROM PREVIOUS LESSONS** • 1.a. Client Letter • 1.c. Problem Scoping Team Prompts **EDUCATOR RESOURCES** • 3.c. Evidence-Based Reasoning Graphic - Poster with Explanation

Overview

Lesson	Time Needed	**Objectives** The student will be able to:
4:Try and Test Anchor Designs	Three 50-minute class periods	• Build a model of an anchor • Test their design and collect data from test results • Learn how to redesign their anchor by modifying their first design • Learn to justify their design decisions based on evidence
5: Analyzing Anchor Designs	One 50-minute class period	• Compare the two anchor designs they made • Decide which anchor should be presented to the client and use evidence to support their reasoning • Learn to make trade-offs and learn to how to prioritize the client's various criteria
6: Memo to the Client	One 50-minute class period	• Collaborate and compromise within their groups to determine which anchor design they want to present to the client • Decide which anchor should be presented to the client and use evidence to support their reasoning • Learn to communicate their solution to a client

Overview

<table>
<tr><th>Materials
* required materials not included in the kit</th><th>Duplication Masters</th></tr>
<tr><td>• Per Classroom: (1) roll of cotton 10 ply string, (1) roll of 1” masking tape*, (20) wooden clothespins, (20) large binder clips, (20) medium binder clip, (20) small binder clip, (20) #16 penny nail, (20) plastic drinking straws, (20) 4mm 12” pipe cleaners, (20) wooden stir stick, (20) round plastic disks, (20) 1.5” carriage bolts, (20) wooden golf tees, (20) plastic golf tees, (20) large paperclips*, (3) .5 cu. ft. bags of pea gravel, (1) Poster size Engineering Design Process slider
• Per Group: (1) K’nex® wind turbine, (2) write & wipe lapboards, (4) racquetballs, (3) size 32 rubber bands, (1) heavy duty paper tray, (1) ruler*, (2) sheets of grid chart paper, (1) set of markers, (2) copies of data recording sheet*, (1) copy of Design 1 Planning sheet, (1) copy of Design 2 Planning sheet, (1) copy of Evidence-Based Reasoning Graphic, (1) copy of Materials Cost and Environmental Impact Sheet*
• Per Student: (2) different colored writing utensils *, (1) engineering notebook*, (1) sticky note</td><td>• 4.c. Data Recording Sheet
• 4.d. Design Challenge Line Plot Sheet
• 4.e. Individual Reflection on Test Results
• 4.f. Team Reflection on Test Results
• 4.g. Evidence-Based Reasoning Graphic
• 4.i. Design 2 Planning Sheet

FROM PREVIOUS LESSONS
• 2.d. Snap Sheet
• 3.a. Design 1 Planning Sheet
• 3.b. Materials Cost & Environment Impact Sheet

EDUCATOR RESOURCES
• 4.a. Wind Turbine Construction
• 4.b. Teacher Observation Protocol: Try/Test
• 4.h. Teacher Observation Protocol: Redesign</td></tr>
<tr><td>• Per Classroom: (1) Poster size Engineering Design Process Slider
• Per Group: Line plot from first anchor design*, Line plot from redesigned anchor*, (1) copy of completed Design 1 Planning Sheet*, (1) copy of completed Design 2 Planning Sheet*
• Per Student: (2) different colored writing utensils *, (1) engineering notebook*, (1) copy of Evidence-Based Reasoning Graphic*, (1) copy of Letter from the Client, (1) sticky note</td><td>• 5.a. Evidence-Based Reasoning Graphic
• 5.b. Criteria-Constraint Checklist

FROM PREVIOUS LESSONS
• 1.a. Client Letter
• 3.a. Design 1 Planning Sheet
• 4.e. Design 2 Planning Sheet</td></tr>
<tr><td>• Per Classroom:(1) Poster size Engineering Design Process Slider
• Per Group: (1) copy of Evidence-based Reasoning Sheet*, (1) sheet of loose-leaf paper*, (1) Rubric for Memo to Client*
• Per Student: (2) different colored writing utensils *, (1) engineering notebook*, (1) copy of individual Evidence-based Reasoning Sheet from lesson 5*</td><td>• 6.a. Evidence-Based Reasoning Graphic
• 6.c. Individual Reflection on Engineering
• 6.d. Team Reflection on Engineering

EDUCATOR RESOURCES
• 6.b. Rubric for Memo to Client</td></tr>
</table>

Overview

	Material	Lessons Where Material is Used
Per classroom	1 poster of Engineering Design Slider 1 roll of string 1 roll of masking tape* 20 clothespins 20 large binder clips 20 medium binder clip 20 small binder clip 20 #16 penny nail 20 plastic drinking straws 20 pipe cleaners 20 wooden stir stick 20 round plastic disks 20 1.5" carriage bolts 20 wooden golf tees 20 plastic golf tees 1 pad of grid chart paper 3 bags of .5 cu. Ft. pea gravel 20 large paperclips*	1, 2, 3, 4, 5, 6 2, 4 2, 3, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4 2, 4, 5 2, 4 2
Per group (assuming 3 students per group)	1 K'nex® wind turbine 2 write & wipe lapboards 4 racquetballs 4 size 32 rubber bands 1 heavy duty paper tray 1 set of markers* 1 ruler* 4 sheets of grid chart paper	2, 4 2, 4 2, 4 2, 4 2, 4 2, 4, 5 2, 4 2, 4, 5
Per student	2 different colored writing utensils * 1 engineering notebook* 3 sticky notes	1, 2, 3, 4, 5, 6 1, 2, 3, 4, 5, 6 1, 2, 3, 4, 5, 6

* required materials not included in the kit

LESSON 1 Earthquake Science

Lesson Objectives

The students will be able to:

- Understand how an earthquake occurs
- Explain how earthquakes affect structures
- Understand context of design project
- Engage in problem scoping with the client letter
- Understand the concept of engineering and the types of engineering this challenge draws upon

Time Required

Two 50-minute class periods

Materials

- **Per Classroom:** (1) Study Jams Earthquake video*, (1) Poster size Engineering Design Slider
- **Per Group:** (1) Problem Scoping Team Prompts
- **Per Student:** (2) different colored writing utensils*, (1) engineering notebook*, (1) copy of letter from client*, (1) copy of problem scoping individual prompts*

Standards Addressed

- Next Generation Science Standards: 4-ESS3-2

Key Terms

earthquake, tectonic plates, fault, client

Lesson Summary

Exploring the cause of earthquakes and how they affect structures. Introduction to the problem from the client and problem scoping based on client letter.

Background

Teacher Background

Teachers should have background knowledge on earthquakes, their causes, plate tectonics, and be prepared to talk to students about constraints and criteria related to solving a client problem. This engineering design challenge falls in the category of civil engineering, which deals with design, construction, and maintenance or redesign of the physical and natural environment. There are three sub-disciplines of civil engineering that this challenge draws on: earthquake, structural, and geotechnical. Earthquake engineering designs and analyzes with earthquakes in mind, which is exactly what the students will be doing with anchors. Another piece related to the anchor design is structural engineering, which looks at structural performance such as stability. Geotechnical engineering is concerned with the behavior of earth materials, such as evaluating how the soil, rock, faults, etc. will interact with the construction. It also assesses the impact or risk from natural hazards like earthquakes. This is a key piece to the challenge as the substrate of pea-gravel creates a rocky environment for the students to consider when designing an anchor that is effective in this environment.

Before the Activity

Have a poster version of the *Engineering Design Slider* posted in an area of the room where it is consistently visible to the class. Insert the *Problem Scoping Individual Prompts* into the students engineering notebooks.

Classroom Instruction

Introduction to the unit:

1. **Introduce the unit. Say:** *We will be working on an engineering project related to a renewable energy company seeking a way to stabilize their wind turbines in an earthquake prone area.*
2. **Introduce the Engineering Design Notebooks. Say:** *Engineers use notebooks to document their design process and keep notes. We will also be using Engineering Notebooks throughout our engineering challenge. Each day, you'll use the notebooks to take notes and record what you are learning. In addition, there are questions that you'll be asked to answer. Sometimes you'll answer the questions first on your own, then in your teams. Each day, turn in your engineering notebooks before you leave class.*

   Note: You can have your students write in their notebooks in two different colors – one for thoughts and prompts that are individual and one for thoughts and prompts that they discuss in their teams. This will help both you assess and the students recognize where ideas came from. You also may want to have students complete a Notebook Cover and start a Table of Contents page. You may choose to have students tape/glue copies of the notebook prompts and/or the duplication masters into their notebooks.

3. **Students individually complete notebook prompts about engineering.** Have students individually answer the following 2 prompts in their notebooks prior to teaching them anything else about the unit or about engineering. Make sure to let them know that it is okay if they do not know very much about engineers or engineering – just have them answer the questions to the best of their ability.
   - What do engineers do?
   - How do engineers solve problems?

Introduction to the Lesson

1. **Students individually complete notebook prompts.** Begin by having the students write a brief reflection in their engineering notebooks about what they know about earthquakes and what they think causes an earthquake.

