It’s Not my Fault!

Target Grade: Elementary/Middle
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Semester: Spring 2019

Brief Overview

More than 2000 fault lines criss cross California and scientists continue to find more. Many of us have perhaps experienced earthquakes as they happen more frequently than we think. In this lesson, we will focus on earthquakes and key causes and effects of these natural phenomena.

Teaching Goals

1. Earthquakes are a result of **tectonic plate** activity
    a. Originate from the **epicenter**, the part of land directly above the *focus*
    b. Transfer their energy through *seismic waves*
2. There are several components to consider when designing a sturdy and resistant structure!
    a. There are two major stresses a material will encounter which must be considered when selecting a material
        i. **Tension -** when a material is pulled apart
        ii. **Compression -** when a material is pushed inwards
    b. **Triangles** are the strongest when it comes to holding their own shape while bearing outside pressures
    c. A structure should be able to withstand high **loads** (outside weights or sources of stress)
3. The **Engineering Design Process**!

Careers and Applications

The primary goal of both civil engineers and architects is to create structurally sound buildings and, especially in the Bay Area, to create structures that are resistant to any natural occurrences, such as earthquakes. Therefore, the enveloping theme of this lesson centers around this career area; however, all types of engineers need to consider the strength of a material before they use it. Any engineer that does not consider the worst case scenario, such as an earthquake, will build products that will not withstand the test of time.

Agenda

- Introduction: (5 min)
- Module 1: What are Earthquakes? (5-10 min)
- Module 2: Loaded Towers (15-20 min)
- Module 3: Building Structure and Stability (20-25 min)
- Conclusion

Introduction

Today's lesson is centered around earthquakes and how civil engineers and architects prepare for them! To understand the problem, we first must learn a little about the earth's different components and how earthquakes are formed.

The earth consists of three fundamental components: the core, mantle, and crust. The **crust** is Earth's thinnest and topmost layer. The crust has two types: oceanic and continental. Furthermore, the crust is made fully of moving plates! The **mantle** is the most massive layer of the earth, consisting of rocks and some fluids; however, it remains mostly solid. The mantle, through movement (by heating from the core), causes plates to shift at the crust. The **core** consists of two parts, inner and outer. The *outer core* is fluid, like the mantle, and can reach staggering heats ranging from 4400 °C in the outer regions to 6000 °C in the inner regions. The *inner core* is approximated to be at a similar temperature of 6000 °C, which is as hot, scientists estimate, as the surface of the Sun!

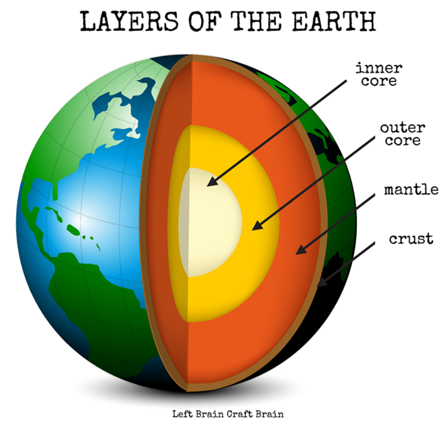


Figure 1: A Diagram of the Earth's Layers

Specifically, for this lesson, we are focusing on the lithosphere, which consists of the crust and the upper mantle, where tectonic plate activity takes place! **Tectonic plates** are individual, puzzle-like pieces of the lithosphere that float over the mantle, and their relative movement determine the formation of many of earth's natural occurrences such as mountains and valleys, volcanic activity, and most importantly for us, earthquakes. Tectonic plates that collide together are known as *convergent faults*. These collisions result in the formation of mountains. *Divergent faults*, on the other hand, are when tectonic plates separate, resulting in the formation of valleys. Lastly, *transform faults* are when two plates slide past one another; this extreme friction causes the **earthquakes** we are talking about! This information is especially relevant to us here in California! The Hayward fault lies very close to us in the Berkeley/Oakland Hills, and the San Andreas fault runs just west of San Francisco. In fact, faults are what created the San Francisco Bay!

Procedure:
Using the styrofoam models of the Earth, illustrate to the class the *different layers of the Earth* and explain some of the core characteristics! Then, using your hands or two pieces of cardboard, exemplify the *distinct types of faults a*nd how they contribute to the formation of many natural occurrences. Emphasize how these faults lie all around us in the Bay Area!

