

# **Arch Building for Kids**

## **What did they learn? What did we learn?**

### **Introduction**

This paper will describe a teaching module that several senior architectural engineering students developed as their senior project. The teaching module targeted 5<sup>th</sup> or 6<sup>th</sup> grade students with the goal of creating an engineering outreach program that demonstrated a structural mechanics concept in a fun and interesting manner. The purpose of this paper is to describe the rationale behind the teaching module, and to document the changes we made to the module as we assessed its impact over several trial runs.

### **The Premise**

The premise of this research project was to devise an outreach program to 5<sup>th</sup> or 6<sup>th</sup> grade students that demonstrates an engineering idea in a fun, yet informative way. At the onset we decided against “trial and error” exercises where the students would be asked to create something strictly from their own imagination or intuition. Our argument against such tasks is that they do not accurately reflect the methods that engineers actually use. We also decided against a strictly “show and tell” approach, wherein an impressive experiment or demonstration is conducted to elicit a strong audience reaction. Our argument against the “show and tell” approach was that the “show” part may stick in the children’s memories, but the “tell” part can be easily forgotten.

This project was not only an outreach effort designed to get children interested in the engineering and design of buildings, but it was also a research endeavor undertaken by three architectural engineering seniors as their culminating senior project. As such, they were charged with creating several assessment devices to gauge the effectiveness of their proposed activities. The activities were meant to take place in approximately a one hour time slot.

### **Literature Review**

Our research had a similar overall agenda as did the study by Chakravartula et al.<sup>1</sup> insofar as we sought to have our university students thoroughly digest the material at hand and create new means of presenting the subject matter and then to act as teachers in a classroom setting with children. We also found motivation from the study of Elton et al.<sup>2</sup> who sought to demonstrate “some interesting and mysterious, but explainable experiments” to a K-12 audience. The key motivator here was the term “explainable,” we really did not want anything to come across as random or inexplicable. The overall structure of our research project, and its credence as a senior capstone project focused on research questions that were similar to Moskal et al.<sup>3</sup>, namely “how are children impacted by an outreach program”?, and “how are the college students and faculty impacted by the outreach program”?. We also noted that Jeffers et al.<sup>4</sup> carefully analyzed similar research questions in outreach programs, namely “how is undergraduate student development positively affected by such outreach programs”?. The Jeffers study explored this and other research questions such as “how do outreach program ultimately affect increases in engineering enrollment”?. We liked the assessment tools suggested by Poole et al.<sup>5</sup> namely

linking evaluation methods such as post-lab questions to specific performance criteria (“can identify,” “can demonstrate,” “can create”) and then linking these back to specific learning outcomes. We also drew a few specific ideas from the study by Carroll<sup>6</sup>, namely to keep the teaching module within a one hour time slot and to introduce pictures of real structures alongside the model making activities. We received encouragement for this activity from our department, and to some extent from the wider university community. This type of scholarship is valued and is growing in importance. Other researchers have recently noticed an ever-growing appreciation of such research<sup>7</sup>.

## **The Vehicle**

We originally planned to center the building activity on the creation of a laminated thin shell arch. The structural units or tiles would be laid flat in a staggered fashion in order to cover or break the joints of adjacent layers. This method of construction results in an extremely thin shell arch or vault and it was championed by the Guastavinos in the early 20<sup>th</sup> century on the East Coast of the United States, and by Dieste in Uruguay in the 1960s and 1970s. There were several reasons for choosing this vehicle. One was that the faculty mentor was conducting research on this technique and there were many examples of bench-top scale models to view and critique in our laboratory. The second reason was that the Guastavinos and Dieste created many historically significant works that were structurally efficient and visually arresting. We assumed that it would be important to show the children images of some of these structures and that such images would be effective in capturing their attention. This assumption will be discussed later in this paper.

We modified our plan to include some simpler activities and we added a section on basic definitions in order to have a starting point for a meaningful presentation of ideas.

