I. Lesson 2: Building Basics

What structural materials and shapes best withstand an earthquake?

Lesson Description: Students are asked to design a new skyscraper for a leading software company in San Jose. Before beginning their building design, students will first test out different materials, shapes and base models.

Grade Levels: 4-12

Education Outcomes:

Students will:

- Define and identify an experimental variable and will explain why engineers conduct tests to see the effect of variables on different building materials.
- Conduct a load bearing test on various materials to identify materials that can best withstand a structural load.
- State, explain and justify how the structural strength of a material can be changed by the way it is shaped.
- State, explain and justify which shapes are structurally stronger than others.

Education Standards

Met: (Note: bolded parts of the standards are fully met by this lesson)

Next Generation Science Standards (NGSS)

3-5-ETS1-3: Plan and **carry out fair tests in which variables are controlled and failure points are considered to identify a model or prototype that can be improved.**

MS-ETS1-3: **Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**

NGSS Science and Engineering Practices (SEP):

Developing and Using Models: **Makes use of models and simulations to analyze systems to identify flaws that might occur or to test possible solutions to a new problem.**

Addressed: (The following standards are practiced in this lesson but are not explicitly taught and assessed)

Next Generation Science Standards (NGSS)

3-5ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

NGSS Cross-Cutting Concepts:

Systems and System Models: Defining the system under study-specifying its boundaries and making an explicit model of that system-provides tools for understanding and testing ideas that are applicable throughout science and engineering.

Common Core Standards:

(4-8) CCSS.ELA-Literacy.SL.4.4, 5.4, 6.4, 7.4, 8.4: Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation.

(6-9) CCSS.ELA-Literacy.RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

II. Advanced Prep & Set-Up for Lesson

Load Bearing Test Set-Up

Materials

NOTE: The following materials are suggestions of the types of materials needed for the lesson. Feel free to modify the following list to easily accessible materials. In general, you will need:

- Adhesives and attaching materials (glue, tape, rubber bands, paper clips etc.)
- Different types of materials of equal length to test (metal, wood, paper, plastic etc.)
- Team journals
- Weights (suggested materials are 500 mL plastic water bottles filled with different amounts of sand: ¼ full, ½ full, ¾ full and completely full. 1 set of 4 per group of students. Objects that weigh varying amounts from ½ to 2 pounds can also be used as long as these weights are consistent across groups).
- 1 string of approximately 15 inches in length for each set of weights.

Sample Materials:

- Popsicle sticks
- Foil
- Pipe cleaners
- Insulated wire
- Paper (any type but medium thickness paper works best)
- Foam sheets
- Straws
- Coffee stir straws
- Rubber bands (multiple sizes)
- Paper clips
- String
- Masking tape
- Bendable plastic (e.g. transparency sheets). *This material is optional but is recommended for grades 4 and 5.*
- 500 mL plastic water bottles filled with different amounts of sand: ¼ full, ½ full, ¾ full and completely full. 1 set of 4 per group of students. *An alternative could be gram stackers or 2 pound weights. Other objects of equal weight will also work.*

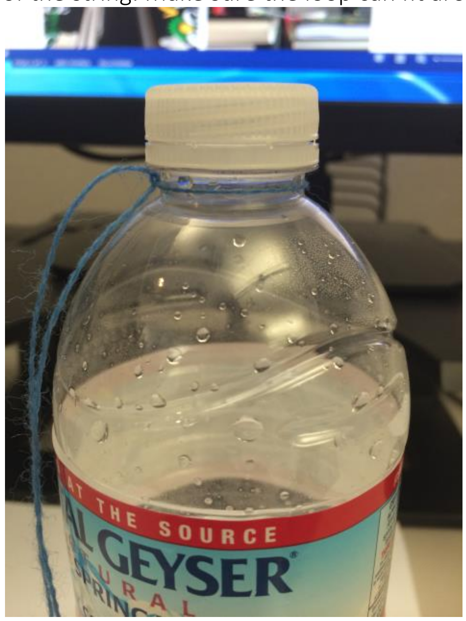
Stations Set-Up

Set up one station for each group as follows:

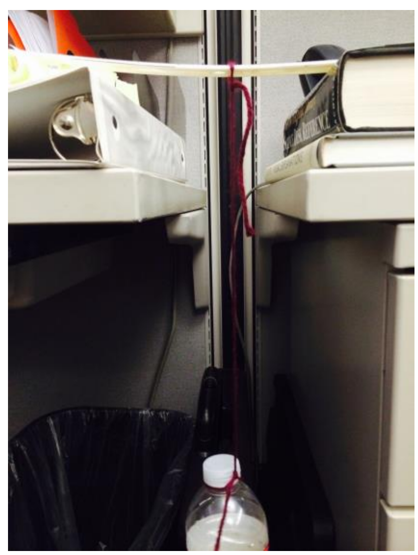
- Place a variety of materials at each group's station (5 types of materials per station). Duplicating materials at each station will allow the class to see patterns in the data and to help control for variables through redundancy.
- Provide masking tape for each station.
- Each station will also need the following Load Bearing Test Set Up.

