Girls to Engineers Network: Design, Print, Crush!

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Abstract

This paper reports on a STEM collaboration between the College of Engineering at the University of Tennessee at Chattanooga and the Chattanooga Girls Leadership Academy to encourage middle school girls to pursue careers in engineering. The program, Girls to Engineers Network, implemented project based learning (PBL) strategies to increase the number of women in engineering by enabling hands-on content in a real-world context. In this pilot program, UTC guided 60 under-represented (female, minority) 8th grade students working in teams through a semester long project to design two single-walled trusses, perform a computer simulation of a truss in SolidWorks, and measure the performance of their 3D printed truss under compressive loading in UTC's Material Testing Lab. The program integrated the following evidence based-strategies: 1) Core engineering content and soft skills through PBL, 2) Real-world experience that impacts the community, and 3) Mentorship by female engineering faculty and students.

Keywords

K-12, STEM, project based learning, strength testing, 3D printing

Introduction

According to data compiled by the National Science Foundation (NSF), women comprise almost 50% of the total U.S. college-educated workforce, but currently represent only about 30% of the STEM workforce. In engineering, the number is lower with less than 15% of employed engineers estimated to be women. These numbers are more pronounced for African Americans and Hispanics, who represent less than 5% and 8% of employed engineers, respectively.[1] Reasons such as stereotypes about academic performance and lack of STEM role models have been shown to be barriers to girls and minorities in pursuing STEM careers. [2] Also, research has shown middle school is an important time to demonstrate in interest in STEM activities and the ambition to pursue STEM degrees and careers.[3] To address these issues and increase the number of under-represented students in engineering, the College of Engineering at the University of Tennessee at Chattanooga (UTC) implemented a pilot program with the Chattanooga Girls Leadership Academy (CGLA), an all-girls public charter school in Chattanooga, Tennessee where 62% are African American, 29% are Latina, and 85% live in the inner city.

Girls to Engineers Network

UTC's Girls to Engineers Network (GEN) builds upon CGLA's STEAM-focused educational model with Project Based Learning (PBL) implemented across the curriculum. PBL has been shown to increase academic achievement in STEM courses, improve problem-solving skills and attitudes toward learning, and encourage high-potential students. Moreover, PBL has been shown to improve attitudes toward self-confidence, communication skills, collaborative behavior, and contextual reasoning, which are vital for success in engineering.[4] To increase the number of women in confident in their abilities to pursue STEM careers, the pilot program was designed with the following objectives:

> **Objective 1:** Increase participants' knowledge of core engineering concepts and real-world impact through hands-on, standards-aligned PBL modules that guide participants through the product development lifecycle.
>
> **Objective 2:** Build participants' teamwork, communication, and presentation skills, which are vital for success in engineering careers, through collaborative modules, and an end-of-semester project showcase.
>
> **Objective 3:** Expose participants to female-led mentorship through regular interactions with female faculty and students from UTC's College of Engineering and Computer Science (CECS).

These objectives were achieved. The effectiveness of the project was assessed through pre- and post- content and attitudinal surveys by the participants. Students did report an increased interest in STEM fields, understanding of engineer's impact on community, and their use of soft skills. Details of the evaluation tools and assessment methodology have been previously presented.[5]

Project Description

The project lasted one full semester (15 weeks) to provide students with an in-depth engineering experience. During the semester, program participants met during school as a pullout group for 35-40 minutes, four days per week, during CGLA's allocated PBL time. Participants also visited UTC four times during the semester. The project is a modern take on the classic bridge design in which students build a bridge from balsa wood and apply weights until it fails. The weak points in such bridges are often the connecting units, not the truss designs.

For this project, the students working in fourteen teams of five designed and sketched two single walled trusses. The stronger of their two designs was selected through a computer simulation analysis. The winning truss for each team was then 3D printed and subjected to compressive loading on mechanical testing equipment. For each truss, the maximum load was determined and the ratio of max load to mass was calculated. An advantage of this test method is that the test specimens are not destroyed in determining the ultimate yield strength. Two teams tied with the highest ratio and were awarded certificates at the end of the project.

In the first curriculum session at CGLA, the students were introduced to the basics of the engineering design process and single wall truss design. In the next curriculum session at UTC, they performed a finite element analysis (FEA) computer simulation in SolidWorks of a sample single walled truss, see Figure 1. For this task, I developed a 40 step tutorial which walked the students through the entire simulation process, including sketching the truss, using the Weldments feature, and applying the run conditions in Simulation Express. Based on these results the teams designed and sketched two original trusses subject to prescribed design constraints.