Don't focus too much on the vocabulary of the different types of faults. The important part to understand is how the plates interact to form mountains, valleys, and most importantly, EARTHQUAKES!

Additional Notes for Mentors
Despite what some may believe, the Earth is not flat!

<u>Module 1</u>: <u>What are Earthquakes?</u>

Introduction
Now that the students have learned a bit about tectonic plate movement and faults, they will be introduced to important terminology regarding earthquakes and their origin.

Teaching Goals:
1. The **focus** is the origin of the earthquake
2. The **epicenter** is the part on land directly above the focus
3. **Seismic waves** are waves of energy produced by earthquakes

Background for Mentors
As we learned from the introduction, an **earthquake** is shaking of the ground caused by sudden movements in the earth's crust. The earthquake's **focus** is where the rock starts to fracture and is the origin of the earthquake. The **epicenter** is the part on land directly above the focus. It is important to know where the epicenter is for preventative measures and to know where earthquakes usually start. Since earthquakes usually happen at the boundaries of tectonic plates, epicenters can help predict where plate boundaries are. Scientists can also locate the epicenter (and the focus) by studying the different speeds of seismic waves!

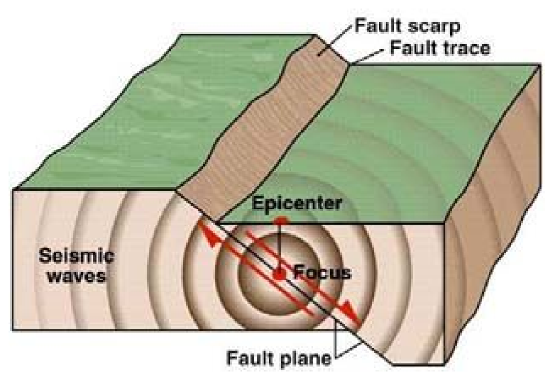
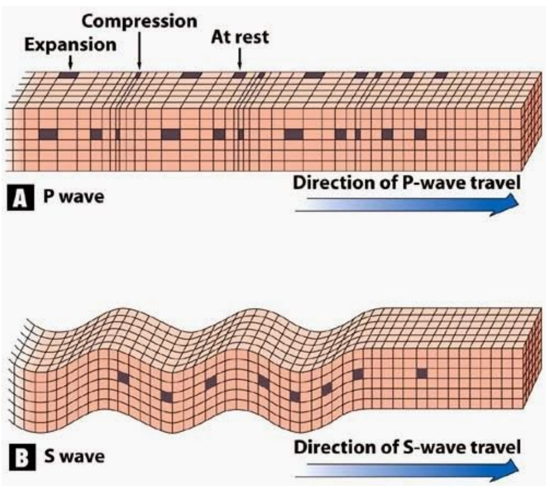


Figure 2: Location of the epicenter and focus

Seismic waves start from the focus and travel outward in all directions. There are various types of seismic waves, and they travel at different speeds and motions. P waves (primary/pressure waves) travel at the greatest velocity through earth. They travel at the speed of sound through air (330 ms-1) or 5000 ms-1 in granite. These kind of waves compress and expand the medium in which they travel through parallel to the direction of wave propagation. Because of the speed, P waves are recorded first on a seismograph. S waves (secondary/shear/transverse waves) travel perpendicular to the direction of wave propagation and are slower than P waves. Surface waves occur when the origin of the earthquake is near the surface. They are analogous to ocean waves, and though they travel slower than S waves, can be the most destructive due to the large amplitude.



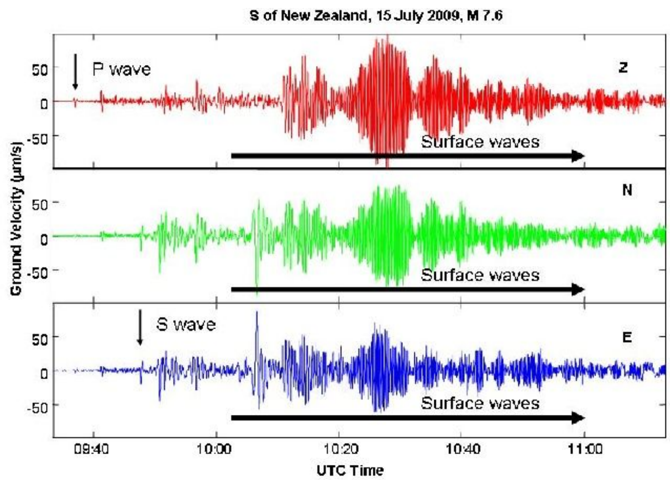


Figure 3A (left): Difference in P wave and S wave motion
Figure 3B (right): Emphasizes the differences in speed and magnitude depending on the type of seismic wave