Load Bearing Test Set-Up

- Cut a piece of string about 15 inches in length.
- Tie a slip knot on one end of the string so that it can be slipped around the neck of each bottle during testing. (You can substitute a different weight, if needed as long as each station is identical).
- Tie a loop and knot at the other end of the string. Make sure the loop can fit around all the objects being tested.



- Place two desks/tables and approximately 6 inches apart. Place one book at the edge of each table closest to the gap.
- NOTE: A variable encountered when we tested this with educators is that the tape doesn't hold the pipe cleaner as well as the straw/craft stick. You might discuss with students, what other ways they could use to hold the material in place that would help control for this. (Place heavy books on each end for example.)
- Images below demonstrate how students will test their materials. (In the images below a straw is being tested):

Data Collection Table

- Draw a data collection table on the white board/chalkboard/projector/computer.
- A sample table is drawn below. Add as many rows as needed (determined by the number of materials you are having students test).
- NOTE: A hand-out with directions and a table are included in Appendix C. This might help students to take notes.

Material	Maximum Weight Held Without Bending/Breaking	Material Test Observations
Sample: Straw	*Sample: 0 bottle of sand*	*Sample: The straw bent in the middle where the weight was attached. It was only able to stay on the books because it was taped. The straw is flexible but cannot bear much weight.*
Sample: 18 Gauge Wire	*Sample: ¼ bottle of sand*	*Sample: The wire held ¼ bottle of sand without bending, but it bent with ½ bottle of sand. The wire is also flexible and can bear some weight.*

Shape Testing Set Up

Materials

- 2-liter bottle filled with sand (one per group) *OR* an object with the same weight (approx. 8 pounds).
- 6 inch x 6 inch piece of cardboard (Any kind. One per group).
- One piece of paper per group (8 ½ X 11 printer/photocopy paper or similar thickness) (We encourage the use of recycled paper!)
- Additional paper that can be provided to groups for additional iterations.
- Scotch or masking tape (7 inches per group)

III. Building Basics Lesson Guide

Guiding Question: What structural materials and shapes best withstand an earthquake?

A. Materials Test Introduction (10 -15 minutes)

This segment of the lesson is designed to discuss the overarching themes and purpose of the unit. It is also designed to expose students to the engineering design process and to basic materials testing.

1. Introduce the design challenge theme. Some of the information you might share in this introduction could include:
   - The city of San Jose has asked us to help design and build a seismically strong skyscraper.
   - The purpose of constructing this building is to convince a large tech company to move its headquarters to San Jose. This means that the building has to look nice, be safe, and must hold the employees and equipment of this company.
   - This project will also help us prepare for the culminating Tech Challenge.

2. Introduce key engineering vocabulary. Information and key vocabulary you might introduce include:
   - Since we are seismic engineers, we need to talk like seismic engineers.
   - We'll encounter many engineering and science terms throughout this project and will talk about each term as we use it. To get us started, a few key terms we will be using today include:
     - **Seismic:** of or related to earthquakes.
     - **Engineer:** someone who finds creative solutions to real-life problems. (You are all engineers whenever you come up with a new way to solve a problem!)
     - **Failure Point:** The point in a system that if it fails, the whole system fails. As engineers, we want our solutions to fail so we can pay attention to how and where they fail. That will allow us to improve our designs at those points, so that we can improve our solutions and make sure they can withstand multiple tests.

> **Facilitator Note:**
> A few tips for introducing and reinforcing vocabulary:
> - Introduce only a few words at a time.
> - Connect these words to context and to experiences to which students can relate.
> - Use these words often and encourage students to use them often.
> - When introduced, post these words in the room.
> - With students, make up hand or body motions that can represent their meaning.

3. Brainstorm a list of questions with students to help develop the Scientific and Engineering practice of Asking Questions.
   - What questions do you have when you think about working on this challenge? What do you need to know? (Accept and record all questions without providing answers. At the end of each activity, re-visit the list to see which questions have been answered.)
   - If students do not provide the following questions, add them to the list:
     - What types of materials do engineers use to build buildings?
     - What kinds of structures best withstand earthquakes? (Materials? Shapes?)
     - How will we know if we are successful? (Is it ok if a building stays standing, but is tilted, for example?)
     - Is a building design successful if it is slightly damaged or is slanted after an earthquake?
     - Would a building design still be considered successful if pieces of it fell off the building after an earthquake?