Activity

1. **Introduce engineering challenge.** Provide each student with a copy of the client letter. Begin by introducing students to the engineering design challenge by reading the *1.a. Client Letter*. Facilitate a discussion about the client letter, the problem, and information needed for a solution, and explain what constraints (limits to the way the problem can be solved) and criteria (solution requirements) are so students are able to identify those pieces during problem scoping.
2. **Introduce engineering.** Lead a discussion on what engineering is and what type of engineering this problem relates to. **Say:** *Engineers use science, math, and the engineering design process to solve problems in order to help people.* Ask the class if they can name any of the different types of engineering. Explain to the class how this problem would fall under the category of civil engineering and draws on geotechnical engineering, structural engineering, and earthquake engineering.
3. **Define the *Engineering Design Process*.** Go through the *Engineering Design Process Slider* and ask the students what they think each stage involves. Be sure to clarify any misconceptions and elaborate where needed. There is a detailed description of the engineering design slider in the front matter of the unit. **Ask:** *Based on what we have discussed so far, where do you think we are in the engineering design process?* (Define).
4. **Develop questions for the client.** Have them individually answer the prompt: *"What questions do you want to ask the client?"* in their engineering notebooks. Then break them into their teams that they will be in for the unit.Give them time to share their list with their team and develop a team set of questions. Students can use a different color pens for their response and their team response.
5. **Share questions.** As a whole group, share these questions. Record students' questions for the client on chart paper labeled "Questions for Client". Leave space near each question for its answer to be recorded later.
6. **Provide the client's answers to the questions.** This may be done in several ways. This includes, but is not limited to: pretending to call or email the client and ask the questions; telling the students that the client has already provided a list of answers to questions they anticipated

Assessments

Pre-Activity Assessment
A reflection on prompt, *"What do you know about earthquakes and what do you think causes an earthquake"* in their engineering notebooks.

Students write in engineering notebook to answer questions "What do engineers do?" and *"How do engineers solve problems?"*

Activity Embedded Assessment
Individual student responses in engineering notebook to problem scoping prompts.

Post-Activity Assessment
Draw and label or describe what causes an earthquake.

DUPLICATION MASTERS

- 1.a. Client Letter
- 1.b. Problem Solving Individual Prompts
- 1.c. Problem Scoping Team Prompts

EDUCATOR RESOURCES

- none

student engineers would ask; telling them that you have had lengthy discussions about the problem, and the client has given you permission to act on their behalf; inviting a guest speaker to pretend to be the client and answer students' questions. Record the client's answers to the questions on the chart paper labeled "Questions for Client", preferably in a different color than the questions.

7. **Students answer the *Problem Scoping Prompts* in their notebooks.** Give the students 15 to 20 minutes to work on the *1.b. Problem Scoping Individual Prompts* in their engineering notebooks. In their teams, students will go through the prompts and have an opportunity to share their responses to the prompts, discuss, and develop a team response together and complete the *1.c. Problem Scoping Team* prompts. You may post these sheets or make copies and have students attach them in their notebooks.
8. **Transition the discussion to earthquakes. Say:** *We are now going to look at how earthquakes affect the stability of structures.* Have the students make two fists and place their knuckles together. **Say:** *Each fist represents a tectonic plate. Have the students push their fists together to the point where their knuckles slip apart.* **Say:** *When you moved your fists, it represented the tectonic plates moving. When your knuckles slipped, it created a fracture or break since your knuckles no longer fit together. This is called a fault. A fault causes earthquakes.*
9. **Show the earthquake video.** Show the Earthquakes video to provide background information. Study Jams earthquake video http://studyjams.scholastic.com/studyjams/jams/science/rocks-minerals-landforms/earthquakes.htm This video introduces the cause of earthquakes and associated vocabulary such as faults and tectonic plates.

   Note: This is the preferred video, but if the link is not available, you can also use:
   - *"What is an Earthquake? The Dr. Binocs Show"* https://www.youtube.com/watch?v=dJpIU1rSOFY or
   - *"What is an Earthquake? Facts & Information Mocomi Kids"* https://www.youtube.com/watch?v=hlePrsXTGxQ
10. **Discuss the earthquake video. Ask:** *What terms or ideas were brought up in the video?* Talk through the vocabulary and concepts that were introduced in the video.
11. **Think-pair-share about how earthquakes affect structures.** Do this individually, then turn to neighbors and discuss, finally share out ideas with the whole class.
12. **Tie to engineering design.** Bring the discussion back to the client letter by **asking:** *How can we use our knowledge of earthquakes to design an effective anchor? How will we test to see if our designs are effective?* Refer the students to the classroom engineering design slider. **Ask:** *Based on what we have discussed today, where do you think we are in the engineering design process now?* (Learn)
13. **Respond to *Exit Slip* prompt.** Have students prepare an exit slip (that will be placed in their engineering notebooks later) on a sheet of loose-leaf paper using the following prompt: *Draw and label or describe what causes an earthquake.*

Closure

1. **Review learning.** Review the cause of earthquakes, the student discussions about how they affect structures, and the connection to the client’s problem.

LESSON 1

Name________________________________ Date____________ Period _____

1.a. Client Letter

4321 Shaking Drive
Windy City, USA 12131

Dear STEM students,

Our company is a major developer of wind turbines. Wind energy is rapidly becoming popular as an affordable and clean alternative energy source. We are planning on developing a wind farm to provide Windy City with renewable energy. Unfortunately, Windy City is located in a region prone to earthquakes. Additionally, the land we have purchased to build the wind farm on is very rocky.

Geologists have determined that while a large catastrophic earthquake is unlikely, smaller shocks on the order of magnitude of 1, 2, or 3 on the Richter scale are common. As earthquakes create a risk of our wind turbines falling over, we are seeking an anchor design that will stabilize the wind turbines to withstand earthquakes. The anchor design needs to help the wind turbine withstand earthquakes of lower magnitude on the Richter scale, as well as higher magnitude earthquakes in the event that a catastrophic earthquake does happen.

As we provide a source of affordable energy, we would like to keep the cost of the anchors at a minimum and are providing you with a budget of $2500. Also, since we provide a source of renewable, sustainable energy, anchoring systems with materials that minimize our environmental impact will be an important consideration.

We need your help designing an anchor that can help our wind turbines effectively withstand earthquakes in this area and also considers cost and environmental impact.

Sincerely,

Elsa Marvel

Elsa Marvel
CEO of Breeze Structures Inc.

LESSON 1

Name_________________________________ Date___________ Period _____

1.b. Problem Scoping Individual Prompts

O**n your own**, answer each of the following questions. Later in your team, each person will share their response and discuss. You will then **write a revised answer to these question**, based on the discussion with your team.

1. **Who is the client?**

2. **What is the client's problem that needs a solution?**

3. **Why is the problem important to solve?**

4. **Who are the end-users?**

5. **What will make a solution effective (criteria)?**

6. **What will limit how you can solve the problem (constraints)?**

7. **Think about the problem of wind turbines without anchors during an earthquake. In terms of designing an anchor to stabilize a wind turbine during an earthquake, what do you need to learn in order to create a successful anchor?**

LESSON 1

Name______________________________ Date___________ Period _____

1.c. Problem Scoping Team Prompts

DEFINE THE PROBLEM

Within your teams, each person is to share the following:
1. Information you gathered to understand problem.
2. What you identify as the problem.
3. Why the problem is important to solve.

Then, based on group discussion, answer the following questions as a team:
1. Who is the client?

2. What is the client's problem that needs a solution?

3. Why is the problem important to solve?

4. Who are the end-users?

5. What information will you need to solve the problem?

CRITERIA AND CONSTRAINTS
6. Compare each team members' list of criteria and constraints. How are they similar?

Name__________________________________ Date___________ Period _____

1.c. Problem Scoping Team Prompts

7. Are there any differences?

8. What will make a solution effective (criteria)?

9. What will limit how you can solve the problem (constraints)?

BACKGROUND INFORMATION

10. Think about the problem of wind turbines without anchors during an earthquake. In terms of designing an anchor to stabilize a wind turbine during an earthquake, what do you need to learn in order to create a successful anchor?

LESSON 2

Anchors

Lesson Objectives

The students will be able to:

- Investigate a variety of materials for model anchors to determine which are most effective at stabilizing a structure during an earthquake
- Learn about different types of anchors

Time Required

Two 50-minute class periods

Materials

- See Overview

Standards Addressed

- Next Generation Science Standards: 4-ESS3-2
- Common Core State Standards – Mathematics: 4.MD.B.4

Key Terms

anchor, stability, magnitude

Lesson Summary

Students will learn about anchors and will test and collect observable data on the stability of different materials for model anchors using shake tables.

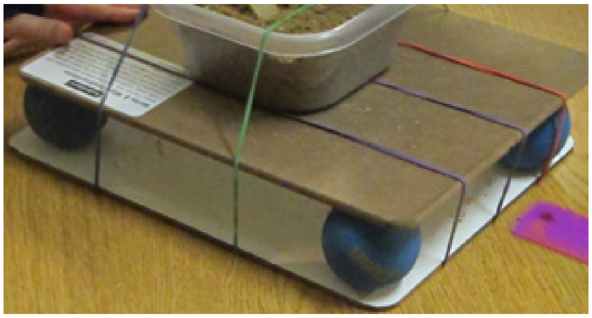
Background

Teacher Background

Structures in earthquake prone areas rely on modifications like anchors to help maintain stability. The engineers job is to secure the structure with an anchoring system. Review two types of anchors with the students: mushroom anchor and screw/single helix earth anchor. A mushroom anchor is shaped like a mushroom, with the head buried into the ground. When a mushroom anchor is buried, it can have a holding power ten times its weight. The greater surface area of the mushroom head helps to disperse the holding power, lending to improved stability. A screw or single helix anchor is run spirally into the ground to resist the force from the earthquake tremors. They typically have a higher holding power, but require the use of special tools to screw in. These two types of anchor designs achieve similar stabilizing results, but through different designs.