Materials

- 1 large piece of cardboard with drawn circles
- 60-70 small block wooden cubes
- 2 blocks of wood or any other level objects
- Rocks to use as weights/loads

Procedure

1. Place the piece of cardboard as shown on top of two objects of equal height (in this case, two blocks of wood)

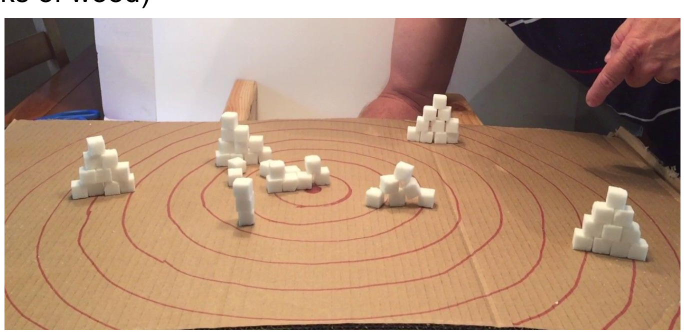


Figure 4: Buildings at varying distances from the epicenter

2. Set up one wooden cube tower directly on the **epicenter** (the center dot) and other towers at varying distances from the epicenter

    a. Tell the students that these towers can represent buildings/ houses
    b. Explain that you are tapping under the epicenter at the **focus**, where the earthquake originates!
3. Start by gently tapping underneath the cardboard at the epicenter for about 5-10 seconds
4. Observe what is happening as the wooden cubes start to separate and the buildings move outward from the center
5. This time, continue to tap at a harder strength underneath the epicenter until a few of the buildings start to crumble
    a. The students should notice that the longer the duration of the earthquake, the greater the damage due to aftershocks
6. Now create rectangular prism buildings such as this one, large enough to support the weight
    a. Now place the weight/load on top (or to the side) of the building at any distance from the epicenter and once again tap underneath the epicenter to see the resulting effects
    b. The students will hopefully be able to see that loads help absorb the shock from earthquakes, thus preventing greater destruction of buildings

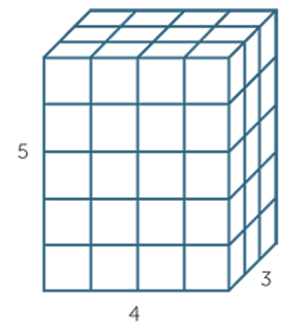


Figure 5: Load placed on a building

Notes for Mentors

If students are interested, feel free to experiment with shaking the cardboard slower vs faster, as the faster waves should affect the smaller buildings more, and the slower waves should affect the taller buildings more.

Module 2: Loaded Towers

Introduction

Following the previous module, students will be introduced to the importance of building stable structures! During an earthquake (which we experience frequently here in the Bay Area), buildings are subject to extreme stresses and strains, so it is essential to focus on building stability when considering any sort of architectural design. In this module, we will be building a tower that can hold as much of a **load**—an outside weight or source of pressure—as possible. This challenge is not about building an earthquake safe structure; rather, it is to emphasize the importance of building a structure that can carry and sustain—without material failure—high loads.

Teaching Goals

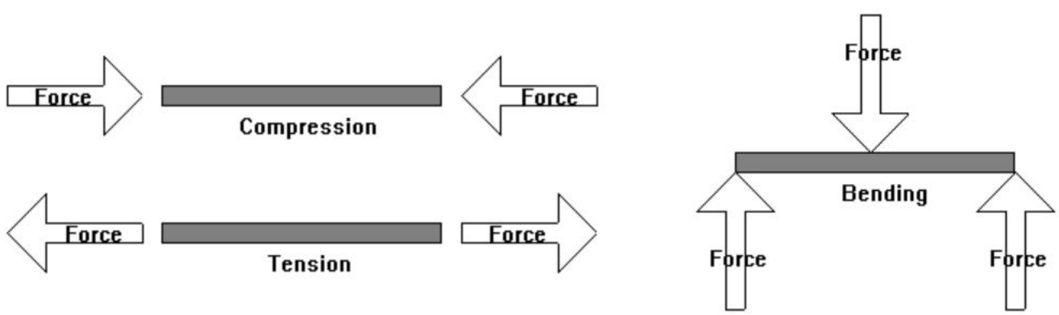
1. Tension and Compression (and Bending)
    a. **Tension -** when a material is pulled apart
    b. **Compression -** when a material is pushed inwards
2. A **load** is a weight or source of pressure placed upon a structure
3. **Engineering Design Process**