Throughout the module, we held to one specific engineering idea: for a given material, shaping that material into a structural arch will result in a stiffer and stronger unit than if that material were shaped into a horizontal beam. To demonstrate that idea, we created a teaching module that briefly explained how a beam works, how an arch works and then we asked the students to explore these mechanics principles by means of model making exercises.

## **The Lesson Plan and Assessments**

Before we began any activities, we handed out “observer worksheets” to any adults who were present (parents, teacher, adult guides). These sheets were an assessment tool that we used to improve our presentation. We asked the observers to continually note their impressions throughout the presentation, not just at the end of the module. A part of the observer sheet is shown in Figure 1.

(1 = strongly disagree    2 = disagree    3 = neutral    4 = agree    5 = strongly agree)

- |   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1. The kids were interested in the presentation.                      | 1 | 2 | 3 | 4 | 5 |
| 2. The kids listened to the lecture<br>(including those in the back). | 1 | 2 | 3 | 4 | 5 |
| 3. The subject was presented clearly.                                 | 1 | 2 | 3 | 4 | 5 |

**Please answer the following questions:**

4. Which, if any, activities did the kids enjoy? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
5. Were the children confused? At which part of the presentation? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
6. Were the kids bored? When? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
7. Who seemed to be more involved: the boys or the girls? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Figure 1. The Observer Sheet**

1. *“What do you know”?*

The first activity was called the “What do you know”? survey. In the first trial at an elementary school, the seniors passed out a survey asking the students if they could write down brief definitions, or draw pictures describing the terms tension, compression, bending and thrust. It was quickly noted that this was not a very encouraging way of starting the presentation, some students got intimidated, others appeared bored. In the next iteration of our teaching module, the presenter asked the questions to the general audience and hands shot up with answers which were either correct or at least very creative. This was a more fun start to the presentation. To assess these verbal responses, the observer student wrote down the children’s suggestions as well as a note of how many people raised their hands for each question and whether or not there was a difference according to gender. A trend was noted that boys were more eager to offer up answers to these initial questions.

2. *“How would you cross the river”?*

We then showed a hiker trying to cross a river and we looked for suggestions from the children advising how to get the hiker across (Figure 2a). Eventually, the children formed the answer that a bridge of some sort was needed. Then we asked them if a slender stick would be appropriate (Figure 2b). Finally, we asked if a very heavy piece of timber would be appropriate (Figure 2c).

How would you cross this river?



Figure 2a. Hiker to cross river



Figure 2b. Hiker on slender stick



Figure 2. Hiker on heavy timber

The purpose of the animations (the hiker walks and the sticks fly in to support him) are to lighten the mood a bit because they are humorous, and also to lead the discussion towards bending. The students grasped that the heavy timber was overkill, yet the slender stick might not be strong enough to meet the task at hand.

3a. *Structural terms explored.*

We showed five terms on the next Powerpoint slide and we asked them to brainstorm in small groups of two or three children, and to write down, what these terms might mean. The terms were: *tension, compression, force, load, thrust*. Small groups were quickly formed by asking them to pair up with people sitting next to them. Having a paper trail here, and having a slightly different group dynamic was meant to encourage less confident students to participate and it also gave us some data to assess after the event since we had their written responses.

3b. *Structural terms explained.*

We collected their responses and read a few answers out loud. Then we proceeded to show the class our definitions of these terms, along with some humorous illustrations that the seniors drew themselves (Figures 3a and 3b).



