ENGINEERING FACULTY INVOLVEMENT
IN K-12 EDUCATION
AN HISTORICAL PERSPECTIVE

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Abstract

The human mind is of its very nature inquisitive. It is a mystery of sorts why so relatively few individuals pursue science and engineering careers, especially since they are well paying and very satisfying. This paper presents a history of the involvement of engineering faculty for more than 35 years in teaching students from kindergarten through Junior High School about the excitement and challenge of engineering and technology careers. Examples of experiences with 1st through 12th grade students using hands-on experiments and simple topics, such as center of gravity, mass center and "limits," are illustrated. The paper presents a concept initiated by the authors, called "An Experiment in a Box," which presents a number of simple and interesting experiments that can be accomplished in one class period or less, fit in a 10 ream paper box, and can be tailored for various age groups. In addition, the paper describes a series of hands-on experiments, suited to senior high school and freshmen college students, to introduce students to science, engineering and technical skills without any in-depth prerequisite math or science knowledge.

Early Elementary Grades (EEG)

Our experience with EEG was challenging and exciting. Initial thoughts were how we would keep five to six years olds interested for thirty or forty minutes continuously. Our surprise was that after over an hour we were tired and the youngsters were clamoring for more. At this very early level we introduced youngsters to concepts such as *center of mass* and *limits* in mathematics. To introduce them to center of mass, the students were shown that the center of mass of a symmetrical geometric figure would lie on an axis of symmetry, and that, if two intersecting axes could be identified, their intersection would be the center of mass. To demonstrate this concept experimentally after it was shown geometrically, the youngsters cut out symmetrical geometric shapes and hung them with a plumb-line from two points on different lines of symmetry confirming that their intersection was the center of mass as shown in Figure-1. Through simple qualitative discussion and demonstration the students were introduced to the fact that for every object, regardless of its shape and size, when freely suspended from any point on the shape, a plumb line will always pass through the center of mass. Using two points not on the same line of "mass symmetry" will result in an intersection which is the mass center of the object as illustrated in Figure-2.

During this experiment the principal of gravity and how it works was explained and demonstrated. The youngsters grasped this concept very well. To extend this to any plane shape, they then cut out various figures such as stars, crescent moon shapes and likewise hung them with a plumb-line from two arbitrarily chosen points on the figure establishing the center of mass (COM) of the figure by the intersection of mass symmetry. Once the mass center was established the students engaged in a discussion about how they might validate their answer. They readily developed the idea of selecting a third point from which to suspend the object to see if the plumb line passes through the center of mass. They were now introduced to some basic concepts of engineering without necessarily knowing they had experienced the validation of their work without an answer book.

This was so exciting for the youngsters that they wanted to determine the mass center of various shapes such as their house, their car and just about anything else they could think of, such as a heart as shown in Figure-3. It was exhausting for us. They had endless curiosity and energy. For us this demonstrated that the curiosity of the young mind is naturally directed towards things in science, engineering, and technology. In determining the mass center of a crescent moon, as shown in Figure-4, a very curious observation was made by the youngsters. The COM was not inside the object but outside. See Figure-5, a large "L" shaped pipe assemble, that clearly illustrates the COM out side of the object. How could this be? This illustrated an abstract concept that was then reinforced by showing the youngsters the classic dinner-table "trick" of balancing a spoon and a fork with a tooth pick on the edge of a water glass as shown in Figure-6. This "trick" is accomplished by inserting the bowl of a teaspoon between the tines of a fork and then balancing the fork and spoon on the edge of a glass with a toothpick (this requires a bit of careful manipulation). This simple experiment awakened in them that something that appears mysterious or magical is readily explained by basic concepts and principles of science. When circumstances permitted an additional engineering concept was demonstrated with the dinner table trick. The ends of the toothpick may be lit with a match and allowed to burn until they are extinguished when the flame reaches the fork and the glass also illustrated in Figure-6. The dissipation of heat into the fork and the glass extinguishes the flame (many schools do not permit an open flame; this is only possible when you may). Additionally the balanced fork may be lifted from the glass with a piece of thread applied at the end of the toothpick near the glass. The ability to lift the suspended fork and spoon from the glass is always a crowd pleaser see Figure 7.