4. Lead a discussion that draws on students' prior knowledge of earthquakes and engineering for earthquakes. Sample questions might include:
   - How does the ground move during an earthquake?
   - What happens to a building during an earthquake?
   - What types of designs do engineers use to make buildings safer during earthquakes?

> **Facilitator Note:**
> For background information on earthquakes, See Lesson 1 Appendix A. Students are not expected to know about designing for earthquakes. They will learn about some seismic engineering techniques through these lessons.

5. Discuss the role of modeling in the design and engineering process. Tell students they will first create scale models of their skyscrapers. You might include the following talking points:
   - Modeling is cost effective because it is cheaper to plan and test on a smaller scale than before construction of the actual structure.
   - Modeling and testing a design on a smaller scale is safer because it allows engineers to test and look for structural/design weaknesses before they build the actual building.
   - Building a model first will allow engineers to better plan the construction of a building.

6. Discuss journals as an engineering tool. The following are suggested questions and information that you might include in this discussion.
   - In what ways have you used a journal for science or engineering? What has been most helpful to you?
   - Is there additional information that you wish you had recorded in your journal? Why?
   - Some of the information that engineers document very carefully include:
     - Sketches and photos of design ideas
     - Data from materials or performance tests
     - Careful documentation of the variables that are changed in each design (of materials, shapes, sizes, load placement, etc.)
     - Documentation of both successful and unsuccessful designs and failure points—so that they can be remedied in future designs
     - Budget for each design
     - Because we will be scaling up our designs for the culminating Tech Challenge, it will be particularly important to document everything so you can replicate successes and correct for failures.
   - Judges at The Tech Challenge will also be reviewing your journal to understand:
     - the process you went through to develop your solution
     - all the designs you tried and how you changed them
     - your final design including measurements and materials used
     - what you learned through the process
     - specific details that will set you apart from other teams (sketches, specific materials, budgets, number of designs, testing procedures, attendance at Test Trials, meeting minutes, etc.)
     - real world applicability (how would your device work in real life?)

B. Materials Testing (20-30 minutes)

1. Discuss and model materials testing. The following are suggested questions and talking points:
   - How might engineers decide what materials to build with? Why is this important?
   - Materials testing is important because it allows engineers to pick the safest possible materials for their building designs. It also lets engineers test the materials under different variables and conditions so that they can anticipate any weaknesses in the design or structure of a building.
   - Today, as engineers, you will all be examining **load** (weight) and how it affects the materials you are using to build.
   - When engineers test a material, they conduct a **fair test** to ensure that everything stays exactly the same except for the condition or variable that they are testing.
   - The weight represents **building load**, which is the total mass that structure needs to support. This includes the mass of the structure, everything in it and environmental forces (wind, rain, snow, ice etc.).
   - Because we are testing how much weight each material can bear, we call this a **load bearing test**.
   - Model the load-bearing test by placing a sample material across the gap of the load-testing rig and attaching a weight. (See Load Bearing Test Set-Up in Section II of this lesson.)
   - Demonstrate adding additional weight to observe how weight affects the load.
   - Make some observations about the material with the class.

> **Facilitator Note:**
> You might also compare a fair test to a race. Could we compare the speed of 2 students running a race, if one started 3 feet in front of the other?
>
> You might also discuss the importance of repetition of tests during an experiment. Repetition is important because it reduces the effect of human errors of test data. This creates more accurate test results.

- Model recording these observations in the data collection chart.
- A **variable** is anything that can change during an experiment.
- What can change in this experiment of testing a material? (The position of the books. The distance between the desks. How the weight is released. The amount of weight.)
- Which variable are we intentionally changing so that we can test for that change? (Weight. We are testing to see how much weight each material can hold and how that weight affects each material.) We call this the **experimental variable**.

2. While students perform materials tests, ask questions that help to check for students' understanding of variables. Below is list of suggested questions:
   - What are the variables in your experiment? (What could change?)
   - What do you need to try to keep the same in every test? (How the weight is released, distance between the books, where the material is attached, length of the material etc.)
   - What is the experimental variable in the test you are doing right now? (The variable that you are changing in and testing for in each test? The weight in this case)
   - Why is it important to keep all variables the same except for the experimental variable?
   - If you repeat a test, do you get the same result? Why or why not? What might you do if you get a different result?
   - Why do you think engineers put materials through these tests before they build a building?
   - ***Extension:*** During the materials test it might be interesting to have students look at different lengths or how folding/overlapping the materials might affect the results of the tests.

