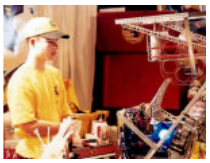

Best Practice

Team Design and Construction of a Toothpick Tower: 9th Grade Girls as Mechanical Engineers

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Introduction:

It is no secret that there is a shortage of women in engineering today. As a teacher of 9th grade girls in an Introduction to Physics course, I have heard first hand comments like "boys are better at this" or "I can't do math, so I don't like science". Girls enjoy expressing themselves creatively through design and construction. They respond eagerly when provided with an engineering challenge and when given support and encouragement during the process. Attendance at a recent summer workshop for high school teachers at Harvey Mudd College of Engineering provided the background to help me to introduce aspects of the Engineering Design Process in the context of commercially available lab kit called "Building A Toothpick Tower". What resulted was a 10 day lesson plan in which girls working in engineering teams applying the basics of the engineering design process (E.D.P.) designing, constructing and testing original towers. Each tower's design had to meet specific requirements and constraints. The finished tower had to be able to withstand simulated earthquakes of varying intensities. Connections were made with earlier course material dealing with balanced forces, gravity, and waves. The relevance of the project to current events was highlighted by homework readings from the New York Times science section, and a visit to NOVA online to from the New York Times science section and the recent NOVA documentary and website highlighting the work of forensic engineers during their in-depth investigation of the precise causes of the collapse of the World Trade Center Twin Towers for the episode "Why the Towers Fell".

Applications:

- Balanced Forces/ Force Vectors
- Formula: Force (N) = Mass (kg) x Acceleration (m/s/s)
- Estimating Measurements
- Calculating Percent Error in Measurement
  - Formula: [Actual Weight (N) - Estimated Weight (N)]/Actual x 100
- Earthquake Waves and Energy Transfer
  - Primary (compressional), Secondary (transverse) & surface waves
- Supporting Structures: pilings, corner braces, support beams, base isolators
- Engineering Design Process (ref 2)
- Forensic Engineering and the World Trade Center Disaster
  - NOVA: "Why the Towers Fell"/ NY Times engineering articles

Learning Objectives:

The specific objectives of the project were (1) to apply the stages of the engineering design process, specifically the identification and prioritization of the design criteria: objectives, limiting factors and functions .to their tower design; (2) to draw 3 alternative designs for their tower, rate each design and make a design choice on based on how well each design fits their criteria and (3) to build a stable tower based upon their chosen design from a combination of wood glue, and wood materials which varied in its ductility, weight and strength; (4) to draw appropriate connections between this lab activity and the safe design of structures for stability and its relevance to the current work of forensic engineers investigating the structural remains of the World Trade Center disaster.

Alignment of Learning Objectives with ITEA curriculum Standards:

ITEA Standards: International Technology Education Association
Design
Standard 8: students will develop an understanding of the attributes of design
Standard 9: students will develop an understanding of engineering design
Standard 10: students will develop an understanding of the role of troubleshooting, research, and development, invention and innovation and experimentation in problem solving
Abilities of a Technological World
Standard 11: Students will develop abilities to apply the design process
Standard 13: Students will develop the abilities to assess the impact of products and systems
The Designed World
Standard 20: Students will develop an understanding of and ability to select and use construction technologies
From ITEA Website: www.iteawww.org/TAA/Listing.htm

Lab Materials:

- Wards Towering Toothpick Disaster Kit
  - (SK-4449-11; I kit for 40 students, 3-4 students per group)
- 1Shake Rattle and Roll Board (for earthquake Simulations; Wards 36-4520)
- 2 extra bottles of wood glue
- 1 large box of Q-tips to apply glue to wood
- Wax paper to cover working space when gluing
- Water Soluble Craft Paints in 6 or more colors
- Foam paint brushes
- Newspaper to cover working areas when painting
- Tools: 4-5 pairs tin snips to cut wood, rulers, levels, tape measures, small handsaws.
- Safety goggles
- Hot glue gun for securing pilings within the foundation
- 4, 3 inch C clamps to secure building and foundation to earthquake simulator
- 6 cork borers to make holes in Styrofoam base-isolators for pilings to make a foundation

The Lab Packet (1 per student) includes:

1. A coversheet with all of the assignments and due dates in the project.
2. The student background information from the kit about construction for strength and stability and earthquakes
3. A description and group worksheet for the Engineering Design Process (see Appendix, Worksheet 1)
4. Graph paper for a labeled diagram drawn to scale for the final chosen design of the groups' tower
5. An Estimating and Measuring Forces Worksheet (see Appendix, Worksheet 2)
6. NY Times Science Section article: Under the Towers, Ruin and Resilience (by Dennis Overbye, 10/9/01) with study questions
7. NY Times Science Section article: Wounded Buildings Offer Survival Lessons: Two Buildings Burned Only One Building Fell (by James Glanz, 12/0401) with study questions