A very controversial issue is the teaching of mathematics. It is not the intent of the authors to become embroiled in this issue. However, at a very early age, youngsters can grasp some concepts that are not taught until much later in their education. One of these is the concept of limits in calculus. We found that having students approach a wall advancing only half the distance they are from the wall each time they advance they understand that theoretically they never get to the wall, but practically they do. This as well as many other mathematical concepts can be illustrated to youngsters. Unfortunately a discussion of them would require more space then available for this paper

Middle Grades (4th, 5th, and 6th grades)

During a recent visit to a 4th grade class at a middle school in Maryland, we were allotted a15 minute session. The authors used their "experiment in a box" that illustrates the basic forces with which everyone is familiar, that of *push* and *pull*. Using volunteers from the class these forces and corresponding resistance (stress) that material objects provide to these forces were demonstrated. To illustrate pull and corresponding resistance of tension, we asked for three volunteers. They were put in a row and the student in the middle held one piece of chord in her left hand and one in her right hand. The students on either side of her pulled on the ends of the chord while the young lady in the middle held her hands out straight and tried to prevent her arms from being pulled apart. This simple experiment illustrated the force of pull to the class, and the student in the middle experienced the resistance or *tension,* which results in an object once subject to a pulling force. This is an excellent means for demonstrating a physical concept to middle school children.

Next two students were asked to push on some foam. Foam was used so that the students could see the result of pushing that results in the stress called *compression*. Now that the students had been introduced to fundamental forces of push and pull and corresponding resistance (stress) of *tension* and *compression* we then used a single sheet of ordinary 8.5 x 11 paper to demonstrate the characteristic difference between tension and compression. First, the students were asked to grasp the paper with their thumb and fingers placed as far from edges as possible and very carefully with a constant pulling motion try to pull the paper apart. Of course this is virtually impossible and the students observed that paper is reasonably strong in tension. They were then asked to hold the paper again but this time, apply a pushing motion. Of course, the paper crumpled demonstrating that a single sheet of paper has virtually no resistance to pushing.

Now at this point the role of the engineer in the design of the structure (building columns are used as an example) was introduced. The students had acquired a cursory understanding of forces and the resistance of materials to forces. They were introduced to how the engineer takes this knowledge and by changing the form, that is the shape in which the material is used, improve its ability to carry forces.

A single sheet of paper, similar to that which they used was then rolled up into a column. To assure a constant uniform size of column, the paper was rolled up and placed in plastic film canisters to establish a uniform diameter. To keep the paper column from unraveling, a piece of scotch tape was placed on the seam. The students were then asked how much “push” they think this paper column would carry.

For this exercise the authors have a “frame” and steel weights that will enable them to place a load on the paper column. The weights typically weigh 2 to 4 pounds (about 1 to 2 kilograms). The weights were passed around for the students to feel how heavy they are. Then they were loaded on the column, 2 and 4 pounds respectively. Each time a weight was placed, the students were asked if the paper column would carry the weight. Answers varied as additional weights were added to the paper column. At this point all the students were involved in voting on whether the column would support each additional load. This heightens the excitement. In the meantime, we had one student tally the load each time a weight was placed on the column. The column typically supports 15 or more pounds (3 to 4 weights). When the column collapses, it occurs with a loud BANG and everybody jumps. After the column “fails,” we showed the students the accordion shaped tube and explained to them that the column had not torn but actually had “crimpled” (buckled) as shown in Figure-8.

At this moment we use this opportunity to illustrate the physical phenomenon “buckling” by relating it to an experience which most of the students have had, namely having their knee give way (buckle). This simple experiment brings engineering home for this level of students. Interestingly enough, while we originally had a fifteen minute presentation prepared for the allotted time, everyone was so interested and excited, we were asked to extend the presentation to one hour permitting us to talk in depth about this topic and engineering in general. All of this was accomplished with little more than paper and weights.