Background for Mentors

Materials in a tower undergo several different types of strains and stresses; however, for this lesson, we will be teaching the difference between two: **tension** and **compression**. Tension is when a material is pulled apart. Compression is when a material is pushed together. Depending on a material's composition, it can take certain amounts of tension or compression. Concrete, for example, can withstand great amounts of compression; however, it has very low tensile strength. Chalk, on the other hand, has poor compressive and tensile strength and can easily fracture. When a material breaks due to high compression, it is called *buckling*. Alternatively, when a material breaks due to high tension, it is called *snapping*.

Materials can also undergo **bending**, which technically is a combination of both tension and compression, so we will not cover it in too much detail; however, you can mention to the students that materials that bend too much (like a pencil) will also fracture!

Figure 6: 3 Major Stresses a Material will encounter



Lastly, the goal of this this module is to hold as much of a load as possible. A **load** is a force or deformation that is applied to a structure, creating additional stress on the materials that are used to create the structure. Typically, a load will be an outside occurrence that is caused by someone or by something (in our case, an earthquake!). The students will be working to maximize their load of pennies through the **engineering design process**. This is the process of uptaking any sort of engineering challenge. The process begins with brainstorming and designing. Then, building follows, after which testing can begin. Testing is used in order to refine your design and to ensure that your product can withstand all possible kinds of loads without breaking apart!

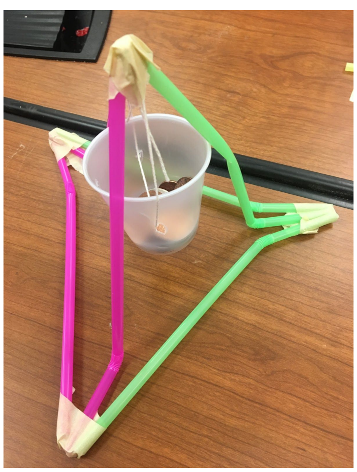
Materials

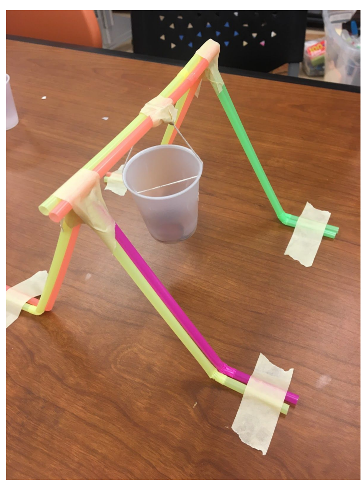
- 10 straws per group
- String
- 1 roll of tape per site
- Small plastic cup per group
- ~100 pennies per site

Procedure

1. Demonstrate the core concepts of tension, compression, and bending with the bendy part of the straw provided or any other material you can find: a toothpick, piece of paper, etc.
2. Introduce the challenge: building a structure that can hold as many pennies as possible in a cup held off the ground
3. Hand out materials and help students work in groups to create their towers!

Figure 7A (above), 7B, 7C, 7D: Examples of Load Tower Designs





Additional Notes for Mentors

Students are allowed to tape down their structures to the ground if they are struggling; however, we recommend giving them the challenge of making it free-standing! Another suggestion for strong towers is to double up straws by taping them together for additional strength. *Make sure students don't overuse materials such as straws or tape!*

If your site is in a time crunch, skip this module and focus on module 3!

Module 3: Earthquake Proof Buildings!

Introduction

For their final challenge, students will be experimenting with various structures in creating the most stable, earthquake-proof building possible! Each group of structural engineers will follow certain guidelines and engage in a friendly competition in designing this building.

