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Straws, Balloons, and Tootsie Rolls: The Value of Hands-On Activities in the Engineering Classroom

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Straws, Balloons, and Tootsie Rolls: The Value of Hands-On Activities in the Engineering Classroom

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Abstract

Within engineering education, long-term retention of major concepts is a key objective. Numerous classroom techniques combine to work towards this goal, including testing, laboratories, and demonstrations. One highly effective, yet often underutilized, tool for improving long-term understanding is hands-on activities that students do at their desks, especially those involving simple items with which they are already familiar. Five characteristics are common to a productive, in-class, reinforcement activity.

(1) All students participate, preferably at their own desks.
(2) Items involved are commonplace, familiar to the students, and low-cost.
(3) Activities are relatively quick, providing a brief break within the lecture.
(4) Elaborate setup or support equipment is not required.
(5) Before the activity, students are given a few moments to predict results.

This paper describes a variety of quick, hands-on activities used in a recent mechanics class at the United States Naval Academy.

Keywords

Hands-on, Activities, Engineering, Education, Mechanics

Full Paper

Within engineering education, long-term retention of major concepts is a key objective. Numerous classroom techniques combine to work towards this goal, including testing, laboratory work, and demonstrations. One highly effective, yet often underutilized, tool for improving long-term understanding is the use of hands-on activities that students do at their desks, especially those involving simple items with which they are already familiar.

Five characteristics are common to a good, in-class, reinforcement activity.

(1) All students can participate, preferably at their own desks.
(2) Items involved are commonplace, familiar to the students, and low-cost.
(3) Activities are relatively quick, providing a brief break within the day's lecture.

(4) Elaborate setup or support equipment is not required.
(5) Before the activity, students are given a few moments to predict results.

A good activity is usually one that the students could easily replicate at home to amaze their parents – and many do. Within a recent Mechanics class at the U.S. Naval Academy, quick demonstrations were used to reinforce many of the class's key concepts. Some of these activities are described below.

Brittle versus ductile failure can be quickly experienced with chalk and Tootsie Rolls. For this demonstration, each student pair gets two pieces of chalk and two Tootsie Rolls. (Note: The long, skinny (3" long, 0.5" diameter) Tootsie Rolls that kids get at Halloween work best for this.) Tell the students that they're going to apply a pure axial force to a piece of chalk and then to a Tootsie Roll. Ask them to predict the shape of the failure surface out loud to each other. Then, have each pair apply the force and observe the results. If they did it right and applied purely axial force, the break in the chalk will be a flat break straight across the piece, while the Tootsie Roll will stretch and neck before breaking. Next, do the same thing, but have the student pairs apply pure torsion (twisting) to the other chalk and Tootsie Roll. The chalk will break on a 45 degree angle along a helical spiral shape. The Tootsie Roll, if done correctly, should have a relatively flat break straight across the piece. After these demonstrations, the students are usually quite happy to eat the Tootsie Roll debris. They might not even mind that the lecture then transitions into a discussion of how ductile versus brittle failure relates to Mohr's Circle and stress transformation equations.

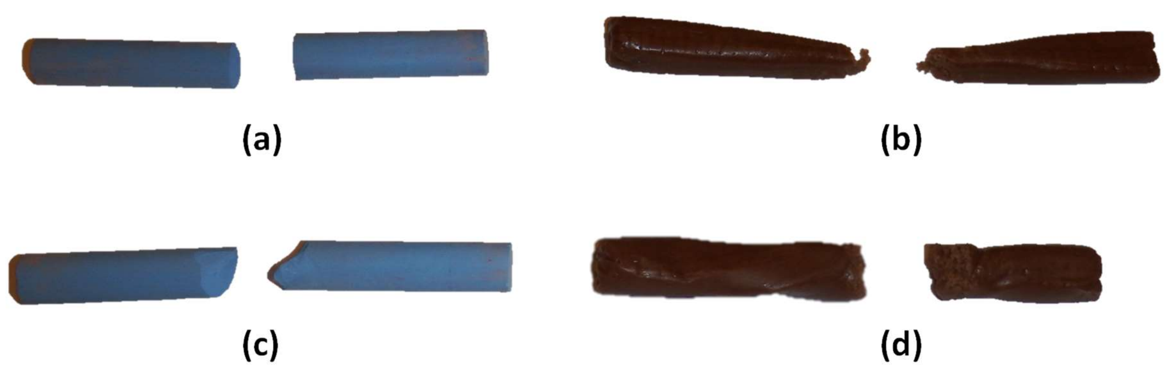

Figure 1: Brittle (Chalk) vs. Ductile (Tootsie Roll) Failure

(a) Pure axial force applied to a brittle material (chalk)
(b) Pure axial force applied to a ductile material (Tootsie Roll)
(c) Pure torsion applied to a brittle material (chalk)
(d) Pure torsion applied to a ductile material (Tootsie Roll)