Before the Activity

Prior to the lesson, the teacher needs to build K'nex® tower and shake tables for each group. The teacher will also need to fill the heavy duty paper tray to a 1.5" height with pea-gravel. This will be placed on top of the shake tables. The K'nex® tower will be placed on top of the pea-gravel substrate. Step-by-step instructions for constructing these items can be found on educator resource pages *2.a. Shake Table Construction* and *2.b. Tower Construction.*



Shake table design (modify rubber bands to two length-wise, and one width-wise across the middle. The heavy duty paper tray will not be secured by the rubber bands; it will simply rest on top.).

Tower design

Classroom Instruction

Introduction

1. **Tie to the engineering problem. Ask:** *What is our engineering design problem?* (Take students answers.)
2. **Identify where they are in the engineering design process. Say/Ask:** *So far, we have defined the problem in detail with help from our client.* (Point out "Problem" block on engineering design process, and have students

look at their Engineering Design Process sliders.) *Before we can start designing solutions, though, we need more information. What step of the engineering design process are we in?* (Learn)

3. **Identify what students need to learn about. Say/Ask:** *In the previous lesson, you all identified what we need to learn about. What were some of those ideas we need to learn?* Remind students to refer to their notes from the previous lesson, specifically the last question. Students should say something about how to mitigate the effects of earthquakes on structures.
4. **Elicit prior knowledge.** Have the students write a brief response in their engineering notebooks to the prompt: *What do you know about anchors, and what factors do you think makes an anchor effective?*

Activity

1. **Show the video and start discussion.** Show the National Geographic Earthquakes video (or alternative). National Geographic earthquake video: http://video.nationalgeographic.com/video/101-videos/earthquake-101 This video builds on students' knowledge of earthquakes and shows the effect earthquakes can have on structures. This is the preferred video, but if it is not available you can use:
   - "Bill Nye Earthquakes" https://www.youtube.com/watch?v=mHX6lnxem-0 or
   - "Earthquakes in 150 seconds" https://www.youtube.com/watch?v=RYQiN_By1Lk

   Facilitate a discussion about the impact of earthquakes on structures. **Ask:** *What did you notice in the video about the impact earthquakes have on structures?*
2. **Discuss anchors.** Bring the discussion to the topic of anchors.
   - Explain two different types of anchors to the students: mushroom anchor and screw/single helix anchor.
   - Explain how each type of anchor provides stability to a structure and draw a diagram of the two types of anchors on chart paper.
   - After explaining how anchor design can influence the effectiveness of an anchor, **ask:** *What other factors do you think influence the effectiveness of an anchor?* If a student mentions material of the anchor, stop the discussion and explain that is what they'll be testing to help with their planning. If no students mention material of the anchor, explain to the class how that is an additional factor that can influence the effectiveness of the anchor.
3. **Demonstrate the effectiveness of a paperclip as a material for the model anchors.** Attach the paperclips to the base of the tower and bury the paperclips in the pea-gravel. Explain the that shake table will be used to simulate an earthquake. Pull the short end of the shake table back 4 cm, 8 cm, then 12 cm using *2.d. Snap Sheet* to measure those distances. Have the class share their observations from the anchor demonstration. While students are sharing, highlight the terms "sway", "tip" and "fall" to come to a common understanding of what each of those terms means.
4. **Introduce testing of anchor materials.** Display *2.e Materials Testing Sheet* or distribute copies to the teams. **Say:** *Each team will select two*

Assessments

Pre-Activity Assessment
A reflection on prompt, *"What do you know about anchors and what factors do you think makes an anchor effective?"* in their engineering notebooks.

Activity Embedded Assessment
Use group completed observation sheets on the effectiveness of each of the two materials that were tested to check for understanding of the factors that affect stability.

Post-Activity Assessment
Students write a response in their engineering notebook to the prompt: *Write a claim about the effectiveness of anchor materials, using the data we collected to support your claim.*

DUPLICATION MASTERS
- 2.c. Observation Recording Sheet
- 2.d. Snap Sheet
- 2.e. Materials for Testing

EDUCATOR RESOURCES
- 2.a. Shake Table Construction
- 2.b. Tower Construction

different anchor materials to test. Each group will have different materials. For materials that cannot attach to the tower on their own, you may get 5 cm of masking tape to secure the material to the structure. Each material needs to be buried in the pea-gravel, and cannot be attached to the sides or bottom of the paper tray. The base of the structure cannot buried in the pea-gravel. For the test, each group will pull the shake table back once at 4 cm, once at 8 cm, and once at 12 cm.

5. **Students test anchor materials.** Have the groups test the materials and record their observations on the effectiveness of the materials. Students should record their observations on *2.c. Observation Recording Sheet* noting how they set up the material, what they noticed happen when they tested, and if the tower swayed, tipped or fell over.
6. **Students share their observations.** Have each group share with the class how they set up both of their materials and the observations they made when testing.
7. **Discuss the factors that affect stability.** With the class, discuss the factors that affect the stability of the tower. Support students in identifying (1) the depth of the anchor, (2) anchoring two sides of the tower, and (3) the effectiveness of different materials as the three main factors. Following this discussion collect student *2.c. Observation Recording Sheets* to make copies so that each group has all the information to design in lesson 3.

Closure

1. **Tie work to the engineering design process. Ask:** *Based on what we have done today, where do you think we are in the engineering design process now?* (Learn). Discuss that they tested materials for their engineering design, but that this is different than the "test" in the EDP which is to test their designed solutions. Have the students write a claim about the effectiveness of (an) anchor material(s) using data to support their claim on a sticky note as their exit ticket.

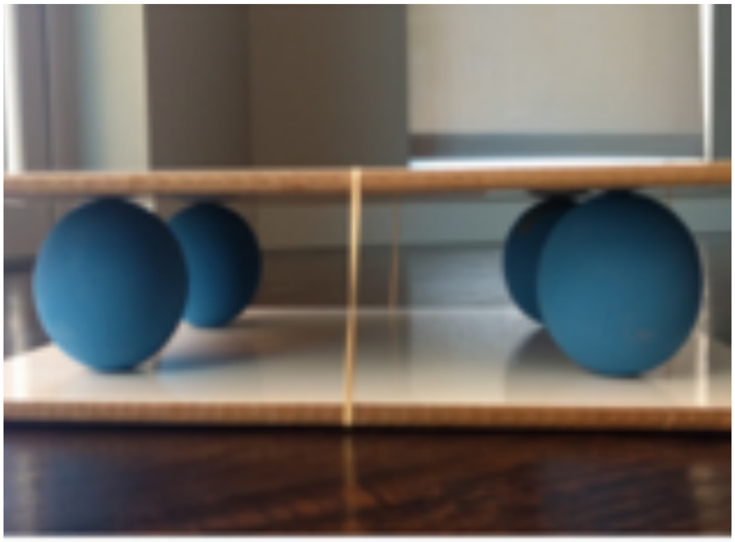
2.a. Shake Table Construction

Step 1
Stack two lapboards.

Step 2
Secure with two rubber bands.

Step 3
Secure with a third rubber band.

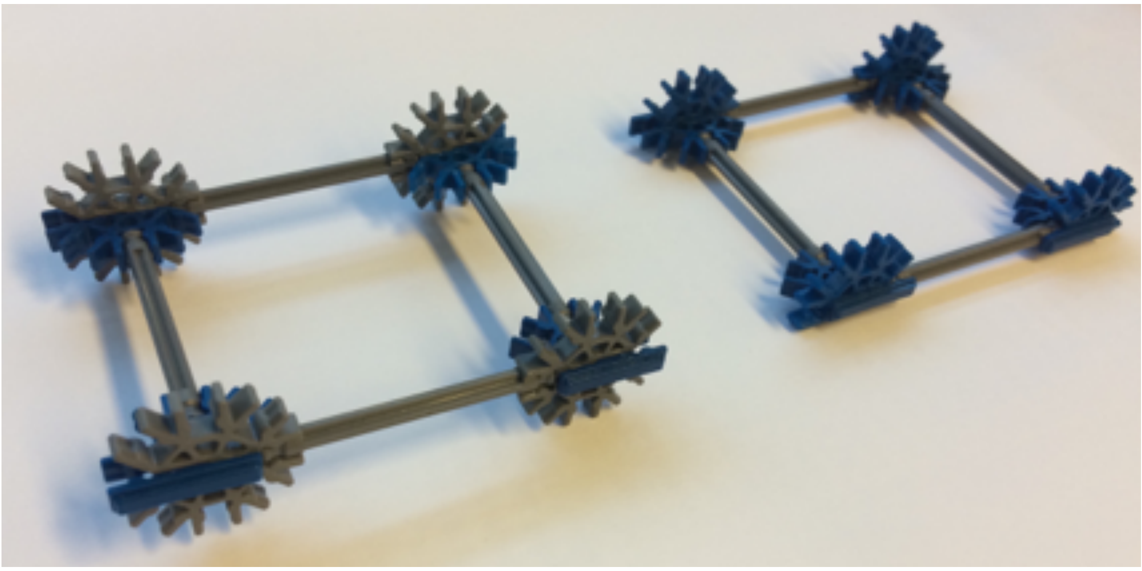
Step 4
Place four raquetballs between lapboards.



2.b. Tower Construction

Step 1

Make bases as shown in the image below.



Step 2

Connect bases at each corner with the long orange K'Nex® pieces.

LESSON 2

Name______________________________________ Date_____________ Period ______

2.c. Observation Recording Sheet

Anchor Material #1 ______________		Test 1	Test 2	Test 3
Pull Distance	4 cm	How was it set up?	How was it set up?	How was it set up?
		Observations	Observations	Observations
	8 cm	How was it set up?	How was it set up?	How was it set up?
		Observations	Observations	Observations
	12 cm	How was it set up?	How was it set up?	How was it set up?
		Observations	Observations	Observations

LESSON 2

Name________________________________ Date__________ Period _____

2.d. Snap Grid

Directions: Place the shake table so the edge lines up with the 0 cm line and the 4 cm, 8 cm, and 12 cm pull distance lines are visible. Pull the top of the shake table to the desired pull distance line and release to test.