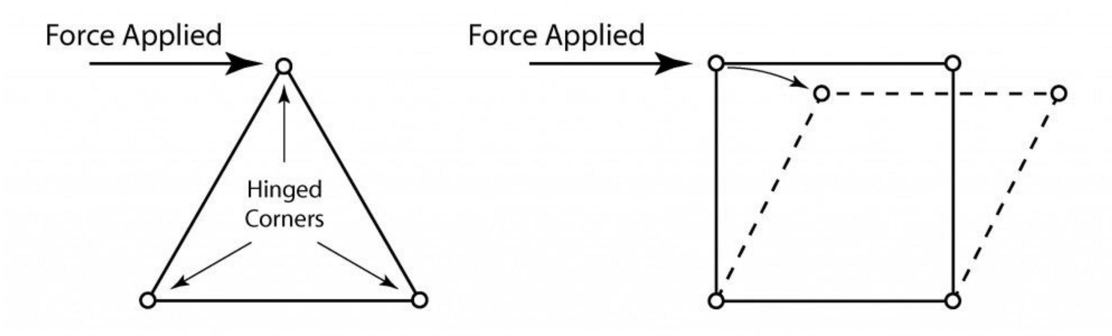
Teaching Goals

1. **Tension** and **Compression**
    a. **Triangles** are the strongest shape!
2. The **Engineering Design Process**

Background for Mentors

Triangles are so strong because of their inherent structural characteristics. The corner angles of triangle cannot be changed without changing the length of a side. Therefore, in order to change the shape of triangle, an edge must collapse. A load applied to a **triangular structure** will not result in geometric distortion. However, a square is more prone to lose its shape. This is shown below:

Figure 8: Why Triangles are Superior



This type of deformation seen in the square could result in the tilting of a tower and ultimately the collapse of the tower, which is why **triangular supports** are so often seen, especially in bridges and towers. Engineers counter this problem by adding diagonal supports through the middle of a square, turning the square into two triangles and thus making a stronger structure.

An example of a common structure used in buildings are trusses. Trusses utilize *triangles* to bear heavy loads. To clarify, a truss is a structure that is made of a web of triangles to help with even distribution of weight and the changes in compression and tension. Trusses are used in a variety of building structures, roofs, and bridges. They are usually made of three components: the top chord (which is usually in compression), the bottom chord (which is usually in tension) and the bracing between the top and bottom chords.

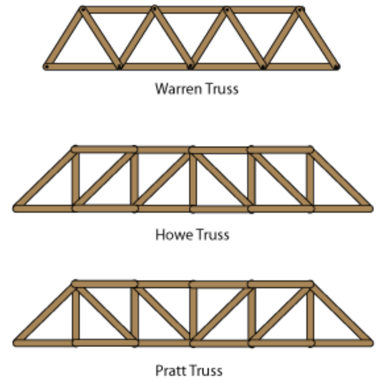


Figure 9: Common Truss Designs

The efficiency of trusses means that there is less material required to support loads compared to solid beams. Here are a few of the most common trusses. Encourage students to incorporate triangular structures in their buildings.

Materials

For the triangle demonstration:

- 7 popsicle sticks
- Masking tape

For the earthquake shake tables:

- 2 pieces of sturdy cardboard
- 2 thick rubber bands
- 2 PVC pipes
- Masking tape

For the buildings (per group of 3-4 students):

- 1 paper (to draw building design)
- ~ 30 toothpicks per group
- ~ 30 mini-marshmallows per group
- ~ 20 spaghetti sticks
- Masking tape

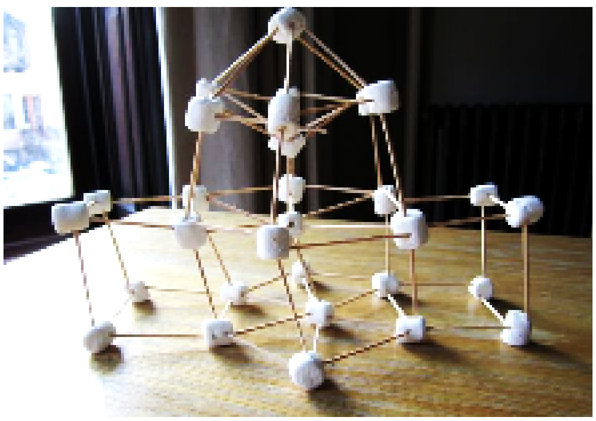
Procedure

1. If not already assembled, tape the popsicle sticks into two separate shapes: a square and a triangle. Demonstrate how triangles maintain their shape better!
2. The shake tables should already be constructed, but it is very easy to assemble as shown in the picture below

Figure 10: A simple shake table

3. Before any construction happens, give each group of students a piece of paper to carefully plan out their idea
    a. Emphasize that their buildings must survive both small and large earthquakes
    b. The buildings must fit on the base
    c. The buildings must have at least 2 stories
    d. The buildings should be free standing
4. Distribute about 2 handfuls each of toothpicks, spaghetti sticks, and mini-marshmallows to every group
5. Let the construction begin!!