Lesson Plan Summary for "Toothpick Tower Lab":

DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
Students assigned to engineering teams of 3. Plan & design with E.D.P. List objectives, requirements and draw 3 brainstorm ideas for tower	Design Optimization Choose Final Design and Draw to scale. Discuss HW terms such as trusses etc.	Flat construction of walls begins	Short 5 minute quiz on vocab from HW and class Construction Of walls continues. Start foundation	Discuss HW article Construction of Level 2 walls
HW: Read background on construction vocab and answer questions	**HW**: Read background on earthquakes and answer questions	**HW:** Study earthquake and construction vocab for quiz	**HW** Read article "Under the Towers" Answer questions	**HW**: no extra HW, catch up on any late or missed work

DAY 6	DAY 7	DAY 8	DAY 9	Day 10
Construct Tower: Level 2 + 3+ Roof	Discuss HW article and Continue Construction	Short Quiz Final Touches on Buildings Complete Group work self evaluation	Estimating and Measuring Forces Worksheet Video: NOVA "Why the Towers Fell"	Testing Day Review types of earthquake waves and shake each tower with the simulator. Discuss group self evaluations
HW: NY Times article: Wounded Buildings	**HW**: Study for quiz on the two NY Times articles	**HW**: none	**HW**: Answer questions to Nova episode	**HW**: Complete all pages of lab packet. Hand in next class day

Assessment Criteria and Expectations:

Students were provided with description of the grading criteria for the completed tower and class teamwork at the onset of the project. Basically to receive an "A" each person needed to hand in a complete and correct Tower Packet by the due date. Each student must have exhibited constructive team membership which included participating fully each workday, working independently with minimum input from the teacher, compromising to solve problems, keeping the work on schedule and most important for 9th grade girls keeping the socializing to a minimum. The tower itself received a separate grade. To receive a grade of "A" (1) it had to be built according all specific design requirements in terms of its dimensions and material limitations. Also (2) It also had to make effective use of supportive design features such as pilings, a base isolator, trusses, symmetrical form corner braces and support beams, as described in the packet background readings. (Appendix: Worksheet 4) Finally, (3) the tower had to be able to withstand 30 seconds of vigorous shaking on the "Shake Rattle and Roll Board" in a manner simulating each of four main types of earthquake waves: Primary, Secondary, and Surface waves (Love and Raleigh Waves). In addition to the teacher's assessment each team member was required to submit a written "Group Self-Assessment" (Appendix: Worksheet 3). Students were also given two short quizzes on homework material during each of the two weeks of the project.

Expected Results:

In general, the girls loved working on this project. I choose to assign them to their teams rather then let them pick partners so that I could include students with various strengths on the same team. For example, a good planner and manager was paired with a strong "mechanical reasoner." On a typical construction day, I would start each 40-minute (or one 60 minute class a week) with 10 minutes on classroom review of concepts central to the project homework or a quiz. I usually found that having 25 minutes of building and 5 minutes for cleanup gave me the best productivity. I found that I had to make a few trips in mid-project for extra glue and small clamps (or clothespins) to hold with wood together while it was drying overnight. The girls worked productively with all groups' towers being completed by day 8 or 9. I added a step to the Ward's lab where each team was encouraged to paint and landscape their towers with craft paint and miniature plants. I was impressed by the stability of their completed towers (all but one passed the shake tests) and the time and consideration that they spent on the aesthetics of their design. Prior to testing, each group completed their "Estimating Forces" worksheet (Appendix: Worksheet 2) where they had to estimate the final weight of their building (by measuring the mass of one of each of the three different types of building materials Popsicle stick, craft stick and toothpick and multiplying by the estimated number of each in the finished tower and multiplying by the force of gravity Force (N) = Mass (kg) x acceleration due to gravity(10 m/s/s)) Next they compared the estimated weight of their building to the actual weight of their building in Newtons and calculated their percent error according to the formula : [estimated weight (N) - actual weight(N)]/ actual weight (N). Finally, they had to list reasons why their estimated and actual weights differed. Their measurements revealed and error rate of anywhere from 15% to 75%.

Overall, students evaluating their course experience rated this unit as a favorite. The girls said that they enjoyed seeing their towers successfully survive the earthquake testing and that they especially enjoyed decorating their towers. The girls speculated that if the same lab were done together with an equal number of 9th grade boys and girls, that the boys might have a tendency to "hog all of the tools" and might "make fun of them when they tried to use the tools". Doing the lab with a smaller, single-sex class (18-19 per class) meant that each girl had the opportunity and responsibility of contributing, and I feel that it went a long way in convincing these 9th grade girls that engineering is as fun as it is interesting and important. The unit's mixture of fun and science was complemented by its powerful connection to the current studies being done by forensic engineers on the remains of the Twin Towers in New York City.