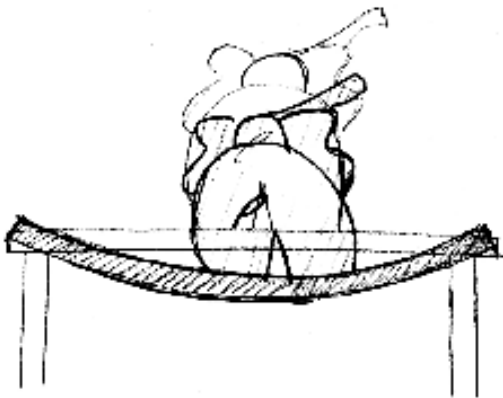
**Figure 3a. Compression**



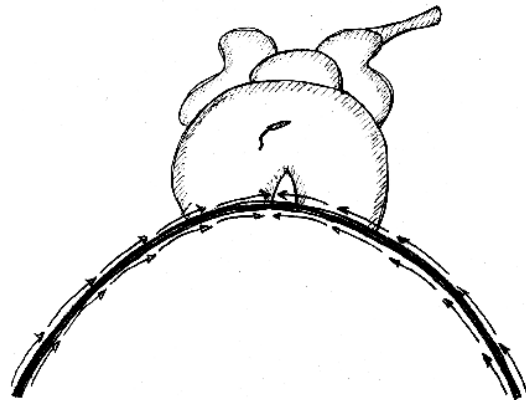
**Figure 3b. Load**

4. *“How does an arch work?”*

At this point we were about 10 or 12 minutes into the presentation. This was one of our last Powerpoint slides because we reasoned that we would soon deplete the reserve of good will that visitors experience in a classroom. Again, we used humorous illustrations to bring home the point of beam bending and arch compression. (Figure 4a and Figure 4b)



**Figure 3a. Beam behavior**



**Figure 3b. Arch behavior**

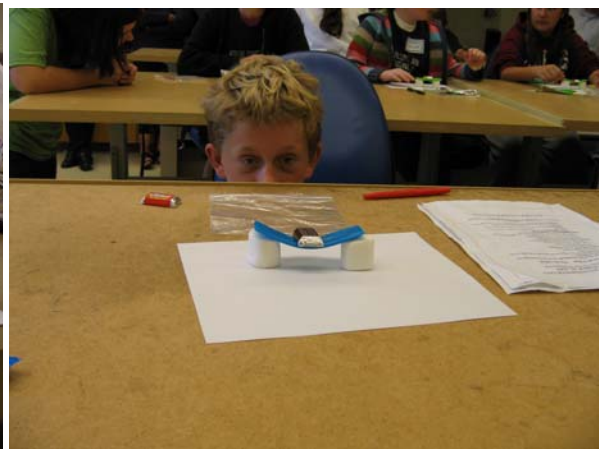
### 5. *Airhead activity.*

This was our first hands-on activity and it started at about the 15 minute mark. We had pre-made ziplock bag packages for each student containing two marshmallows, one Airhead candy (a soft taffy-like candy) and a weight. Initially, the weight was a toy soldier, but our first trial at the elementary school suggested to us to have something less militaristic, so we used chocolate candies as the weight in subsequent trials. The idea here was to place the airhead as a beam on the two marshmallows, and to place a single weight on the beam at midspan. The candy sagged and eventually touched the table. Then, we asked the students to carefully take the deformed beam, invert it and place it between the marshmallows. Now the students had an arch which could easily support several weights. This demonstrated that the arch form is much more efficient than the beam form. We also won great favor by allowing them to eat the candy after this activity.

We initially hoped to take advantage of this “teaching moment” by expanding this section to explain the catenary shape of the airhead. We hoped then to show other famous structural catenaries such as the St. Louis Arch and some of Antonio Gaudi’s structures. After deliberation though, we decided not to pursue this line of thought. (Figure 5a. and 5b.)



**Figure 5a. One arch and one beam**



**Figure 5b. Child observing beam**

### 6. *Human Arch Activity.*

The next activity was to ask for two volunteers to come forward to form a “human arch.” The purpose of this activity was to demonstrate that a shallow arch needs a supporting thrust at its base, whereas a taller arch needs less supporting thrust. This activity was effective because the volunteers as well as the rest of the audience could readily “feel” the thrust at the children’s feet. Our initial attempt at this was not so successful because the floor wasn’t slippery enough. Our subsequent attempts used furniture wax on the floor, then we were nervous that the floor would be too slippery. Figure 6 shows a



human arch with our architectural engineering students ensuring safety, and parent observers in the back of the room.