---

0 cm – Put the edge of the shake table here. ↑

---

4 cm

---

8 cm

---

12 cm

LESSON 2

Name______________________________ Date__________ Period _____

2.e. Materials for Testing

Materials
Clothespin
Large binder clip
Medium binder clip
Small binder clip
#16 penny nail
10 cm drinking straw
Pipe cleaner
Wooden stir stick
Round plastic disk
1.5” carriage bolt
Wooden golf tee
Plastic golf tee
Large paperclip

LESSON 3

Planning Anchor Designs

Lesson Objectives

The students will be able to:

- Understand the terms renewable energy and environmental impact
- Use evidence-based reasoning to justify their design choices
- Draw on science concepts, problem scoping, and client needs to inform their design choices

Time Required

One 50-minute class period

Materials

- **Per Classroom:** Material line graphs from lesson 2*, (1) roll of 1” masking tape*, (1) Poster size Engineering Design Process Slider
- **Per Group:** (1) completed copy of Problem Scoping Team Prompts*, (1) copy of Material Cost and Environmental Impact sheet*, (1) copy of Design 1 Planning sheet*, (1) copy of Evidence-Based Reasoning Graphic*
- **Per Student:** (2) different colored writing utensils*, (1) engineering notebook*, (1) copy of letter from the client*, (1) copy of Evidence-Based Reasoning Graphic*, (1) copy of completed Problem Scoping Individual Prompts*

Standards Addressed

- Next Generation Science Standards: 4-ESS3-2
- Common Core State Standards – Mathematics: 4.MD.B.4

Key Terms

environment, renewable, evidence

Lesson Summary

The students will divide into small groups to plan their initial anchor design, referring to the individual and team problem scoping prompts, and using evidence-based reasoning to support their design decisions.

Background

Teacher Background

The client for the challenge provides a source of renewable energy through wind turbines. Renewable energy means that the energy source is one that can be replenished naturally, such as sun or wind, and unlike oil or coal. It is important to the company to reduce their carbon footprint and therefore, they would prefer to use materials that have a lower environmental impact, such as those that can be recycled or are sustainable.

Before the Activity

Make copies of the *2.c. Observation Recording Sheets* that the students completed in the previous lesson so that each group will have the information about every material tested.

Classroom Instruction

Introduction

1. **Tie to the engineering challenge.** Have the students write a response in their engineering notebook to the prompt: “*Why are the science concepts of earthquakes and stability important to solving the client’s problem of anchoring wind turbines?”*

Activity

1. **Introduce environmental impact.** Introduce the students to the *3.b. Materials Cost and Environmental Impact* sheet. **Say:** *In the letter from Breeze Structures, they mentioned that materials that minimize their environmental impact is important. What do you think they mean by environmental impact?*
2. **Discuss renewable energy.** Explain to the class that wind turbines are a form of renewable energy. **Say:** *Renewable energy is collected from resources that replenish naturally, like wind.* Emphasize that this company is dedicated to reducing harmful impacts on the environment. Materials made of metals or wood have a lower environmental impact because they can be recycled. Explain that while plastic can also be recycled, it is limited in how many times it can be recycled and can be more harmful to the environment.
3. **Show costs of materials and environmental impact.** Using the *3.b. Materials Cost and Environmental Impact Sheet*, show the class that each material has a cost that they must consider when keeping to their budget of $2500 and an environmental impact score.
4. **Complete the *3.c. Evidence-Based Reasoning Graphic.*** Explain that each student will individually complete a *3.c. Evidence-Based Reasoning Graphic* (either have them draw them in their notebooks or attach the copy in their notebook). Inform them that they should refer to the previous lessons work to help them to complete this task. The following will be particularly helpful: *1.c. Problem Scoping Team Prompts*, copies of *2.c.*

Observation Recording Sheets for all materials, *3.b. Material Cost and Environmental Impact Sheet*, and *1.a. Client Letter*.

5. **Discussion of *3.c. Evidence-Based Reasoning Graphic* in teams.** Have the students get in their teams and discuss their responses to the *3.c. Evidence-Based Reasoning Graphic.* They will work together to complete a team copy of the *3.c. Evidence-Based Reasoning Graphic*.
6. **Tie work to the engineering design process. Ask:** *Based on what we are doing today, where do you think we are in the engineering design process?* (Plan) Remind the class that their team copy of the *3.c. Evidence-Based Reasoning Graphic* will be an essential reference point for their design. Students will work in groups to design an anchor for Breeze Structures. They will complete a copy of the *3.a. Design 1 Planning Sheet*. Individual students should keep notes in their notebooks for the *3.a. Design 1 Planning Sheet.*

Closure

1. **Individually reflect on the team design.** Have students answer the following prompts in their engineering notebooks:
   - *What are the pros and cons of your solutions (your individual solution and the team chosen solution)?*
   - *Why did your team choose the solution you did?*
2. **Consider future work on the engineering design process.** After the students have finished their plans. Bring the class together to look at the *Engineering Design Process Slider*. **Ask:** *Based on what we have done today, what stage of the engineering design process will we be at next?* (Try and Test)

Assessments

Pre-Activity Assessment

Have the students write a response in their engineering notebook: *"Why are the science concepts of earthquakes and stability important to solving the client's problem of anchoring wind turbines?"*

Activity Embedded Assessment

Students will individually complete the Evidence-Based Reasoning Graphic to ensure they are all able to contribute to team planning and the team Evidence-Based Reasoning Graphic.

Post-Activity Assessment

Team completes Design 1 Planning sheet with a design and justification that fits with the team responses to the Evidence-Based Reasoning Graphic.

DUPLICATION MASTERS

- 3.a. Design 1 Planning Sheet
- 3.b. Materials Cost & Environment Impact Sheet
- 3.c. Evidence-Based Reasoning Graphic

EDUCATOR RESOURCES

- 3.c. Evidence-Based Reasoning Graphic - Poster with Explanation

FROM PREVIOUS LESSONS

- 1.a. Client Letter
- 1.c. Problem Scoping Team Prompts

LESSON 3

Name________________________________ Date___________ Period _____

3.a. Design 1 Planning Sheet

Engineers: ______________________ ______________________

______________________ ______________________

Sketch of Anchor Design
(Include Labels of Materials)

Material	Cost	Impact
Total		

Impact: 1-5: Low, 5-10: Medium, 11 or more: High

Anchor description: ____

____

____

Why did you make these design choices? ____

____

____

____

Name________________________________ Date____________ Period ______

3.b. Materials Cost & Environment Impact Sheet

Material	Cost	Environmental impact? (1-10) 1 low-impact and 10 high-impact
10 cm string	500	1
5 cm masking tape	500	5
Clothespin	150	5
Large binder clip	600	8
Medium binder clip	450	7
Small binder clip	300	6
#16 penny nail	750	2
10 cm drinking straw	300	8
Pipe cleaner	1200	5
Wooden stir stick	450	2
Round plastic disk	150	8
1.5” carriage bolt	300	3
Wooden golf tee	450	3
Plastic golf tee	300	6
Large paperclip	400	3

LESSON 3

Name________________________________ Date___________ Period _____

3.c. Evidence-Based Reasoning Graphic

Problem with Criteria & Constraints (What do you need to worry about?)	
Problem: ______________________________	
Criteria: ______________________________	
Constraints: ______________________________	
Simplifying Assumptions (What do you not need to worry about?)	
Plan (Design Idea)	**Data/Evidence** (Facts)
Explanation, Justification, Reasoning (Why do you think this will work?)	

LESSON 3

Name________________________________ Date__________ Period ______

3.c. Evidence-Based Reasoning Graphic

Poster with Explanation

Problem with Criteria & Constraints (What do you need to worry about?)

Problem: the engineering problem the client asked you to solve

Criteria: the requirements, or goals, of the designed solutions

Constraints: things that limit design possibilities

Simplifying Assumptions (What do you not need to worry about?)

Ways to make a complex problem simpler

Plan (Design Idea)	**Data/Evidence** (Facts)
• Description of the design • Drawings of the design, different views • Dimensions (sizes) • Label materials in design (show where they are used) • Interesting features	Observations and data that show why you think your design will work Examples: • Data from Conductor Lab and Insulator Lab • Total cost of design

Explanation, Justification, Reasoning (Why do you think this will work?)

Complete sentences that state why you think your design will be successful. These sentences should refer to the problem, criteria, constraints, idea, and data/evidence.

LESSON 4

Try and Test Anchor Designs

Lesson Objectives

The students will be able to:

- Build a model of an anchor
- Test their design and collect data from test results
- Learn how to redesign their anchor by modifying their first design
- Learn to justify their design decisions based on evidence

Time Required

Three 50-minute class periods

Materials

- See Overview

Standards Addressed

- Next Generation Science Standards: 4-ESS3-2
- Common Core State Standards – Mathematics: 4.MD.B.4

Key Terms

test, record, data, magnitude

Lesson Summary

The groups will try and test their anchor design. After the first test, they will plan a redesign. They will then try and test their redesign. Throughout this process the students will be recording data on the effectiveness of their anchor designs at different earthquake magnitudes.

Background

Teacher Background

The strength or magnitude of an earthquake is measured on the Richter scale. The Richter scale measures the magnitude of an earthquake on a scale of 0-9, with 9 being catastrophic. Different earthquake magnitudes will be simulated for the students by having various pull distances for the shake table. The greater the pull distance, the greater the magnitude which results in more shaking/ tremors for the wind turbine anchoring system to withstand.

