Skyscraper Challenge

Lesson Type: Challenge

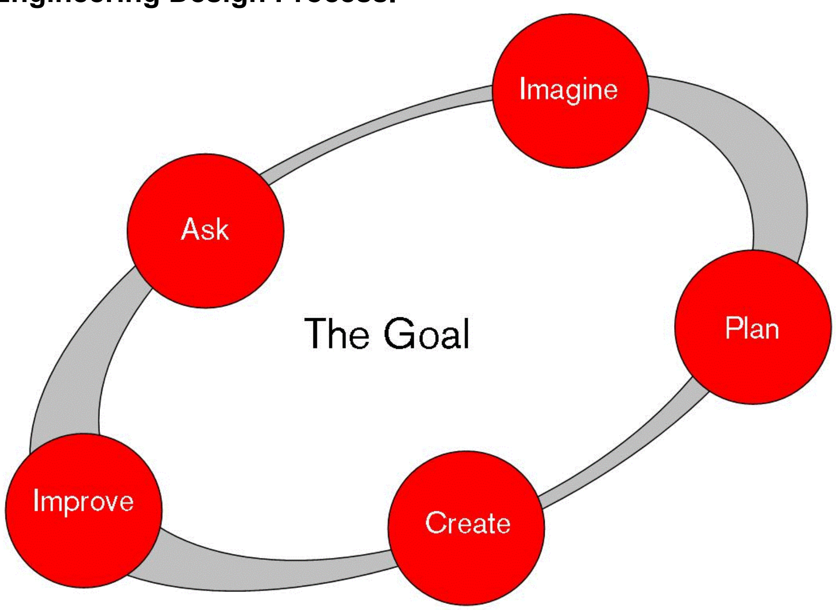
Challenge

The City of Greenberg (capital of Renewistan) has commissioned your engineering firm to build the tallest skyscraper in the world. Unfortunately, Greenberg sits alongside a fault, and earthquakes are a fact of life for Greenbergers. Your engineers must build a skyscraper that can keep its occupants safe during an earthquake.

- The skyscraper must support a full water bottle on the top to simulate load of occupancy.
- The skyscraper must withstand an "earthquake" (tilt the base 10°).

Teaching Goals

- Students will be able to understand and apply the **Engineering is Elementary 5 step Engineering Design Process.**



- Students will work together in teams to achieve a common engineering goal.
- Students will understand how budget and material constraints affect their design process.

Teaching Plan - Session 1 [1.5 hr]

- **Setup** [5 min] (Before mentoring session starts!)
    - Create a "materials bar" where students will purchase their materials as they need them.
    - On one index card for each team, write "$1000" at the top left, with plenty of room

below to update their budget after expenditures.

- Introduce challenge / materials [5 min]
    - What kind of engineers build skyscrapers? (Structural, civil, mechanical, materials engineers, etc).
- Divide into teams of about 4 or 5 [5 min]
    - Have each team appoint one materials coordinator
    - Give each team a budget index card. Write their team name at the top right.
    - Give each team a **Materials Price List**
    - Give each team one free piece of 8 1/2 x 11 paper (for design planning)
    - Give each team one pair of scissors (materials permitting).
- **Start building!**
    - When teams buy materials, have them bring their index card to the materials bar. Cross out their old budget and write their budget minus cost of materials directly under it.
    - If you would like, alter the challenge mid-game by changing material prices. This can simulate a "shortage" or "surplus" that drives market prices.
- With about 15 min left, it's time to start judging.
    - **Take pictures!**
    - Collect the index cards and make notes on the back
        - Measure and note the height
        - Place the (full) water bottle on the top of the structure. See if it holds.
        - Note whether it held or not on the index card.
- If you have time, discuss with the kids which ideas worked or didn't work.
- Remind students that they will be building another skyscraper next week.