**Figure 6. Human Arch**

During the human arch activity, the presentation leader asked targeted as well as specific questions to the participants. These questions addressed basic issues such as: “Does John need a compressive force or a tensile force at his heels”? Of course the purpose of such questions is to gauge the comprehension of the participants.

#### *7. Images of historically significant structures*

We reasoned that the participants would be interested in seeing images of historically significant structures that demonstrated arch behavior. For example, we showed a slide of an arch supported deck bridge as well as a Guastavino laminated vault and we asked the children questions about the design or the aesthetics of the structure. These images did not spark much enthusiasm with the 5<sup>th</sup>/6<sup>th</sup> graders, but they did generate very interesting discussions in a separate outreach program that we designed for high school students. We suspect that the high school students were more comfortable questioning and discussing historical structures because they would have had more exposure to such structures via the History Channel on television or in some of their other courses.

#### *8. Build an arch*

This was one of the highlights of our teaching module and it started at approximately the 40 minute mark. The children at this point have experienced the mechanics of an arch in a very physical manner, yet they also had terms and actions explained to them. They also saw some images of a laminated thin shell vault. This allowed us to introduce the “build

an arch” activity and to show that an arch can be solid (monolithic) or it can be piecewise continuous and laminated. During our brief overview, we were able to touch upon constructability issues (for example, “what if you don’t have one big stick to cross the river”?) as well as the previously explored issue of end thrust. The students built a small laminated arch out of wheat thin crackers and peanut butter.

We showed them the following image and guided them through the construction process



**Figure 7. Crackers and peanut butter laminated arch**

The children needed guidance here, some were nervous about “making a mistake.” In our later iterations of this teaching module, we had one of the architectural engineering students demonstrate the building technique via a projector camera. That was helpful and it instilled greater confidence in the children. The students were totally engaged in this activity and the parents expressed how impressed they were by this unique and fun arch building. Some of the children realized that it is easier to build the arch on its side and then to perform a “tilt-up” operation to make it stand (See Figure 8).



**Figure 8. Laminated arch being constructed on its side**



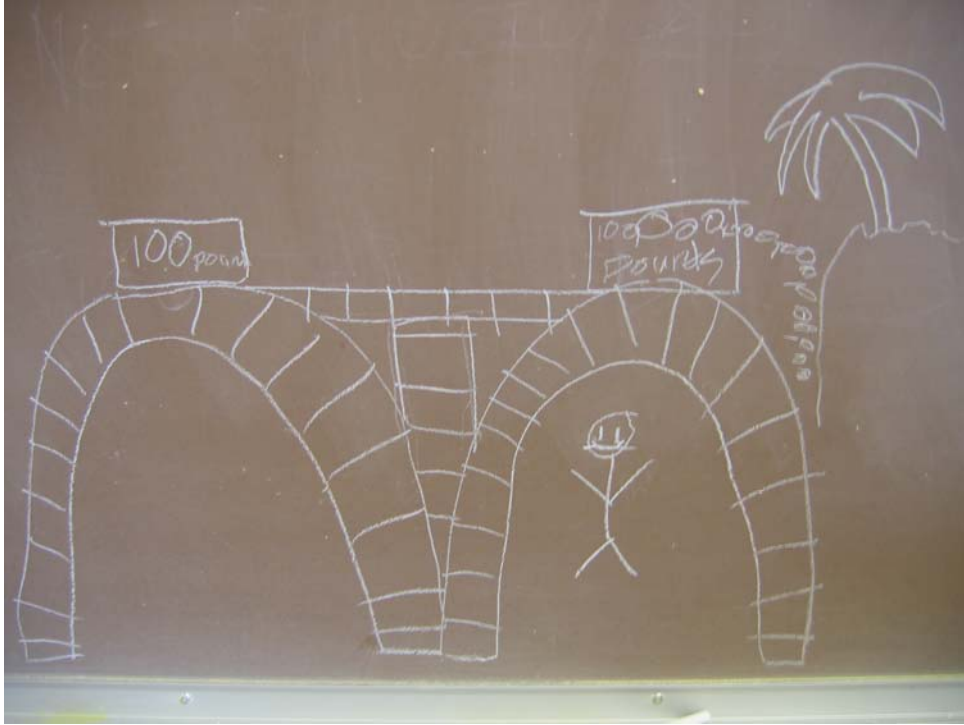
Other students came to understand that a buttress of some sort was needed to provide the lateral compressive end thrusts. (See Figure 9).