6. When the students are ready to test, make sure all the requirements have been met.
7. For the test, tape down the base of the structure to the shake table, just to make sure the structure does not fall off the table. Hold onto the ruler, pull, and let go! An alternative method is just holding onto the edge of the top piece of cardboard and shaking it from side to side
    a. Start with a smaller earthquake and then gradually produce larger earthquakes
8. Observe the results and allow the students to think about how they can improve the design for better structural integrity
9. As this is a competition, encourage students to make the tallest building possible!
10. Most importantly, though, just have fun!



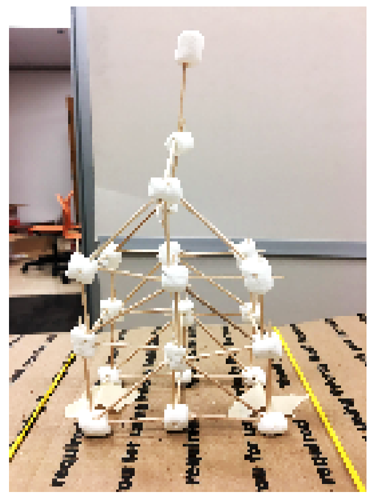


Figure 11: The picture on the right is a simple, basic design which the students could incorporate vs an example of an intricate building on the left

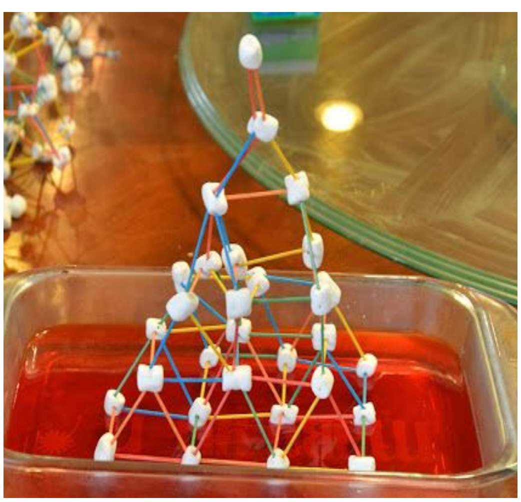


Figure 12: By now, we know that the building on the right would be less stable than the one on the left. However, don't just tell the students that fact, let them see it for themselves too!!

Additional Notes for Mentors

If the students do not follow the guidelines exactly, it's alright, as long as they understand the main concepts. However, it should be a bit of a challenge to create the ideal building. If you're worried about toothpicks being too easy, have the students start with spaghetti and then move onto toothpicks if they are having difficulty! If not, give them the option of either material.

Conclusion

As students clean up, ask them what they would do differently if they had more time: Would they consider creating a wider base? Would they want to add more triangles for cross-bracing? What other types of materials could they use to make for a stronger tower? Ask them about the process engineers take to design earthquake-proof structures. Finally, remind the students that they were just civil engineers as they built their towers!

References

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- Teacher Tip: Simulate an Earthquake with an Easy-to-Make Shake Table, EIE http://blog.eie.org/teacher-tip-simulate-an-earthquake-with-easy-to-make-shake-table?fbclid=IwAR17ab00ti8V-K3IF8zCZFT8-tBIQs5K3dn3wFnFmIfSdJB2cSroRrMg-aU

Summary Materials Table

Material	Amount per Group	Expected $$	Vendor (or online link)
Styrofoam spheres	1 per site		Amazon

Large Piece of Cardboard w/ Drawn Circles	1 per site		Inventory
Wooden Cubes	~60-70 per site	$27	Amazon
Rocks	2 or 3 per site		Mother Nature
Platforms for Module 1 (maybe find something in Bechtel too)	2 per site		Inventory
Plastic Straws	~100 per site	$30-$40	Amazon
Tape	1-2 per site		Inventory
Plastic Cups	10 per site		Inventory
Pennies	~50 per site	~$5	Inventory/Amazon
Cardboard Platform for Shake Table	2 per site		Inventory
Large Rubber Bands	2 per site		Inventory
PVC Pipe	2 per site		Inventory
Marshmallows	~180	< $10	
Spaghetti sticks	~120		
Toothpicks	~180		Inventory/Amazon