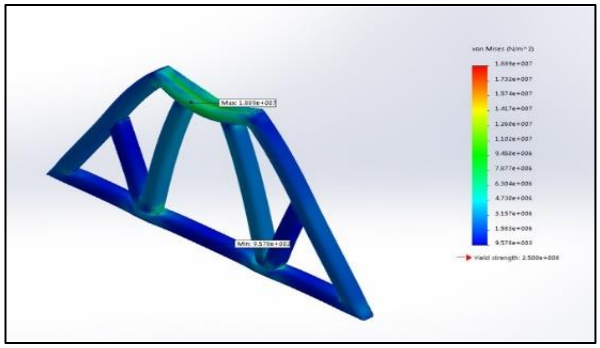

Figure 1: FEA analysis of sample truss.

Next, we performed FEA simulations on all 28 trusses to select the winning designs. For each team the truss with the highest Factor of Safety (FOS) for a load of 10,000 N was chosen as the winning design, where the FOS is defined as the ratio of the Maximum Load of the Bridge to the Maximum Load of the Material. This number is calculated and reported during the simulation process.

The winning truss from each team was then 3D printed in UTC's Fabrication Lab on MakerBot Replicators from PLA filament with slicer settings of 2 shells and 15% linear infill, Figure 2b. Prior to mechanical testing, each truss was weighed on an analytic force balance for a precise mass measurement, see Table 1.

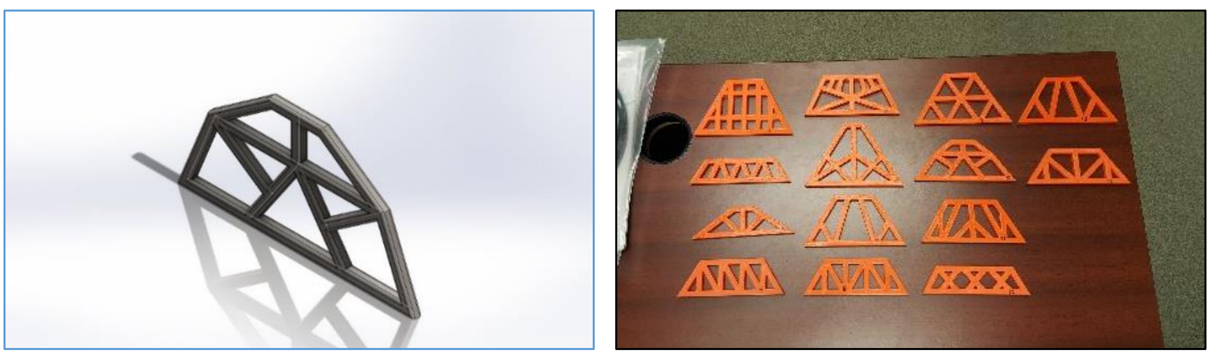

Figure 2: a) SolidWorks CAD file and b) 3D printed trusses.

Results

During the next curriculum session at UTC the students got to participate in the crushing of their truss. Each team's 3D printed truss was subjected to performance testing in our Materials Testing Lab. An Instron 5560 outfitted for compression tests was used for the performance analysis, Figure 3. A typical result from an axial loading test is a force versus displacement plot. The part goes through an initial linear elastic region where the material behaves like a spring and would return to its original shape if the load were removed. Beyond the elastic region the part experiences permanent deformation in the plastic region, and after reaching the ultimate yield strength begins to fail. Further loading leads to fracture and eventual failure of the part.[6]

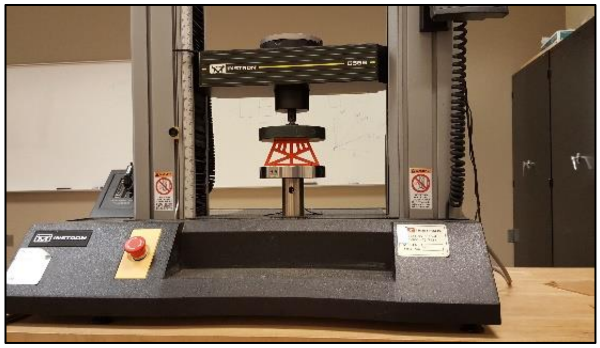

Figure 3: 3D printed truss during mechanical testing.

The result of each test is a set of raw data containing forces and displacements, Figure 4a. As expected the parts exhibit a linear region, a plastic region, an ultimate yield strength, and a tail leading to fracture. Although it is generally more appropriate to convert the applied forces and resulting displacements into stress (force per area) and strain (percent length change) to account for various sample sizes, all the trusses tested had a common base area of 5 inches by .25 inches, and so to simplify the analysis, the data was kept in its original form. The slope of the data in the elastic region is proportional to the Young's Modulus of the composite structure and was extracted with a linear fit to the data between the displacement range of .75 -1.25 mm for all test specimens, see Figure 4b. The average R^2 of the trendlines was .9995, giving good confidence to the linear fit.