Teaching Plan - Session 2 [1.5 hr]

- **Setup** [5 min] - same as session 1.
- Introduce the **Engineering is Elementary 5 step Engineering Design Process.** [15 min]
    - Hand each team a **Session 2 planning worksheet**
    - Lead a discussion on the (Improve) and (Ask) steps.
        - What is the goal?
        - What are the constraints?
        - What designs or ideas worked or didn't work?
- **Start building again!**
    - While students are building, have one of your mentors construct a tilt measure for testing. Make a right triangle from cardboard or stiff paper with legs of length **10 x 1.8** (inches or cm, doesn't matter) - This will create an angle of 10° which can be used for judging.
- With about 15 min left, final judging.
    - **Take more pictures!**
    - Judge as before, but add the 10° tilt test. You may tape the bottle to the top if necessary.

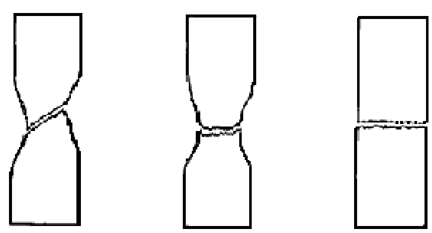
Background for Mentors

In order to build sturdy structures, mechanical and structural engineers have to understand the strength of materials. Materials generally fail in two ways: either the material reaches the plastic stress limit, or the part (beam, column, etc) buckles. We will discuss these separately.

Plastic Limit

Every material has some inherent strength due to intermolecular bonds, microstructure, or interactions between different phases in a composite material. Simply stated, a material fails (deforms) when the **stress** in the material exceeds a some **critical stress value.** The stress a material is under is expressed as a **Force per Area**. Notice that the units are the same as **pressure.** Thus a part with a larger **cross section** can withstand a larger force. For a simple, one-dimensional loading:

$$\sigma = \frac{F}{A} < \sigma_{crit}$$



Ductile shear fracture in Aluminum

Ductile fracture in steel

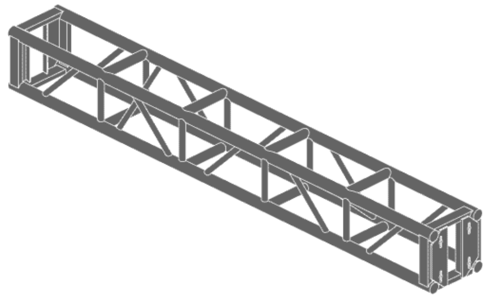
Brittle fracture in steel

Buckling

Many parts used in structural applications have a large **aspect ratio** (ratio of length to width). If a long slender part is put under compression, it is likely to **buckle.** Buckling occurs when a part deforms long before the **plastic limit** is reached. This is easy to demonstrate with a flexible ruler, a straw, or a toothpick. If you try to compress it along the long axis it will “bow” out and fail to support the load. Analysis of buckling reveals that the critical load for buckling is given by:

$$F_{crit} = \frac{\pi^2 EI}{(KL)^2}$$

where E is the modulus of Elasticity, I is the area moment of inertia, L is the length of the column, and K is a factor that depends on how the part is supported. This equation reveals that buckling can be avoided by choosing a stiffer material, decreasing the length, or by increasing the area moment of inertia. Thus if you are making a cardboard or paper tube, try increasing the radius a little to increase the area moment. Buckling can also be avoided by using thinner parts to “stiffen” a long, flexible frame, as shown below:



Note that for almost every situation arising in this challenge, buckling will be primary (if not only) mode of failure. Help students choose designs which maximize the buckling load, as described above.

Worksheets

- Materials Price List (half sheet)
- Session 2 Planning Worksheet

Resources

http://www.mos.org/eie/engineering_design.php

Materials to Request from Site

- Table for the “materials bar.” Preferably 3 or 4 desks wide.
- 1 pair of scissors for each team.
  - If only “kid” scissors are available, ask for 1 pair of “adult” scissors to be made available to the mentors to help mentees cut materials.

Bill of Materials

Quantities specified are **per team, per project**. Thus for 5 teams and 2 weeks, multiply by 10.

Item	Quantity (per team)	Cost to Students
3/16” x 20” x 30” foamcore	1	\$2 / in^2
Cardboard	1 medium box	\$1 / in^2
Skewer Sticks	20	\$10 each
Paper	20 sheets	\$10 / sheet
Masking Tape	1 roll per 2 teams	\$1 / in

Water bottle	1	(for loading the structure)
Index card **OR** 1 Laptop for accounting	1	For tracking team’s budget Each team starts with $1000