Upper Elementary Grades

We selected two experiments to illustrate exercises for upper elementary and high school students. The first one studies elementary probability and statistics. The concepts of samples and population as they refer to this study are discussed with simple illustrative examples. We used enrollment in the students’ school as an example of a population and the number of students in the class as a sample. The students readily grasped the difference between the use of statistics and probability for estimating results. A characteristic of the class, such as gender, represents a parameter of a sample of the school’s population; from this, an estimate can be made of the same characteristic in the school’s population based on its presence in the class. Depending on the particular class, ancillary observations may be made; for example, if the class is a home economics class of primarily girls then one can consider reasons why characteristics of that class might not produce accurate estimates for the whole school population because the class sample is biased (i.e., primarily girls). This led to a discussion of the concept of and the necessity for random sampling and what random means.

The second part of this exercise demonstrated the basic concepts of probability theory. We illustrated the situation in which the population is observed (known) and characteristics of the population are estimated. The roll of two die was used as the population. Since this is a relatively small population and there is an infinite number of samples (rolls of dice), the students were introduced to the theory of probability. Our experiment in a box as shown in Figure-9 provides a hands-on exercise for the students to experiment with the outcome of the dice and compare it with the theoretical histogram for the roll of the dice. This led to an interesting discussion as to the reasons for discrepancy between theory and practice. The authors think this is an excellent introduction to any field of science and engineering. As one can see from Figure-9, everything necessary for this hands-on classroom experience fits in a 10-ream paper box.

For an enrichment exercise to be conducted at home, the students can be asked to flip 10 pennies at once in a cup a hundred times and record the outcome and plot a histogram for the number of times heads and tails come up and bring it to class for discussion. Since we are usually not there for the discussion, if the teacher desires we leave them with discussion material.

Senior High School

For upper division students we have an interesting experiment that introduces students to the concept of ***buckling*** and how the unsupported length of a column significantly influences its ability to support weight. For this experiment we are fortunate to have our machine shop model maker fabricate a test apparatus for loading plastic straws. This test frame shown in Figure-10 permits us to load standard drinking straws and to demonstrate the different load carrying capacity of the straws based on their unsupported length. The advantage of using the straws is that there is a very clear visualization of the bending of the straw prior to its buckling failure. In some classes where students are taking AP (Advanced Placement) calculus, the Euler Column Formula may be introduced and discussed as an application of the calculus. The effective length of the column may be changed by using an adjustable piece that may be placed any where along the straw reducing the effective column length. Again, the hands-on nature of the experience maintains interest, motivates discussion, and hopefully plants a seed of interest for an engineering career.

Pre-College and Undeclared Freshmen

A traditional experiment which has been used by many others is the paper bridge. This exercise is designed to permit total freedom in thought and design. Here, the students are given a requirement that they design and construct a paper bridge that will span 14 inches. See Figure-11 for the frame and Figure-12 for the paper bridge. The only materials they have are 10 sheets of standard 8.5 x 11 paper and a roll of tape. The span is set such that a single sheet of paper will not suffice. Students are free to use their imagination. The test of their paper bridge, which is loaded with pennies, is to maximize load to sheets of paper ratio:

$$\beta = \text{Number of Pennies} / \text{Number of sheets of Paper} + 2$$

(See Appendix for the sample requirement sheet.) This simple experiment leads to significant discussion, which includes one of the principal norms of engineering: to arrive at a least cost solution. At the end of the testing period, the competition between student groups results in animated discussion of which designs worked best. The exercise forms an excellent introduction to how *shape* and form influence final *design*.

Conclusion

Over the past 45 years faculty from the University of the District of Columbia and its predecessor institutions (The District of Columbia Teachers College—Minor and Wilson Normal Schools, The Federal City College, and The Washington Technical Institute) have been engaging young people with engineering experiments to interest them in STEM (Science, Technology, Engineering and Mathematics) careers. Over 140 school visits touching the minds of more than 1500 youngsters have molded the concepts presented in this paper. The authors are convinced that all youngsters have an inquisitive mind and when nurtured have the potential for some engineering or related technical career. As we venture into the future it is imperative that we (engineering faculty) reach out to the youngsters of every gender and ethnic identity exposing them to the essence of engineering, exciting them to consider joining our ranks for the future well-being of humankind.