Ductile to Brittle Transition Temperature (DBTT) can also be incorporated into the chalk and Tootsie Roll demonstration. However, it does require access to a freezer in the immediate vicinity of the classroom, plus a little bit of prior planning. For this demonstration, Tootsie Rolls must be frozen ahead of time. After the students have completed the initial chalk and Tootsie Roll experiment, perhaps when it is time for another lecture break, give two frozen Tootsie Rolls to each student pair. Have the students make predictions about what effect the cold will have when an axial force then torsion are applied, as before, but this time to frozen Tootsie Rolls. Conduct the experiments quickly, as the Tootsie Rolls don't take long to thaw. If done correctly, the failure surfaces for the frozen Tootsie Rolls should look very similar to those for the brittle chalk. Axial force results in a clean, perpendicular break across the frozen Tootsie Roll. Pure torsion results in a helical spiral shape at a 45 degree angle. Again, students are usually happy to help with the cleanup and far more engaged in the follow-on discussion about DBTT.

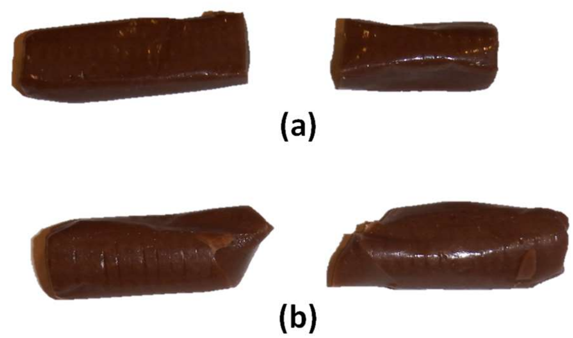

Figure 2: Ductile to Brittle Transition with Frozen Tootsie Rolls

(a) Pure axial force applied to a frozen Tootsie Roll
(b) Pure torsion applied to a frozen Tootsie Roll

Another simple, hands-on demonstration for Mechanics class uses balloons to reinforce the principles of stress in pressure vessels. This activity requires a little bit of preparation ahead of time by the teacher, but it doesn't take long. Two types of balloons are needed: round ones and long cylindrical ones. Before class, use a permanent marker to draw a square on the side of each balloon. During the class discussion about stresses in pressure vessels, give one of each balloon type to each student pair. Ask the students to predict (out loud and to each other) what will happen to the shape of the square when each of the balloons is inflated. Have them inflate the balloons then discuss the results. Most likely, the students will correctly predict the results for the round balloon – the square shape stays square as it expands evenly in all directions. But most students will incorrectly predict the results for the cylindrical balloon – the square stretches out to a rectangle that is longer around the circumferential (hoop) direction. After this quick, hands-on demonstration, students invariably start thinking more closely about the difference between hoop and axial stress, as well as the implications of making repairs to a pressure vessel.

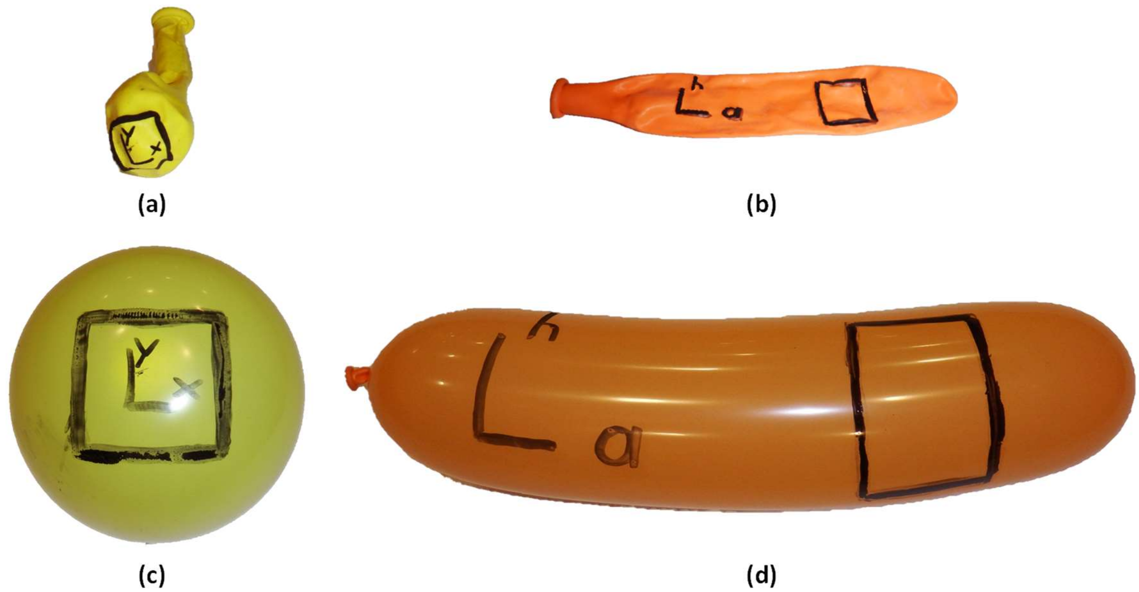

Figure 3: Pressure Vessel Balloons

(a) Square drawn on uninflated round balloon
(b) Square drawn on uninflated cylindrical balloon
(c) Expansion of the square when the round balloon is inflated
(d) Deformation of the square when the cylindrical balloon is inflated