3. Once students have recorded all of their data, have students share out their data to the class. During this time the students or the facilitator should record the observations in the class data collection table. Discuss as a class: Look at the data. What do you notice?
   - What if different groups got different results for different materials?
   - What materials would make the safest building? Why do you think this?
   - Why do engineers perform materials tests?
   - Why is it important to test different variables?
   - Which questions on our list have we answered?

> Facilitator Note:
> Groups can record data in different colors so that it is easy to see which group collected which observation data.
>
> An important skill in Common Core and Next Generation Science Standards is stating an argument and supporting it with evidence. As students state their conclusions, ask them to support these with specific data or evidence. For example, "The craft stick is the strongest material, because it could hold the most weight without bending or breaking."
>
> Some data you might expect is that thicker material will be able to hold more load. For instance any wood or folded wire will be able to hold more load. Objects like straws or pipe cleaners will bend more easily because of the flexibility of its material.

C. Shape Testing (20 – 30 minutes)

1. Introduce the paper challenge.
   - Pull out a piece of paper.
   - If I put this piece of paper through the same load test that we put all the other materials through, what do you think would happen? Why?

> Facilitator Note:
> Please refer to The Tech's Innovation Process PDF for an overall guide on how The Tech views this process and what we believe can cultivate innovation in all ages.

Challenge:

Build a building base that can support a 6 inch x 6 inch piece of cardboard and a 2-liter bottle filled with sand (or 8 pounds of weight).

Criteria (Design Requirements):

- Your structure must hold the cardboard and one 2-liter bottle of sand (or 8 pounds of weight) for at least 30 seconds
- The base needs to be at least 2 inches high
- As you test different designs, record your observations in your engineering journal

Constraints (Design Limitations):

- Budget: You may only use one 8.5 X 11 sheets of paper and 7 inches of masking tape
- Schedule: You have 20 minutes to complete this challenge

2. While the students are building their paper structures, walk around and ask questions. Some suggested questions are:
   - Are some shapes working better than others? Which ones?
   - Why do you think some shapes are working better than others?
   - Do you think the shape changes the strength of a material? Why or why not?

> **Facilitator Note:**
> At your discretion, if groups need to iterate, give them a second or third sheet of paper to try new designs.
>
> This would be a great opportunity to talk about failure and how it is an integral part of the design process. Failure during prototyping leads to stronger and safer designs because it show engineers the weaknesses in their designs. Have students reflect on how they responded to their own failures and help them shift how they look at failure.

3. As students achieve success, give them 2 sheets of paper and ask them to test how their design scales up by holding the weight at least 6 inches off the ground.

4. As students share their designs with the group, debrief the challenge. Suggested questions:
   - Were you able support the cardboard and bottles of sand? How many bottles of sand? How were you able to do this?
   - Which shapes were stronger? Why?
   - Do you think changing the shape of a material can make it structurally weaker or stronger? Why? What evidence do you have to back up this claim?
   - What did you notice about where you needed to place your load?
   - What were some weakness or "failure points," you saw in your design? How could you improve upon these?
   - How does design failure lead to stronger and safer building designs?

> **Facilitator Note:**
> The strength of the shape depends in the material and its position in relation to the load. Generally, triangles or three-dimensional rectangles or cylinders are able to bear the most loads. This is because the shapes distribute the force of the load more evenly and efficiently. This is why you see lots of triangles in bridges or vertical scaffolding of a building. It is also why you see support columns of a building that are cylindrical or rectangular in shapes.
>
> Students should also notice that the most effective designs are ones in which the load is balanced over the center of the structure. If they do, you can introduce **center of gravity**, which is the point in an object at which gravity is concentrated. This is where the mass or weight of an object is evenly dispersed such that all sides are in balance.

5. Debrief the class through questioning about testing material types and shapes. Below is a list of suggested questions to discuss with students.
   - Based on the results from your load tests, which material/shape combination(s) do you predict would be strongest? How could you find out for sure?
   - How will you use what you learned in your skyscraper design? Explain your design decisions using evidence from your tests today.
   - If I gave you different materials than the ones today, but gave you the same challenges, what would you do? Why?
   - Why is materials testing so important when designing a building?
   - How does shape change the structural strength of a material?
   - What is a variable? How did we test for different variables today?
   - How does failure during the design process lead to safer and more durable building designs?
   - Which questions on our list have we answered?