Resources:

- Partners in Engineering Problem Solving (PEPS) Program at Harvey Mudd College Contact: Drs. Lori Bassman and Patrick Little – URL: www.hmc.edu
- Wards Science Kits (800-962-2660)
  - Toothpick Tower Kit (catalog number 36J4515, price $75.95)
  - The Shake Rattle and Roll Board (catalog number, 36J4520, price $179.50)
- "Under the Towers, Ruin and Resilience" (by Dennis Overbye,
  - New York Times Science Section 10/9/01)
- "Wounded Buildings Offer Survival Lessons: Two Buildings Burned Only One
  - Building Fell" (by James Glanz, New York Times Science Section, 12/04/01)
- NOVA video and website for "Why the Towers Fell"
- "Achieving Gender Equity in Science Classrooms (A Guide for Faculty)" compiled by the women science students and science faculty and staff at the New England Consortium for Undergraduate Science Education (NECUSE) Colleges and based upon initial work by students at Brown University. 1996, Published by the Office of the Dean of the College at Brown University.

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APPENDIX of Worksheets

Worksheet 1: The Engineering Design Process: The Toothpick Tower Project

(Adapted from the Partners in Engineering Problem Solving at Harvey Mudd College and

Engineering Design: A Project Based Introduction by Clive L. Dym and Patrick Little, Wiley and Sons, 2000)

Engineering Team Members:_____ _____ _____

Objectives:

- Focus = work constructively at all times
- Group Process = Listen to and compromise with other team members
- Independent Thinking = make sure you read the directions and discuss it with your team before you ask the teacher for input
- Organization = have your previous night's homework out at the start of class, plan your workday and clean up your workplace each day
- Product = your tower must be built to all specifications and pass the earthquake test

After reading the background information in this packet

A. Identify the 3 objectives of your original building's design and list them

B. Identify the 7 design requirements (limiting factors) of the tower project

C. After brainstorming with your team, in the space below, sketch 3 alternative design models for your tower that would fit both the objectives and the requirements of the project

D. Design optimization: As a group, rate each of your 3 models according to how you think each one might perform according to the criteria below (1=good, 2= OK, 3 = bad)

	Model A	B	C
(1) can be built only with the tools and material at hand			
(2) looks stable, probably won't fall during the earthquake test			
(3) looks easy to build, and can be done in time allowed			
(4) I like the look of the design (aesthetics)			

Add the scores for each model, the largest score is the recommended model.
The final design chosen by our group was _____ because _____.

E. On a separate graph paper, draw a diagram of your model to scale. Label the support Structures that will be incorporated to give your tower strength and stability

Worksheet 2: Toothpick Tower: Estimating and Measuring Forces Sheet

1. Draw a force vector diagram showing the two main forces acting on your tower at rest.

2. Estimating the weight of your building.

    2a. Measure the weight in grams of a single popsicle stick.

    Popsicle stick_____ grams = _____kg

    2b Estimate the total number of toothpicks in your tower

    _____ # sticks x _____kg/ea stick = _____total kg Tower Mass

    2c.Weight (N) = Mass (kg) x gravity = _____N

3. Measuring the Actual Weight of the Building
Measure the actual mass of your building on the large balance in the lab and calculate the actual weight of your tower:

    Actual Weight (N) = Actual Mass(kg) x gravity

    _____ = _____x gravity

4. Compare the estimated and the actual weights of the tower

    Actual weight (N)_____

    Estimated weight (N)_____

5. What is the percent difference or error between the two measurements?
    %error = (actual-estimated/actual)x100

6. Discuss 3 sources of error such that the actual does not equal your estimated weight

Worksheet 3: A group Self-Evaluation Worksheet

Team:_____ _____ _____ _____

Please rate each of the following aspects of your group's design process on the following scale: 4 = excellent, 3= very good, 2= so-so, 1 = not good, 0 = poor. Below each selection please explain WHY you chose the rating that you did. Please note that I expect you to be honest, respectful and complete with your answers. (In other words don't write all 4's for each). Your grade on this self-evaluation will reflect the completeness and thoughtfulness of your answers.

1. There were clearly defined roles for each team member:____
   Explain:

2. All members of the group contributed each working day:____
   Explain

3. The team was organized and used its time effectively:_____
   Explain

4. Each member listened and compromised:_____
   Explain

5. The thing that my group did best was:

6. The one thing I would try to have my group improve for next time was:

7. Your personal comment about the project:

Worksheet 4: A Tower grading rubric/ checklist

Construction Criteria Rating

___ entire building 45 cm
___ 3 stories
___ each floor is 15 cm
___ each story has a floor
___ building has a roof
___ Building does not have solid walls
___ Building base is 22.5 X 22.5 cm
___ Materials not exceeding 600 wood
___ used only wood glue on wood (except pilings)

Earthquake resistance

____ 30 seconds lateral shaking
____ 30 seconds vertical shaking
____ 30 seconds circular shaking

Comments and Grade:

Sample of Student Diagram from Worksheet 1