Before the Activity

Prior to the lesson, the teacher needs to build K'nex® wind turbines and shake tables for each group (see 4.a. Wind Turbing Construction for instructions). The teacher will also need to fill the heavy duty paper tray to a 1.5" height with pea-gravel. This will be placed on top of the shake tables. The K'nex® wind turbines will be placed on top of the pea-gravel substrate.

Classroom Instruction

Day 1

Introduction

1. **Tie lesson to engineering design.** Inform the students that they will be building and testing their first anchor design today. **Ask:** *Can you tell me where we are on the Engineering Design Process Slider right now?* (Try) Have the students write a reflection on prompt, *"Why is it important for engineers to test their designs?"* in their engineering notebooks.

Activity

1. **Gather materials.** Groups will collect the materials listed on their *3.a. Design 1 Planning Sheet.*
2. **Give directions for trying their design.** Remind the students that they must build their anchor as it was drawn, any changes they would like to make can be saved for the redesign. Groups will build the design they sketched on their *3.a. Design 1 Planning Sheet.*
3. **Assess students as they try their design.** Use the *4.b. Teacher Observation Protocol: Try/Test Lesson* sheets to assess students as they try their design (Part 1 and Part 3).
4. **Test the anchor designs.** After building their first anchor design, groups will attach the anchoring system to the K'nex® wind turbine and bury the anchor in the pea-gravel. Remind the class that the anchor cannot be attached to the paper tray.
   - Explain to the class that earthquakes can have different magnitudes. The magnitudes are measured on the Richter scale. Explain that they will be simulating different earthquake magnitudes by pulling the shake table back to different distances of 4 cm, 8 cm, and 12 cm. Pull the short end of the shake table back 4 cm, 8 cm, then 12 cm using *2.d. Snap*

Sheet to measure those distances.The greater the pull distance, the greater the magnitude.

- **Ask:** *Could someone tell me what magnitude Breeze Structures needs the anchors to withstand?* After student responses, **say:** *Even though a high magnitude earthquake is unlikely, remember that Breeze Structures is still seeking an anchoring system that can withstand a catastrophic earthquake as a precaution.*
- Groups will test their anchor by placing the paper tray of pea-gravel containing their anchor and the K'nex® wind turbine on the shake table.
- The group will test the anchor 3 times at each one of the pull distances. They should readjust the wind turbine and anchor with each test. With each test, groups should record their observations on the effectiveness of the anchor on the *4.c. Data Recording Sheet* and put this in their notebooks.

5. **Assess students as they test their design.** Use the *4.b. Teacher Observation Protocol: Try/Test Lesson* sheets to assess students as they test their design (Part 2 and Part 3).
6. **Create a line plot for first anchor design.** After testing, each group will create a line plot on *4.d. Design Challenge Line Plot Sheet*, for their first anchor design using the data from the *4.c. Data Recording Sheet*. The effectiveness of the anchor will be numerically represented from 0-3 on the x-axis (least effective to most effective: fell over – 0, tip – 1, sway – 2, did not move – 3) with frequency represented on the y-axis.

Closure

7. **Students answer the *Reflection on Test Results* in their notebooks.** Give the students 15 to 20 minutes to work on the *4.e. Individual Reflection on Test Results* in their engineering notebooks. In their teams, students will go through the prompts and have an opportunity to share their responses to the prompts, discuss, and develop a team response together and complete the *4.f. Team Reflection on Test Results* prompts. You may post these sheets or make copies and have students attach them in their notebooks.
8. **Tie back to engineering design process.** After all the groups have completed their line plot for their first anchor design and reflected in their notebooks, **ask:** *Thinking about the activities we did today, can you tell me where those activities would be placed on the Engineering Design Process Slider?* (Test)

Day 2

Introduction

1. **Introduce activity for the day and tie to engineering design process.** Inform the students that they will be planning their redesigned anchor today. **Ask:** *Can you tell me where today's activities are on the Engineering Design Process Slider?* (Plan)

Activity

1. **Recall testing from previous day.** As a class, have the students share about their experiences from testing their first anchor. **Ask:** *What worked*

Assessments

Pre-Activity Assessment
A reflection on prompt, "Why is it important for engineers to test their designs?" in their engineering notebooks.

Activity Embedded Assessment
Team copy of Evidence-Based Reasoning Graphic for redesign of anchor. While students are building their anchors, walk around to each team and assess their progress with the Teacher Observation Protocol: Try/Test Lesson sheets and the Teacher Observation Protocol: Redesign Lesson sheet. Students will use notebook prompts on testing as reflection.

Post-Activity Assessment
Individual exit slip on a sticky note that states which of their two designs they think they should recommend to Breeze Structures and why.

DUPLICATION MASTERS

- 4.c. Data Recording Sheet
- 4.d. Design Challenge Line Plot Sheet
- 4.e. Individual Reflection on Test Results
- 4.f. Team Reflection on Test Results
- 4.g. Evidence-Based Reasoning Graphic
- 4.i. Design 2 Planning Sheet

EDUCATOR RESOURCES

- 4.a. Wind Turbine Construction
- 4.b. Teacher Observation Protocol: Try/Test
- 4.h. Teacher Observation Protocol: Redesign

FROM PREVIOUS LESSONS

- 2.d. Snap Sheet
- 3.a. Design 1 Planning Sheet
- 3.b. Materials Cost & Environmental Impact Sheet

well? What are you considering changing? Why?

2. **Students redesign their anchors.** Have the students get in their groups and discuss their thoughts on the *4.g. Evidence-Based Reasoning Graphic* for their redesign. Remind the class that the data and information from when they did their first team copy of the *4.g. Evidence-Based Reasoning Graphic* is still relevant. Emphasize that since they have tested their first design, they now have even more evidence and data to inform their design choices on the redesigned anchor. They will work together to complete a team copy of the *4.g. Evidence-Based Reasoning Graphic*. They should also draw a version of the team *4.g. Evidence-Based Reasoning Graphic* in their individual notebooks.
3. **Assess students as they redesign.** Use the *4.h. Teacher Observation Protocol: Redesign Lesson* sheet to assess students as they redesign their anchors.
4. **Complete the *Design 2 Planning* sheet.** After completing the team copy of the *4.g. Evidence-Based Reasoning Graphic,* groups will work on the *4.i. Design 2 Planning Sheet.* **Say:** *Remember that the Evidence-Based Reasoning Graphic is essential to helping you complete a redesign plan that uses informed design choices.* Teacher will circulate and prompt the groups with questions about why they are making their design choices.

Closure

1. **Tie back to engineering design process.** After the students have finished their redesign plans. Bring the class together to look at the *Engineering Design Process Slider.* **Ask:** *Based on what we have done today, what stage of the engineering design process will we be at next?* (Try and Test)

Day 3

Introduction

1. **Connect Day 2 to Day 3.** Inform the students that they will be building and testing their redesigned anchor today. Have the groups get together and review their redesign plan to ensure everything is complete.

Activity

1. **Gather materials.** Groups will collect the materials listed on their *4.i. Design 2 Planning Sheet.*
2. **Give directions for trying their redesigned anchor.** Remind the students that they must build their anchor as it was drawn. Groups will build the design they sketched on their *4.i. Design 2 Planning Sheet*.
3. **Assess students as they try their redesigned anchor (optional).** Use the *4.b. Teacher Observation Protocol: Try/Test Lesson* sheets to assess students as they try their design (Part 1 and Part 3).
4. **Test the redesigned anchor.** After building their redesigned anchor, groups will attach the anchoring system to the K'nex® wind turbine and bury the anchor in the pea-gravel. Remind the class that the anchor cannot be attached to the paper tray.
   - Remind the class that they will be simulating different earthquake magnitudes during their testing process by pulling the shake table back to different distances of 4 cm, 8 cm, and 12 cm. Pull the short end of the shake table back 4 cm, 8 cm, then 12 cm using *2.d. Snap Sheet* to

measure those distances. The greater the pull distance, the greater the magnitude.

- Groups will test their anchor by placing the paper tray of pea-gravel containing their anchor and the K'nex® wind turbine on the shake table.
- The group will test the anchor 5 times at each one of the pull distances. They should readjust the wind turbine and anchor with each test. With each test, groups should record their observations on the effectiveness of the anchor on the *4.c. Data Recording Sheet*.

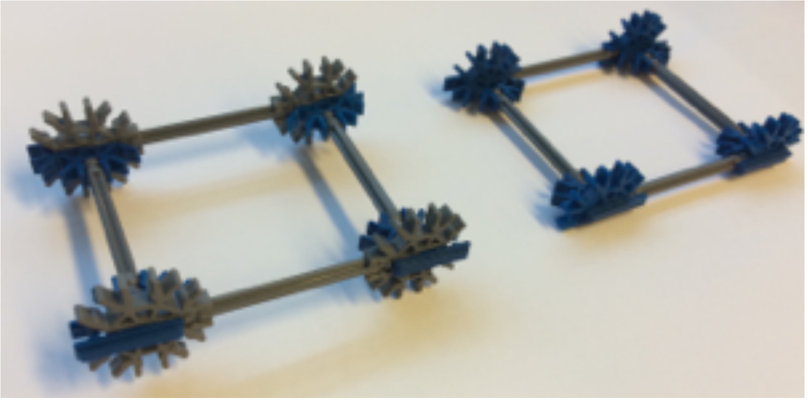
5. **Create a line plot for redesigned anchor.** After testing, each group will create a line plot on *4.d. Design Challenge Line Plot Sheet*, for their redesigned anchor design using the data from the *4.c. Data Recording Sheet.* The effectiveness of the anchor will be numerically represented from 0-3 on the x-axis (least effective to most effective: fell over – 0, tip – 1, sway – 2, did not move – 3) with frequency represented on the y-axis.