Column buckling is another mechanics subject that lends itself well to hands-on activities in class. One simple, yet highly effective, demonstration requires only drinking straws and scissors. Students are each given a straw and asked to buckle it by applying force on both ends with their fingers, noting how much force it took to buckle the straw. Students then cut the straw in half and use their "highly calibrated fingers" to measure the force required to buckle the shortened straw. (It should take four times as much force to buckle the halved straw.) Students cut the remaining straw in half again and buckle it one more time, again noting the required force. (The quarter straw should take sixteen times as much force to buckle as the original straw and four times as much force as the halved straw.) This demonstration is especially impactful if done prior to lecturing about the critical buckling force equation. Students will usually be able to derive the inverse squared relationship between column length and buckling force on their own.

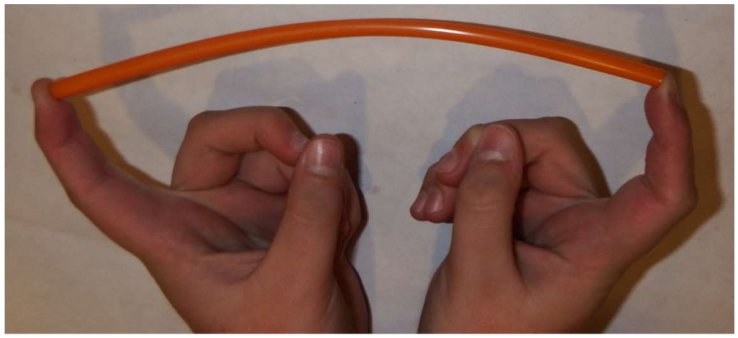

Figure 4: Buckling of a Drinking Straw Column

A follow-on to the straw buckling demonstration is to have the students attempt to buckle a straw with thicker walls or one made from a stronger material. Using just their "fingertip force sensors," students will be able to recognize the proportional effects of both cross-sectional geometry and material composition on critical buckling force. Before the critical buckling force equation has even been introduced in class, students will have already derived most of its relationships on their own. In so doing, the students are more apt to remember the relationships long-term and be able to apply them.

Another simple, but memorable, demonstration of buckling can be done with empty soda cans. Each student is given an empty can and asked to balance their weight on top of it. For most of the students, the can will immediately crush. However, one or two of the smaller students in class might be able to balance temporarily on top before their slightest wiggling causes the can to collapse. The teacher then demonstrates how easy it is to balance on top of a can and asks the class why they can't do it. The observant – or skeptical – student will quickly guess that something is different about the teacher's can. The teacher might use a full can of soda, demonstrating the effect of cross-section on critical buckling force. Or the teacher might use a steel can, such as those for some meal replacement drinks, demonstrating the effect of material properties on buckling. If time permits, another fun demonstration is to place a board over six empty cans then have the lightest student in the class stand on top. Typically, this does not result in buckling, as the weight per can is lower than the can's critical buckling load.

(a) **(b)**

Figure 5: Buckling of Soda Can Columns

(a) Standing on a single, empty soda can leads to its immediate failure
(b) Standing on a board across 6 empty soda cans does not cause buckling

A final buckling demonstration is to give each student a plastic ruler and push on the ends until it buckles but doesn't break. Point out to the students how the ruler will always buckle about the same axis (the short and wide rectangular cross section, which is the axis with the lowest second moment of area). Have them try to buckle the ruler about the other axis via any means they can imagine, but they won't be able to do it. Another activity with the ruler is to have the students compare the extra force required to buckle the ruler if the ends are constrained by their hands versus being free to rotate. Should they ever have to shore up a structure to prevent buckling, hopefully the students will remember the importance of constraining the ends and of choosing the proper cross-section of the beam.

These are just some examples of quick, low-cost, hands-on activities that students can do during class to reinforce concepts. Typically, such activities are memorable and fun for the students, providing a needed break from lecture. They make the concepts seem real and applicable to the world around them. More importantly, they aid students' long-term understanding of engineering principles. Hands-on activities are a key strategy in preparing graduates for a lifetime of engineering decision making.

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