Building a Table: A Lesson in Strength

This lesson plan teaches students to understand structural integrity and basic lightweighting concepts by allowing them to quickly design, build, and test a scale model of a table. The students can then compete to see who's created the strongest and lightest table. This project should take 2 – 3 days depending on which sections are assigned as homework and how long your class periods are.

Objectives and Goals:

- Students will be able to understand basics of structural strength and lightweighting
- Students will gain an appreciation for engineering tradeoffs (optimizing for one variable often negatively affects another) by balancing various metrics
- Students will be able to do basic modeling and construction using computer aided design (CAD) programs

Standards Met (Common Core):

- **CCSS.ELA-Literacy.RST.11-12.3:** Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

- **CCSS.ELA-Literacy.RST.11-12.9:** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Materials Required:

- Computers (Mac or PC) capable of running 123D Design and 123D Make (123Dapp.com) [Note: these programs are free, but must be downloaded]
- Cardboard (you may have the students collect this before starting the project as a homework assignment)
- [OPTIONAL] A laser cutter will save your students a lot of time, but it is not necessary as the cutting can be done using a utility knife
- Utility knives for finishing up the laser cutting
- [OPTIONAL] A printer, in case you are not using a laser cutter
- Glue, for holding together the models
- A set of weights for testing the tables
- A sensitive scale for weighing the tables (ideally accurate to the gram)

Activity:

Step 1 (Before Class): Acquire materials

Students should collect enough cardboard to construct their models. A sheet of 2 feet by 3 feet will easily be enough for one model and will allow students to share in case some are unable to acquire cardboard in time for class. Students may collect whatever quality or kind of cardboard they like, and this choice will affect their eventual structures.

Additionally, you should install 123D Design and 123D Make on all the computers to be used in class. This should be done at least 1 day before class.

Step 2 – Introductory Presentation (5-10 minutes):

A brief introductory presentation should be made on the goals for the activity. The aim of the presentation is to discuss the concepts of structural integrity and lightweighting.

Step 3 – Determine Scoring Metrics as a Class (5-10 minutes):

Students will be competing to make the "best" table, so you may choose to work together to create the scoring method you will use to determine the winner, although example metrics and scoring are shown below. The metrics should include the weight supported (potentially with some maximum weight cap) and the weight of the table (the lower the better). Other metrics could include the table's height or beauty of the design (as voted on by the class).

The aim of these scoring methods is to force students to choose which aspects of their table they will optimize for. For example, does it make more sense for them to create weak but lightweight tables or strong but short ones? These metrics are designed to allow students to create a wide range of tables.

Example scoring method 1:

$$\frac{load\ supported\ (pounds)\ up\ to\ 20}{weight\ of\ table\ (ounces)} \times height\ (ft) \times beauty\ score\ (0.75\ if\ class\ decides\ \text{ugly}, 1\ for\ normal, 1.33\ for\ beautiful)$$

Example scoring method 2:

- Strength: 5 points if it holds 10 pounds, 1 additional point for each additional pound up to 15
- Weight: 1 point for each ounce under 8 ounces
- Height: 3 points if at least 8 inches, ½ a point for each additional inch
- Beauty: 5 points for classes' favorite design, 3 points for second favorite, 1 point for third

The class should also agree on a testing method. One example could be using a clipboard as a tabletop, and having the students add weights one pound at a time to their own table until failure. Another is to add reams of paper until the structure is close to failure and then add short stacks of paper until failure. This allows for a sort of makeshift weighing system. Each student may add the weights to their own structure. Of course placing the weights gently and centered is to their advantage, but it is up to them.

Step 4 – Open 123D Design and Get Started (30-40 Minutes, may also be assigned as homework):

Students should design their table using 123D Design. They should remember to balance the importance of designing a strong table against the importance of the other metrics. They may use this Instructable for guidance on design:

http://www.instructables.com/id/Design-and-Build-a-Table-in-a-Day-Design/

Step 5 – Slice and Build the Tables (30-90 minutes, may also be partially assigned as homework):

This step will be significantly easier if you have access to a laser cutter, although it is still possible without one. Have your students follow this Instructable for information on how to set up 123D Make to create the templates for building the table and for how to physically assemble their tables:

http://www.instructables.com/id/Design-and-Make-a-Table-in-a-Day-Assembly/

The assembly of the parts can be done at home if you would like to save in class time for other things. Students may use any kind of glue they like, although of course using an excessive amount will negatively impact the weight of the structure.

Step 6 – Testing (10-20 minutes):

Before testing students should guess how their table will fail. Students should test the strength of their table in class using the agreed upon methods. The failure point (if it is reached) should be recorded along with the other agreed upon metrics. At the end, each student should record how their table failed.

Step 7 – Determining the Winner (5 minutes):

Tally up the points and determine the winning table. You may also choose to give accolades for the winners of individual categories or for particularly creative design. This is meant to be a motivating factor for the students, so make sure it is fun for everybody, not just the "winner."

Step 8 – Finishing Class Discussion (10-20 minutes):

The students should briefly discuss what they noticed about their tables. How did they fail? Are there certain ways in which they were strong? Are there certain ways in which they are weak? Discuss the strength of cardboard and other materials in simple tension, compression, and bending (the tables should not have experienced any appreciable torsion forces, but you may choose to briefly cover this as well).

Students should also discuss how the metrics the class used for scoring affected their tables. How could the scoring system be changed to encourage lighter tables? What about stronger but heavier tables?

Step 9 – Clean Up (5 minutes):

Students should clean up their desks and exit the class calmly and quietly.

Homework and Assessment:

As noted above, both the design of the table and construction of the table can be assigned as homework. For homework following the completion of the project students should write a one page assessment of what they learned from the exercise. For example, how would they build their table differently if they could do it again? What limitations did they have based on how the table was made? If they could, what other methods of lightweighting would be helpful when creating a table? This should include both concepts discussed in class and out of class research. These responses will be graded based on the understanding of the concepts, ability to integrate and evaluate multiple sources of information, and clarity of thought.

They should additionally discuss where they see examples of lightweighting in their everyday life. Why is lightweighting important? What are the implications of lightweighting from environmental, economical, and functionality perspectives? A good answer could include a discussion of lightweighting in cars. Lighter cars are functionally better as they can accelerate faster, and environmentally better as they use less gas. However, using stronger and lighter materials is often costly, and so can lead to a higher initial cost to the consumer (of course, this may be recouped in savings on gas).