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References

1- “ *Paper Bridge*”, Physics Olympics 1996, contest developed by the University of British Columbia

Appendix I: Paper Bridge

STEM SUMMER 2007

UDC/SEAS/Engineering

Paper Bridge

The object is to build a paper bridge with the smallest amount of materials that supports the largest possible load (weight).

Materials:

1. one roll of Scotch Tape (used for connecting paper components only).
2. Scissors.
3. Ten 8.5 x 11 in. sheets of paper.

Rules for Construction of Bridge:

1) The bridge must be constructed during a 15 minute period. It must be constructed from no more than ten (10), 8.5 by 11 in. sheets of paper and Scotch Tape only. The paper will be 20 lb. long grain white copy paper of the type typically used in copiers. The paper may be cut into any shape and as many pieces as desired.

2) The bridge must have a minimum clear span of 14 inches (~36 cm) and an overall length of no more than 16 inches (~41 cm). It must be constructed in such a way that it can be supported at both ends on a flat horizontal surface (the end supports of the bridge may not be held in anyway, they must rest freely on the supports). It must have a roadway, i.e. a deck that is at least 2 inches (~5 cm) wide and no more than 3 inches (~8 cm) wide.

3) Bridge must be strong enough to support the maximum load for 10 seconds.

4) The score for each bridge will be determined by the following formula: W/(P+2)
where W is the weight supported by the bridge and P is the number of sheets of paper used in whole or in part to make the bridge. The bridge that maximizes this score wins.
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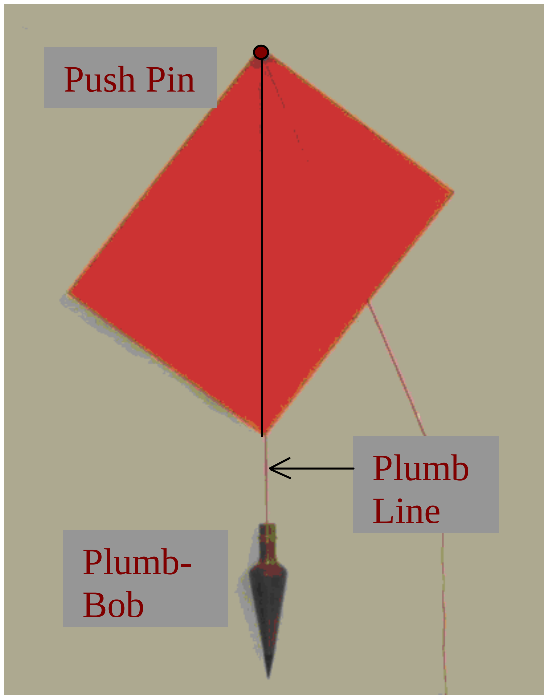
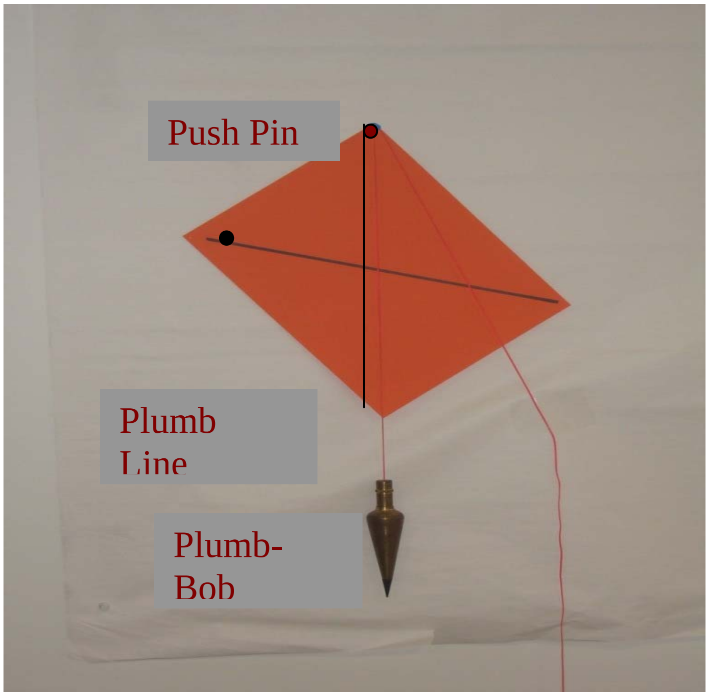
Adapted from a "Paper Bridge" contest developed by the University of British Columbia, Physics Olympics, 1996