Closure

1. **Reflect on two designs.** Have the students write individual exit slip on a sticky note that states which of their two designs they think they should recommend to Breeze Structures and why.

4.a. Wind Turbine Construction

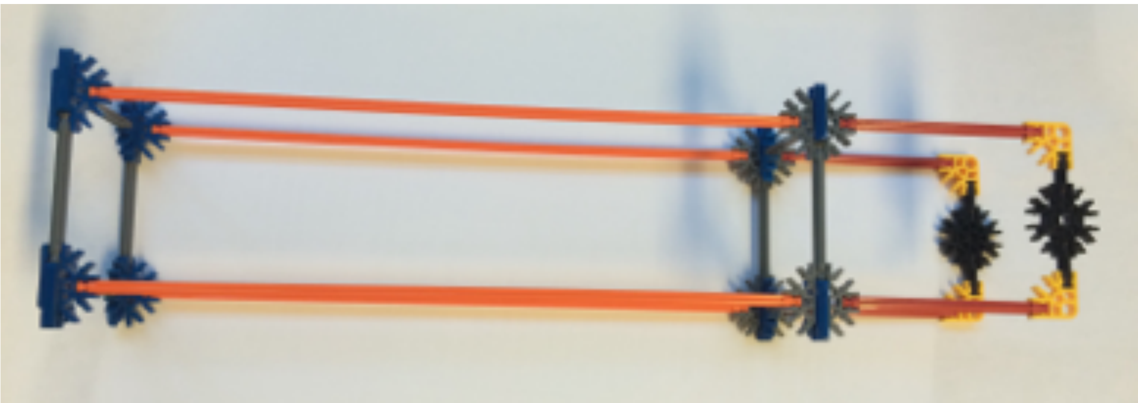
Step 1
Make bases as shown in the image below.



Step 2
Connect bases at each corner with the long orange K'Nex® pieces.

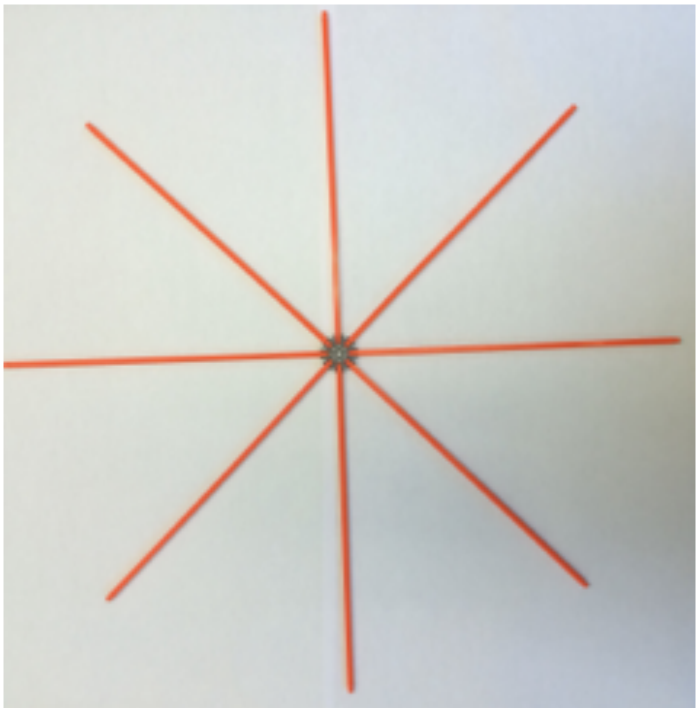
Step 3
Make extensions to tower as shown in the image below.

Step 4
Secure tower extensions to tower.

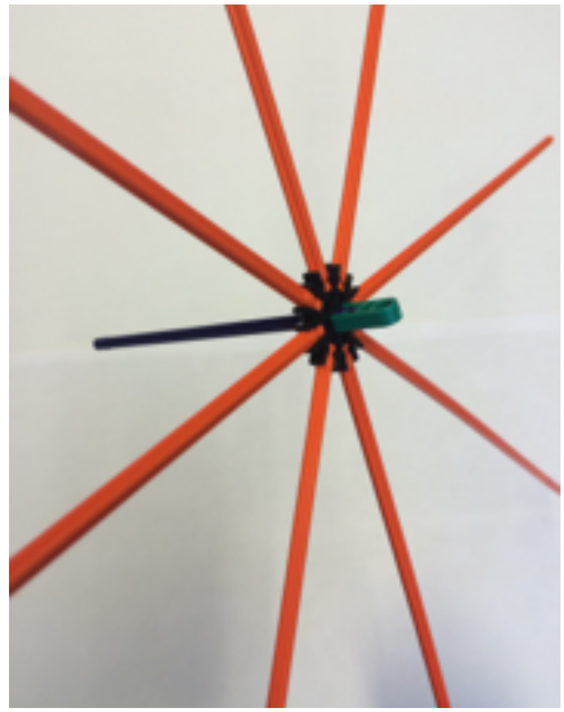


4.a. Wind Turbine Construction

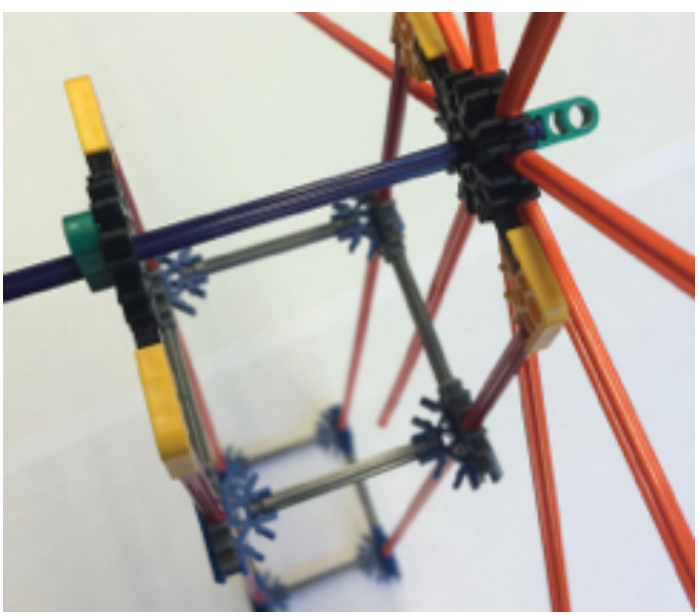
Step 5
Assemble blades and rotor as shown below.



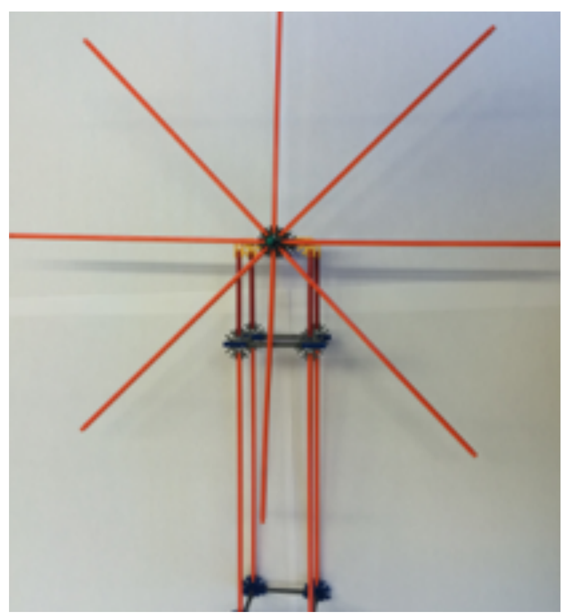
Step 6
Add the axel to the blade/rotor assebly from Step 5.



Step 7
Attach axel/blade/rotor assembly to the tower extensions.



Step 8
View of final windmill.



LESSON 4

Team:____ **Educator Resource**

4.b. Teacher Observation Protocol: Try/Test

Directions:
This is an observation assessment. The main purpose of this assessment is to observe evidence that student teams are working together to make their solution. In addition, this is opportunity to further assess that students are making design-decisions based on understanding the problem.

- **Part 1 and 2:** As you walk around to each team, please put a check by the behaviors you observe during the try and test.
- **Part 3:** Interact with each team to assess their progress on the project. You may choose to ask some of the following questions or your own questions. You may also choose to add (or not) your own additional teaming-related assessment, as you deem appropriate. There is space for you to take notes of your observations.

Part 1: Behaviors during Try

- ☐ All team members are on-task to make/try their solution.
- ☐ One or more team members are not on-task.

Notes:

- ☐ Team has made appropriate progress on their solution.
- ☐ Team is struggling to make their solution.

Notes:

- ☐ Team is making/made a solution directly related to problem.
- ☐ Team is making/made a something unrelated to problem.

Notes:

Part 2: Behaviors during Test

- ☐ All team members are on-task to test solution
- ☐ One or more team members are not on-task.

Notes:

- ☐ Team has made appropriate progress on testing and analysis.
- ☐ Team is struggling to test or analyze their solution.

Notes:

- ☐ Team has identified how to improve solution.
- ☐ Team is struggling to consider improved performance.

Notes:

4.b. Teacher Observation Protocol: Try/Test

Part 3: Plan/Try Question Prompts

Note: You do not need to ask all of these questions. Please make sure to ask some questions to each team. These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/ question for the purpose to support learning. There is space to make notes about student responses below.