**Figure 9. Completed arch**

### *9. Chalkboard activity*

For our final activity we invited the children to come up to the front blackboard and to draw either a picture of an arch, or a picture of an engineer. Almost all the children participated gleefully in this activity. We were very impressed with the drawings and we used them as an assessment tool to see what the children took away from the activity. Many drawings showed an impressive level of detail. Figure 10 show a beam between two arches. The arch is prepared to carry millions of pounds of load.



**Figure 10. Chalkboard drawing of arch**

In Figure 11, we see not only an arch, but some sort of truss acting as the web of an arch. This is something that we did not discuss in the teaching module.



**Figure 11. Detailed drawing of arch**

In Figure 12, a child pointed out which configurations are stronger and which are weaker, then the child drew a dome-like structure created from a series of arches. We did briefly discuss domes during our teaching module, this child must have really been paying attention!



**Figure 12. Detail of chalk drawing**

### **Activity Wrap-Up**

We ended the activity with a “what did you learn” survey for the children, a part of which is shown in Figure 13.

**Please circle the number that best describes what you think about the following:**  
(1 = not at all    2 = not really    3 = sort of    4 = yes    5 = yes, very much)

- |  |   |   |   |   |   |
|--|---|---|---|---|---|
| 1. The material was presented clearly.                               | 1 | 2 | 3 | 4 | 5 |
| 2. I enjoyed the activity.   | 1 | 2 | 3 | 4 | 5 |
| 3. The presenters understood the subject.                            | 1 | 2 | 3 | 4 | 5 |
| 4. I want to learn more about arches.                                | 1 | 2 | 3 | 4 | 5 |
| 5. I am interested in learning more about Architectural Engineering. | 1 | 2 | 3 | 4 | 5 |
6. What did you learn? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
7. What was your favorite part of the presentation? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
8. What was your least favorite part? \_\_\_\_\_  
\_\_\_\_\_
9. What were you confused with? \_\_\_\_\_

**Figure 13. Portion of “what did you learn” survey**

We collected the observer worksheets and we handed out a take-home flyer which summarized the activities, pointed to our department’s website and pointed to a website that one of the architectural seniors designed for this project. That website ([www.freewebs.com/howarcheswork](http://www.freewebs.com/howarcheswork)) had many of the images used in the teaching module, as well as links to other sites of interest, as well as a place available for visitors’ comments.

### **Lessons Learned**

The students’ written responses led us to believe that they were comfortable with the material and understood most if not all of what we described. Figures 14, 15 and 16 summarize written comments that the children submitted to us at the end of the activity.