> **Facilitator Note:**
> Another important discussion point is about variables. When designing their bases, students are now combining and testing multiple variables at once. Since there are so many variables changing at once, it will be hard to know the source of design failure. This is why engineers perform tests (like the materials test) in controlled environments (like the materials test).

IV. Appendices

A. Vocabulary and Background Information

The following is the start of a suggested list of words to discuss as you read and discuss with students.

Building load – The total mass that structure needs to support. This includes the mass of the structure, everything in it and environmental forces (wind, rain, snow, ice etc.). The "live load" is the weight of the people and goods (furniture, other supplies) in a building or vehicle.

Center of gravity – the point in an object at which gravity is concentrated. Where gravity is uniform, this is where the mass or weight of an object is evenly dispersed such that all sides are in balance.

Engineer – Someone who finds innovative solutions to real-life problems.

Experimental variable – This is the variable that is being changed during an experiment. The experimental variable is the factor that is being tested during an experiment. In the case of this lesson, "load" is the experimental variable because it is being changed during each individual materials test.

Failure Point – This is the point in a system that if it fails, the whole system fails. For instance, if an important structural component of a building fails during an earthquake, the building will experience catastrophic structural failure. When modeling, engineers look for possible failure points to see where their designs can be improved.

Fair test - When you change only one factor (variable) and keep all other conditions the same.

Load bearing - The load bearing part of a structure is the section of the structure that supports most of the load of a structure.

Load bearing test – A test where you determine a material's or structure's ability to bear different loads.

Scientific modeling - is a generation of a physical, conceptual, or mathematical representation of a real phenomenon that is difficult to observe directly. An example would be creating a small model that shows how tectonic plates move. A model would make it easier to observe this process because tectonic plates are typically very large and in parts of the world that we cannot observe.

Seismic – of or related to earthquakes.

Variable – Any item or factor that can be controlled or changed during an experiment. Scientists control experiments so that they can test different variables in isolated circumstances. This is because they want to see how a variable might change the results of an experiment. In the case of this lesson, "load" is the variable. This is because the students are testing the effects of load on different materials.

B. References

1. "Experimental variable." *The Free Dictionary*. Farlex, 1 Jan. 2012. Web. 22 July 2014. <http://www.thefreedictionary.com/experimental+variable>.

2. "How it Works: Building Loads." *FineHomebuilding.com*. N.p., 1 Jan. 2014. Web. 22 July 2014. <http://www.finehomebuilding.com/design/articles/how-it-works-building-loads.aspx>.

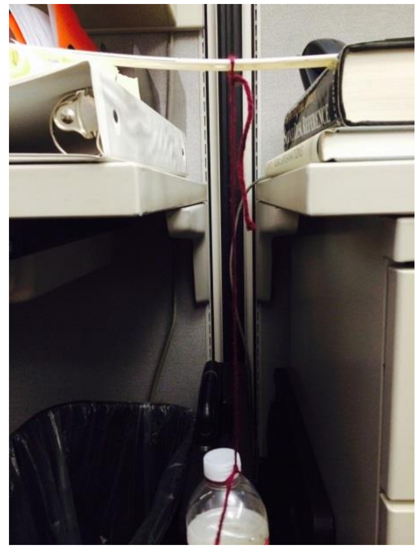
3. "Variables for Beginners." *Doing a Fair Test:*. N.p., n.d. Web. 22 July 2014. <http://www.sciencebuddies.org/science-fair-projects/project_experiment_fair_test.shtml>.

4. "The Engineer's Companion/FAQ on Failures, Part One." *The Engineer's Companion/FAQ on Failures, Part One*. The Engineer's Companion, 1 Jan. 2008. Web. 22 July 2014. <http://www.designnotes.com/companion/failure1.html>.

C. Materials Testing Data Collection Sheet

What structural materials and shapes best withstand an earthquake?

Materials Testing



Directions

1. Tape material across 6-inch gap in desks.
2. Tie end of string around the center of the material.
3. Hang different weights on the loop of the string starting with the lightest (1/4 full).
4. Take notes on what you observe in the data collection table below. What happens to the material? What is the maximum weight your material can hold without bending? Without breaking?
5. What conclusions can you draw from your experiment?

Data Collection Table

Material	Maximum Weight Held Without Bending/Breaking	Material Test Observations
Sample: Straw	*Sample: 0 bottle of sand*	*Sample: The straw bent in the middle where the weight was attached. It was only able to stay on the books because it was taped. The straw was not a strong material.*
Sample: 18 Gauge Wire	*Sample: ¼ bottle of sand*	*Sample: The wire held ¼ bottle of sand without bending, but it bent with ½ bottle of sand.*