1. Can you tell me about your solution? What are you designing?

2. What were some of the other solution ideas you generated? How well did they address the problem?

3. How did you decide to move forward with this idea? What evidence do you have that your design will solve the problem for the client?

LESSON 4

Name________________ Date________ Period ____

4.c. Data Recording Sheet

Anchor Material	Pull Distance	Did Not Move *(Most Effective – 3)*	Sway *(Fairly Effective – 2)*	Tip *(Somewhat Effective – 1)*	Fall *(Least Effective – 0)*	Other Observations
Design 1	4 cm					
	8 cm					
	12 cm					
Design 2	4 cm					
	8 cm					
	12 cm					

LESSON 4

Name________________________________ Date__________ Period _____

4.d. Design Challenge Line Plot Sheet

Pull distance	Design 1	Design 2
4 cm	0 1 2 3	0 1 2 3
8 cm	0 1 2 3	0 1 2 3
12 cm	0 1 2 3	0 1 2 3

LESSON 4

Name________________________________ Date___________ Period _____

4.e. Individual Reflection on Test Results

O**n your own**, answer each of the following questions. Later in your team, each person will share their response and discuss. You will then **write a revised answer to these questions**, based on the discussion with your team.

1. What have you learned about the performance of your solution from your test results?

2. What changes will you make to your solution based on the results of your tests? Explain why you want to make those changes.

3. What changes will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.

4. In what ways does your solution meet the criteria and constraints of the problem?

5. In what ways does your solution not yet meet the criteria and constraints of the problem?

6. Go back and look at how you described the problem right after talking with the client. How would you change your description of the problem now that you have planned, tried, and tested a solution? (Think about criteria, constraints, client need, and/or things you need to learn.)

LESSON 4

Name________________________________ Date__________ Period _____

4.f. Team Reflection on Test Results

Based on group discussion, answer the following questions as a team:

1. What have you learned about the performance of your solution from your test results?

2. What changes will you make to your solution based on the results of your tests? Explain why you want to make those changes.

3. What changes will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.

4. In what ways does your solution meet the criteria and constraints of the problem?

5. In what ways does your solution not yet meet the criteria and constraints of the problem?

6. Go back and look at how you described the problem right after talking with the client. How would you change your description of the problem now that you have planned, tried, and tested a solution? (Think about criteria, constraints, client need, and/or things you need to learn.)

LESSON 4

Name______________________________ Date__________ Period _____

4.g. Evidence-Based Reasoning Graphic

Problem with Criteria & Constraints (What do you need to worry about?)	
Problem: ______________________________ ______________________________ **Criteria:** ______________________________ **Constraints:** ______________________________	
Simplifying Assumptions (What do you not need to worry about?)	
______________________________ ______________________________	
Plan (Design Idea)	**Data/Evidence** (Facts)
	______________________________
Explanation, Justification, Reasoning (Why do you think this will work?)	
______________________________	

4.h. Teacher Observation Protocol: Redesign

Directions:
This is an observation assessment. The main purpose of this assessment is to observe whether teams are testing their improved solution and analyzing results. In addition, this is opportunity to further assess that students are making design-decisions based on understanding the problem.

- **Part 1:** As you walk around to each team, please put a check by the behaviors you observe.
- **Part 2:** Interact with each team to assess their progress on the project. You may choose to ask some of the following questions or ask your own questions. You may also choose to add (or not) your own additional team-related assessment, as you deem appropriate. There is space for you to take notes of your observations.

Part 1: Plan/Try Behaviors

☐ All team members are on-task to retest solution.

☐ One or more team members are not on-task.

Notes:

☐ Team has attempted to improve performance of solution.

☐ Unclear what improvements team made.

Notes:

Part 2: Question Prompts During Retest

Note: These questions can be used to further draw out and scaffold students' evidence-based reasoning. While the main purpose of these questions is to assess students' reasoning, it is also appropriate to interact with students/question for the purpose to support learning.

6. What did you find out from testing?

7. How did you interpret the findings from your tests? What do you think the results mean?

8. How did you decide what could improve your solution's performance?

LESSON 4

Name______________________________ Date__________ Period _____

4.i. Design 2 Planning Sheet

Engineers: ____________________ ____________________

____________________ ____________________

Sketch of Anchor Design
(Include Labels of Materials)

Material	Cost	Impact
Total		

Impact: 1-5: Low, 5-10: Medium, 11 or more: High

Anchor description: ____

____

____

Why did you make these design choices? ____________________________

____

____

____

LESSON 5 Analyzing Anchor Designs

Lesson Objectives
The students will be able to:
- Compare the two anchor designs they made
- Decide which anchor should be presented to the client and use evidence to support their reasoning
- Learn to make trade-offs and learn to how to prioritize the client's various criteria

Time Required
One 50-minute lesson

Materials
- **Per Classroom:** (1) Poster size Engineering Design Process Slider
- **Per Group:** Line plot from first anchor design*, Line plot from redesigned anchor*, (1) copy of completed Design 1 Planning Sheet*, (1) copy of completed Design 2 Planning Sheet*
- **Per Student:** (2) different colored writing utensils *, (1) engineering notebook*, (1) copy of Evidence-Based Reasoning Graphic*, (1) copy of Letter from the Client, (1) sticky note

Standards Addressed
- Next Generation Science Standards: 4-ESS3-2

Key Terms
trade-offs

Lesson Summary
The groups will analyze the effectiveness of the anchoring systems used to attach a model wind turbine in a pea gravel substrate. They will compare their two designs and decide on one to present to the client based on data collected from trying and testing.

Background
Teacher Background
When engineers design a solution for a client, sometimes trade-offs are necessary. For example, while they may have effectively solved the client's problem, the solution may be over budget. In this scenario, cost would be a trade-off for effectiveness. In the context of this challenge, factors that might be involved in a trade-off are cost, effectiveness of anchors at higher earthquake magnitudes, or environmental impact of materials.

Before the Activity
Have the students line plots from design 1 and the redesign ready at their groups.

Classroom Instruction
Introduction
1. **Tie to engineering design process. Ask:** *Now that we have tested the first anchor and the redesigned anchor, where are we on the Engineering Design Process Slider?* (Decide)

Activity
1. **Introduce trade-offs.** Explain to the class that engineers sometimes need to make trade-offs in their designs. For example, while they may have designed an effective solution for their client, it may be over budget. In this scenario, cost would be a trade-off for effectiveness.
2. **Reflect on client's needs and trade-offs.** Have the students write a notebook reflection on the prompt, "*How would you rank the importance of each of the client's needs? Give an example of a trade-off that you might have to make based on this ranking"* in their engineering notebooks.
3. **Review client letter.** Have the students review the *1.a. Client Letter* from the client once more, paying attention to the client's criteria and constraints for the anchor.
4. **Compare and contrast each design.** Using their completed *3.a. Design 1 Planning Sheet* and *4.e. Design 2 Planning Sheet*, each group will complete sheet *5.b. Criteria-Constraint Checklist* for each of their designs. Students will then use *5.b* to compare their two designs and how those designs did or did not meet the criteria and constraints.
5. **Individually complete an *Evidence-Based Reasoning Graphic*.** After completing *5.b.*, students will individually think about the comparisons between the two designs and decide on the anchor they think should be presented to the client. Individually, the students will complete an *5.a. Evidence-Based Reasoning Graphic* on their chosen anchor as the solution to Breeze Structure's problem.

Analyzing Anchor Designs

Closure

1. **Tie to engineering design process. Ask:** *Where do you think we are in the engineering design process now?* (Decide – but individually). *What do you think we should do next?* Take student answers, but let them know we are going to work on deciding and communicating to the client in our teams in the next lesson.
2. **Exit slip on possible improvements.** Have the students prepare an exit ticket on a sticky note to the prompt, *"If you were given the chance for one more redesign, what might you consider changing and why?"*

Assessments

Pre-Activity Assessment
A reflection on prompt, *"How would you rank the importance of each of the client's needs? Give an example of a trade-off that you might have to make based on this ranking"* in their engineering notebooks.

Activity Embedded Assessment
Students will individually complete the *Evidence-Based Reasoning Graphic* to decide which of their designs they want to present to the client.

Post-Activity Assessment
An exit ticket on a sticky note to the prompt, *"If you were given the chance for one more redesign, what might you consider changing and why?"*

DUPLICATION MASTERS

- 5.a. Evidence-Based Reasoning Graphic
- 5.b. Criteria-Constraint Checklist

EDUCATOR RESOURCES

- none

FROM PREVIOUS LESSONS

- 1.a. Client Letter
- 3.a. Design 1 Planning Sheet
- 4.e. Design 2 Planning Sheet

LESSON 5

Name________________________________ Date__________ Period ____

5.a. Evidence-Based Reasoning Graphic

Problem with Criteria & Constraints (What do you need to worry about?)

Problem: ____

____

Criteria: ____

Constraints: ____

Simplifying Assumptions (What do you not need to worry about?)

____

____

Plan (Design Idea)	**Data/Evidence** (Facts)

Explanation, Justification, Reasoning (Why do you think this will work?)

____

____

____

____

____

____

____

Name________________________________ Date__________ Period _____

5.b. Criteria-Constraint Checklist

Design # ________

Criteria or Constraint	Did you meet this criteria or constraint?	How did your design meet this criteria? or How did your design work within this constraint?