# What kids learned about...

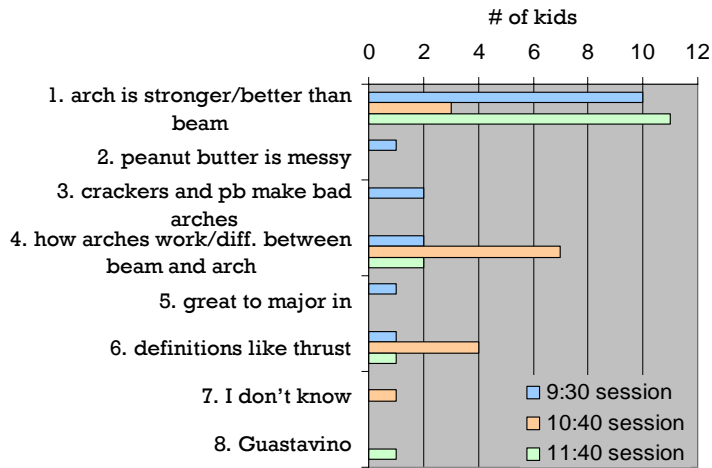


Figure 14. Children's comments

# Kids' least favorite part

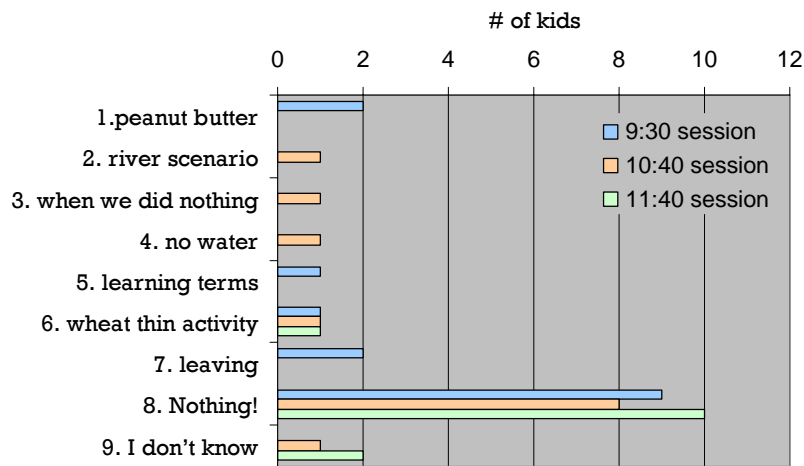
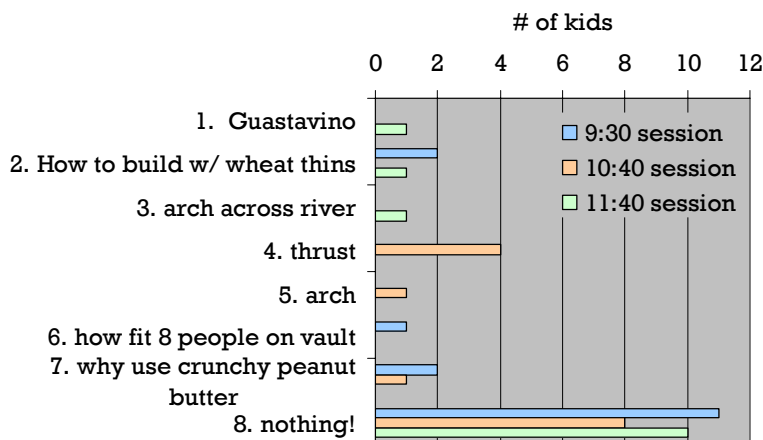


Figure 15. Children's comments continued



## Kids were confused about...



**Figure 16. Children's comments continued**

We learned many things from the several iterations of our teaching module. One thing we continually worked on was getting everyone involved somehow. In each session, there were always outgoing and eager students whose hands shot up immediately. Our challenge was to get the more reticent children to ask questions or to venture a guess to our questions. We combined written answers with verbal answers and we also allowed them to draw some images. This combination seemed to work well. We also struggled with the “wow factor.” Many of these children have been exposed to very ingenious presentations in their classrooms. We avoided the temptation to create a really high tech teaching module, and instead we chose to try to create an ingenious, yet fun way of exploring an engineering idea. This led us to the idea of creating a laminated arch. We offer this model up to others who are interested in K-12 outreach so that they too might be inspired to demonstrate our rich engineering heritage as we seek to inspire future generations of engineering students.

## Bibliography

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