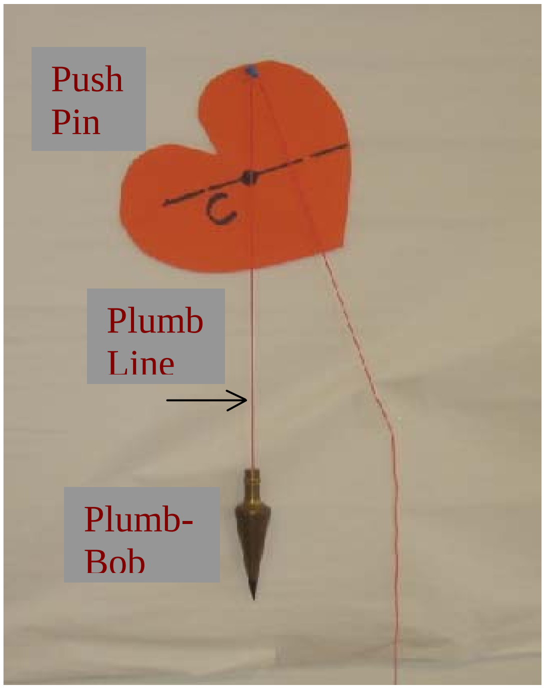
Appendix II: Figures



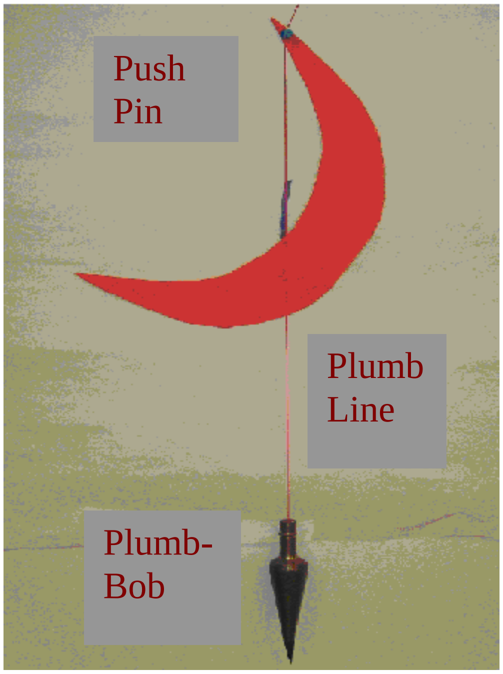
COM-Rectangle
Figure -1



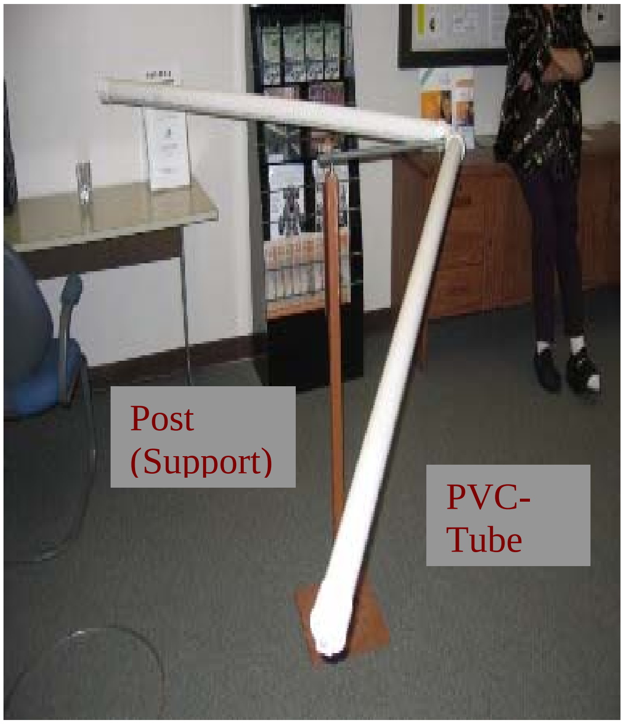
COM-Rectangle
Figure-2



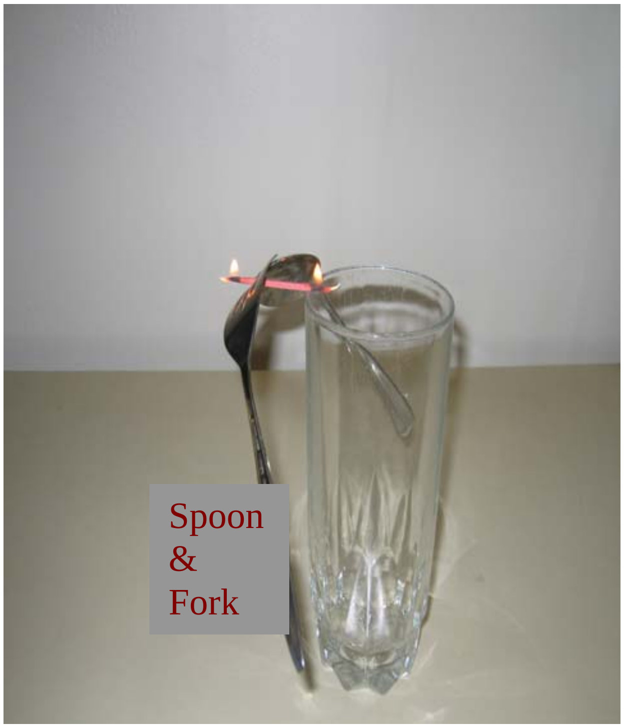
COM-Heart
Figure-3



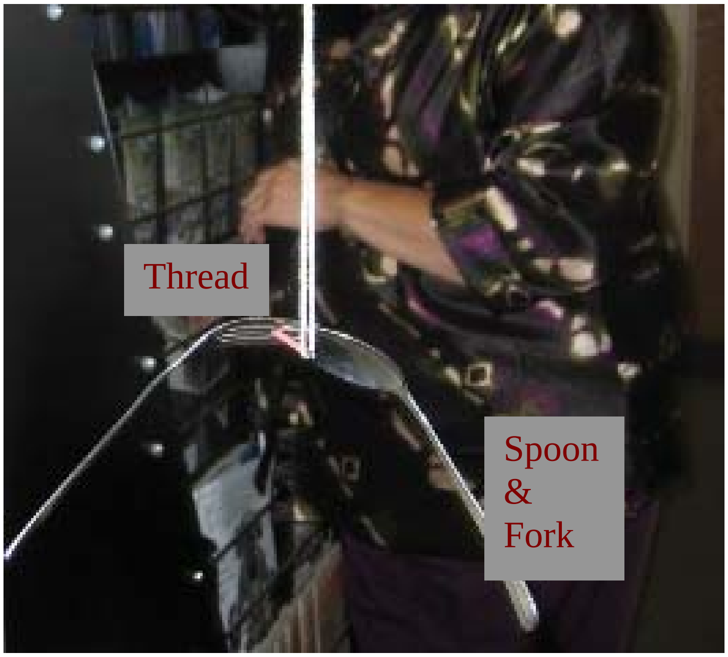
COM-Crescent
Figure-4



COM-L Shape PVC Tube
Figure-5



COM-Fork and Spoon
Figure-6



COM-Fork and Spoon
Figure-7

Paper Column, After Buckling
Figure-8

Probability & Statistics
Figure-9

Plastic Straw Column Stability
Figure-10

Paper Bridge
Figure-11

Paper Bridge
Figure-12