LESSON

6 Memo to the Client

Lesson Objectives

The students will be able to:

- Collaborate and compromise within their groups to determine which anchor design they want to present to the client
- Decide which anchor should be presented to the client and use evidence to support their reasoning
- Learn to communicate their solution to a client

Time Required

One 50-minute class period

Materials

- **Per Classroom:** (1) Poster size Engineering Design Process Slider
- **Per Group:** (1) copy of Evidence-based Reasoning Sheet*, (1) sheet of loose-leaf paper*, (1) Rubric for Memo to Client*
- **Per Student:** (2) different colored writing utensils *, (1) engineering notebook*, (1) copy of individual Evidence-based Reasoning Sheet from lesson 5*

Standards Addressed

- Next Generation Science Standards: 4-ESS3-2

Key Terms

evidence, client, design process

Lesson Summary

The students will continue to work in small groups to prepare a memo to the client about their anchoring design.

Background

Teacher Background

An important part of engineering is collaboration and communication. By coming to a consensus after creating individual Evidence-Based Reasoning Graphics, students will practice making claims supported by evidence.

Before the Activity

Write the engineering notebook prompts on the dry-erase board or chart paper.

Classroom Instruction

Introduction

1. **Connect to Lesson 5.** In their groups, have the students share their individual Evidence-Based Reasoning Graphics from lesson 5. The groups must come to a consensus on which of the two anchor designs they will share with the client in the memo. After the group discussion, students will write a response in their engineering notebook to the prompt, *"Which anchor has your team decided to present to the client? Why? Is this the same design that you chose individually?*

Activity

1. **Connect to engineering design process. Ask:** *Where are we on the Engineering Design Process Slider today?* (Decide and communicate)
2. **Teams complete an Evidence-Based Reasoning Graphic.** Now that each team had decided on an anchor design to present to Breeze Structures, they will complete a team copy of the *6.a. Evidence-Based Reasoning Graphic* for the chosen anchor design.
3. **Write a memo to the client.** Once the team *6.a. Evidence-Based Reasoning Graphic* has been completed, each group will write a memo to the client about their anchor design. They will need to explain how it meets the client's criteria/constraints, including: cost, environmental impact, effectiveness at different earthquake magnitudes, sketch of anchor design, and materials used. The memo to the client should draw heavily from their team *6.a. Evidence-Based Reasoning Graphic* and include justifications for the decisions made. You will need to provide feedback to the teams from the client. A rubric for assessment (*6.b. Rubric for Memo to the Client*) is included in the duplication masters.

Closure to the Unit

4. **Students answer the *Reflection on Test Results* in their notebooks.** Give the students 15 to 20 minutes to work on the *6.c. Individual Reflection on the Engineering* in their engineering notebooks. In their teams, students will go through the prompts and have an opportunity to share their responses to the prompts, discuss, and develop a team response together and complete the *6.d. Team Reflection on the Engineering* prompts. You may post these sheets or make copies and have students attach them in their notebooks.

LESSON 6 Memo to the Client

Assessments

Pre-Activity Assessment
After a group discussion, students will write a response in their engineering notebook to the prompt, *"Which anchor has your team decided to present to the client? Why? Is this the same design that you chose individually?"*

Activity Embedded Assessment
Write a memo to the client using the information from a team created *Evidence-Based Reasoning Graphic*. A rubric for assessing these is included.

Post-Activity Assessment
Students will write a response in their engineering notebook to the prompt, "*How would you explain the engineering design process to someone who doesn't know anything about it?"*

Post Unit Assessment
Students will write a response in their engineering notebook to the prompts that include unit reflections on their understanding of the problem, designing solutions, and how engineers solve problems.

DUPLICATION MASTERS

- 6.a. Evidence-Based Reasoning Graphic
- 6.c. Individual Reflection on Engineering
- 6.d. Team Reflection on Engineering

EDUCATOR RESOURCES

- 6.b. Rubric for Memo to Client

LESSON 6

Name________________________________ Date___________ Period _____

6.a. Evidence-Based Reasoning Graphic

Problem with Criteria & Constraints (What do you need to worry about?)	
Problem: ____________________	
Criteria: ____________________	
Constraints: ____________________	
Simplifying Assumptions (What do you not need to worry about?)	
Plan (Design Idea)	**Data/Evidence** (Facts)
Explanation, Justification, Reasoning (Why do you think this will work?)	

6.b. Rubric for Memo to Client

	4 - Exceptional	3 - Proficient	2 - Developing	1 - Beginning
Evidence-Based Reasoning Graphic Included	All parts are included with all necessary information and the justification is clearly connected to the information included in the EBR Graphic.	All parts are included with most of the necessary information and the justification is connected to the information included in the EBR Graphic.	All parts are included with some of the necessary information AND the justification is somewhat connected to the information included in the EBR Graphic.	Some parts are included with some of the necessary information. The justification is not clear OR connected to the information included in the EBR Graphic.
Complete information included: 1. Sketch of anchor 2. Cost 3. Environmental Impact 4. Effectiveness at different earthquake magnitudes 5. Materials used	All parts are included and cohesive with the EBR Graphic.	All needed parts are included.	One of the needed parts is missing or incomplete.	Two or more parts are missing or incomplete.
Memo	Memo is clear, creative, persuasive, and backed up with data.	Memo is clear and backed up with data.	Memo is somewhat clear AND somewhat backed up with data.	Memo is somewhat clear OR somewhat backed up with data.
Participation	All group members are actively involved in creation of memo. An extra effort is made to do quality work.	All group members are involved in the creation of memo.	Most group members are involved in the creation of memo, but effort shown is unequal.	Most group members are NOT involved in the creation of memo and have made little effort.

LESSON 6

Name________________________________ Date___________ Period _____

6.c. Individual Reflection on Engineering

O**n your own**, answer each of the following questions. Later in your team, each person will share their response and discuss. You will then **write a revised answer to these question**, based on the discussion with your team.

1. Look back in your Engineering Notebook to see how you defined the problem throughout solving the problem. **How has your understanding of the problem changed during the design process?** Think in terms of client needs, criteria, constraints, and the science and mathematics needed to solve the problem.

2. Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem. **How has your understanding of how to design a solution changed during the design process?** Think in terms of what you did and how you made decisions to solve the problem.

3. How do engineers solve problems?

LESSON 6

Name_________________________________ Date___________ Period _____

6.d. Team Reflection on Engineering

Based on group discussion, answer the following questions as a team:

1. Look back in your Engineering Notebook to see how you defined the problem throughout solving the problem. **How has your understanding of the problem changed during the design process?** Think in terms of client needs, criteria, constraints, and the science and mathematics needed to solve the problem.

2. Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem. **How has your understanding of how to design a solution changed during the design process?** Think in terms of what you did and how you made decisions to solve the problem.

3. How do engineers solve problems?

Notebook Prompts and Titles

Teacher Directions:

If you prefer to have students write the answers to prompts right in their notebooks (rather than on the handouts and then adhere them to the notebooks), you should have the students put the bold title for each prompt and then answer the question that follows. The format for each will be as follows:

Prompt title:
Question to answer

Have students answer each set of questions as they appear in the curriculum. If any questions are included in the curriculum, but not included here, you may determine the title for the prompt.

Problem Scoping Lessons - Define and Learn

Section 1:

Engineers:
What do engineers do?

Solve Problems:
How do engineers solve problems?

Section 2:

Questions for client:
What questions do you want to ask to the client?

Section 3:

Client:
Who is the client?

Problem:
What is the client's problem that needs a solution?

Why it is important:
Why is the problem important to solve?

End-users:
Who are the end-users?

Criteria:
What will make the solution effective (criteria)?

Notebook Prompts and Titles

Constraints:
What will limit how you can solve the problem (constraints)?

What we need to learn:
Think about the problem of wind turbines without anchors during an earthquake. In terms of designing an anchor to stabilize a wind turbine during an earthquake, what do you need to learn in order to create a successful anchor?

Generate Ideas/Plan Lessons

Section 1:
EBR Graphics can just be drawn in notebooks.

Section 2:
Have students answer the following after EBR graphics are complete.

Pros and Cons:
What are the pros and cons of each of your solutions?

Why we chose our solution:
Which solution did your team choose and why?

Test Solution Idea(s) Lessons

Section 1:
Ask students to complete after they have run their tests.

Learned from test results:
What have you learned about the performance of your solution from your test results?

Changes from test results:
What changes will you make to your solution based on the results of your tests? Explain why you want to make those changes.

Changes from science/math learned:
What improvements will you make to your solution based on the science and/or math you have learned? Explain why you want to make those changes.

Notebook Prompts and Titles

Section 2:

Section 2 questions should come after the students have run their tests and have had an opportunity to answer Section 1 questions.

How solution meets criteria and constraints:
In what ways does your solution meet the criteria and constraints of the problem?

How solution does not yet meet criteria and constraints:
In what ways does your solution not yet meet the criteria and constraints of the problem?

Changed problem description:
Go back and look at how you described the problem right after talking with the client. How would you change your description of the problem now that you have planned, tried, and tested a solution? (Think about criteria, constraints, client need, and/or things you need to learn.)

Decide/Final Solution Lessons

Section 1:

Students use evidence-based reasoning in reporting their final solution to the client. This can happen through use of the EBR graphic as part of their memo or presentation, or you can have the students include the aspects of the EBR graphic (without the graphic itself) in the memo or the presentation.

Section 2:

These questions should be completed after presenting the solution to the client and the entire design challenge is complete.

Understanding of the problem:
Look back in your Engineering Notebook to see how you defined the problem throughout solving the problem. *How has your understanding of the problem changed during the design process?* Think in terms of client needs, criteria, constraints, and the science and mathematics needed to solve the problem.

Understanding of designing a solution:
Look back in your Engineering Notebook to see how you developed your solution throughout solving the problem. *How has your understanding of how to design a solution changed during the design process?* Think in terms of what you did and how you made decisions to solve the problem.