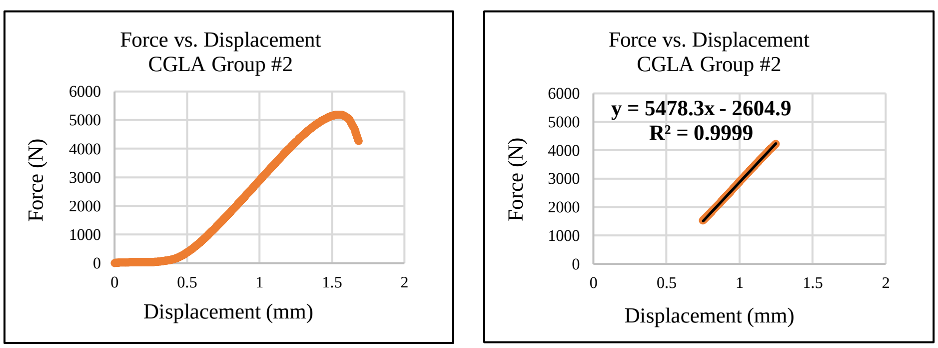

Figure 4: Force vs Displacement plots, a) total data and b) linear region.

In all cases the test was stopped after the ultimate yield point was reached but before fracture, so that the trusses were not destroyed, and the teams were able to keep them. In addition to the slope for each truss, the max load or ultimate yield strength was recorded. The results for all fourteen trusses are given in Table 1. These results have been sorted on the final column, the ratio of strength to mass. As can be seen Group 2, was the winner with a final number of 546. However, it can be noted that Group 12 had the highest max load and strength, but their bridge being slightly more massive than Group 2. For this reason the competition was declared a tie, and both teams were awarded a certificate during the final awards ceremony (Figure 5).

Group	Max Load [N]	Strength [N/mm]	Mass [g]	Strength/Mass [N/mm/g]
2	5185.2	5478.3	10.039	546
12	5954.6	5676.8	10.742	528
4	4800.2	4653.8	12.378	376
8	4530.7	4737.3	12.702	373
11	4100.5	3223.2	13.331	242
14	3008.4	2631.1	11.424	230
3	1766.3	1563.8	7.924	197
13	3078.4	2234.4	12.126	184
7	3308.3	2164.3	11.93	181
5	2821.4	2196.9	14.762	149
1	4299.5	2648.9	18.192	146
10	2571.7	1677.8	12.01	140
9	2683.4	1793.0	14.861	121
6	2181.1	1364.6	15.315	89

Table 1: Results of mechanical testing, sorted by Strength/Mass ratio.

Conclusion

This paper reported on a STEM collaboration project between the UTC College of Engineering and CGLA with 8th grade students to increase the number of minority females pursuing degrees and careers in engineering. Through project based learning, real world project application, and female faculty mentorship the program met all the objectives. The students working in teams designed and tested a single walled truss, learning core engineering skills and increasing their confidence to be engineers. A follow on program is being designed in which the students will design and launch small model rockets.

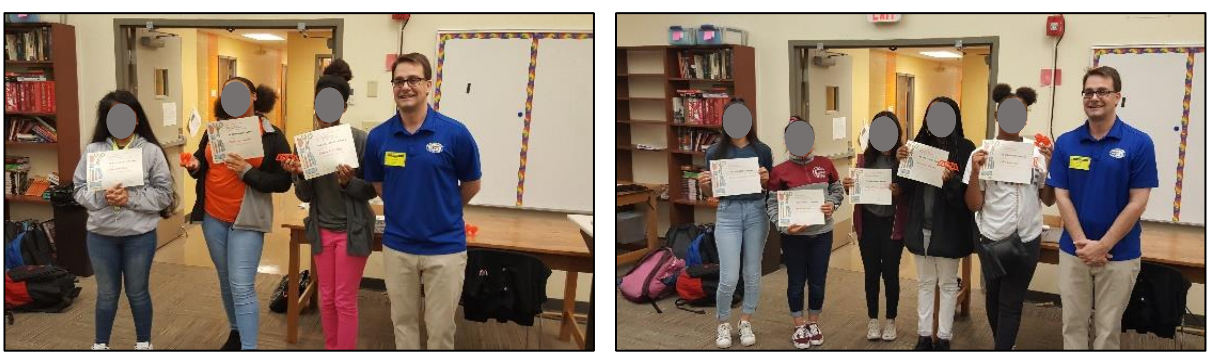

Figure 5: The two winning teams with certificates.

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Louie is a tenure track Assistant Professor of Mechanical Engineering at **the University of Tennessee at Chattanooga**. His engineering research includes simulation and modeling of complex systems, numerical design optimization, and performance characterization of additive manufactured parts. He is founder and faculty advisor for the 3D Print Club and has led 25 freshman design teams on assistive technology device prototypes. He is a member of the American Society for Engineering Education and the American Society of Mechanical Engineers.