Introduce High School Students to Engineering Disciplines: Activities and Assessment

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Abstract

Our presentation documents and describes the educational summer camp program developed for high school students. The overarching broader impact goal of the Intro summer camp is to introduce the students to various engineering disinclines and help them to make a better decision on choosing career or disciplines they want to pursue. Several activities are designed to achieve the goals. This presentation focus on the hands on activities offered in the Architectural Engineering and Civil Engineering programs. Activity details are described in this paper and the results are discussed. Students showed success in implementing the engineering principles into basic engineering problems through a problem-based learning activity. Students enjoyed the activities and showed improved learning after the hands on program. Overall the Intro summer camp was very positive for both the participants and their mentors.

Key words: Intro to Engineering, Problem based learning, summer camp, High school students

Introduction

Making a decision to be an engineer and choosing an engineering discipline is a challenge for senior high school students who have limited knowledge about various engineering disciplines. Such a decision is even more challenging for first-generation college students or minority students due to the lack of knowledge about higher education, lack of the information they need to choose the right discipline and school, limited access to resources to ask questions and even not knowing the right questions to ask along the decision making process [Moody 2019]. There have been several programs to introduce high school students to engineering and science. Some programs target high school teachers and some other programs directly involve high school students [Cardella et al, 2019, Drummund, et al. 2019, Campbell, et al. 2019, Evans et al., 2019]. The Jackling Introduction to Engineering Camp (Intro Camp) is a 5-day program offered by

Missouri University of Science and Technology (Missouri S&T) to introduce high school students to various engineering disciplines. The Intro Camp occurs at three different times during the summer and typically attracts incoming high school juniors and seniors. The Intro Camp was established with the following goals: (1) increasing students' knowledge of various engineering disciplines, (2) enhancing students understanding on how math and science relate to the field of engineering through hands-on activities, (3) introducing the educational and research opportunities at Missouri S&T, and (4) preparing high school students for making a thought-out decision on choosing career or disciplines they want to pursue.

Several activities are designed to achieve these goals. An overview of each discipline is given on the first day of camp. Participants then have the opportunity to select five departments to explore in more depth. Visiting each department includes providing detailed presentation of the discipline followed by a tour on lab facilities guided by faculty and grad or undergrad students. Students also gain experiences during the department visits by doing a hands on activity and testing their understanding and skills in friendly student competition. All students also participate in a team design competition and recreational activities.

On average, about 300 to 500 students attend in the Intro camp every summer, with the majority of students coming from all over state of Missouri as well as from surrounding states. Demographic analysis of participants in 2019 sessions show 77.6% of students are from Missouri, 7.5% from Illinois, 3.4% from Kansas, 3.1% from Texas and the rest came from Arkansas, California, Colorado, Iowa, Massachusetts, Michigan, Minnesota, Nebraska, Oklahoma, Tennessee, and Wisconsin; 22% of students were female and 78% were male. Figure 1, summarizes the demographic information of participants in the 2019 sessions. The number of students varied each year but same trend was observed in the previous years.

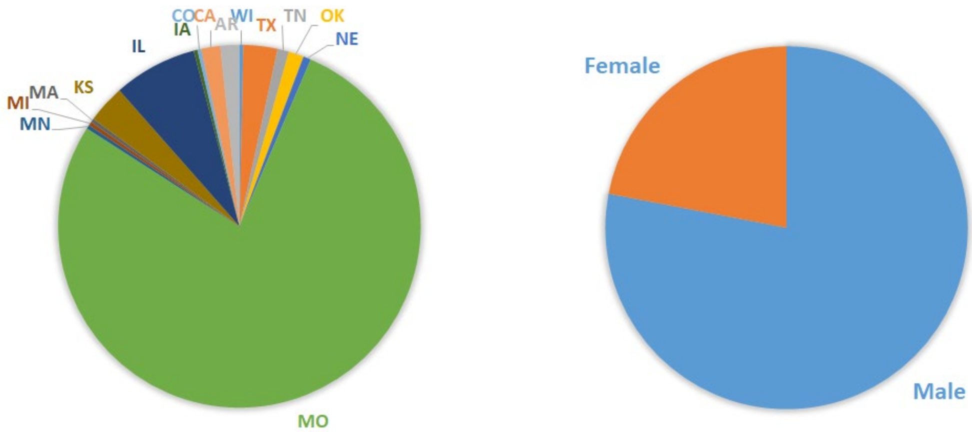


Figure 1. Demographic information of participating students in 2019 program

Hands-on activities in Civil and Architectural Engineering:

At the camp, students will learn how math and science relate to the field of engineering. By seeing first-hand what engineers actually do, campers can better decide on a career or discipline they want to pursue. Whether a student is interested in clean energy, cars and motorcycles, explosives, or building bridges or towers, the camp will educate them through hands-on activities, computer laboratory visits and practical demonstrations. The civil and architectural engineering program is no exception to this exercise. Both programs offers a tour through some of the various research/laboratory facilities and provide similar demonstrations in statics and mechanics of materials. What the students saw in the labs is further reinforced in the classroom by conducting a project base learning (PBL) exercise.

Architectural Engineering: The architectural engineering program offers a PBL exercise known as, "The Great Popsicle Tower Challenge." This exercise test several key factors and provide insight as to how an engineer must learn to work together with a partner or partners to find a solution that is both viable and aesthetically pleasing. This is particular true for architectural engineering as they work with architects and other related building professionals in the industry. In terms of skill, the tower has several key factors. They include strength to weight ratio, height to weight ratio and overall aesthetics. The challenge lies in the understanding as to what type of structural system provides the greatest amount of capacity with the least amount of materials. The limitations are simple. In approximately 1-1/2 hour in teams of 2 to 3 members in a group design a tower that is a minimum of 12 inches tall using a maximum of 150 Jumbo Size Popsicle Sticks. The top of the tower is to provide a flat surface to support steel plates weighing 25 pounds each with a maximum total maximum weight of 150 pounds. With each stick having a maximum of 6 inches in length the group must design the tower with a minimum of two Popsicle sticks standing on each end. The students may cut the sticks. The assembly of sticks employs the use of a hot glue gun and refillable glue sticks for ease yet rapid production. During the exercise, a simple discussion about the importance of rigid structures as demonstrated in the figure 3, below and further reinforce with images of past tower designs.

Figure 2. Free Body Diagrams of a Non-Rigid vs. Rigid Diaphragm

The criteria for a successful design are three main categories. The strength to weight ratio, the height to weight ratio and the overall aesthetics. The aesthetics is important because architectural engineers will be working with other disciplines that will be critical of a buildings overall appearance. The maximum points for each of the three categories equates to 20, 10 and 20 respectively. Figure 4, show some of the creative results and testing of towers from this past summer.

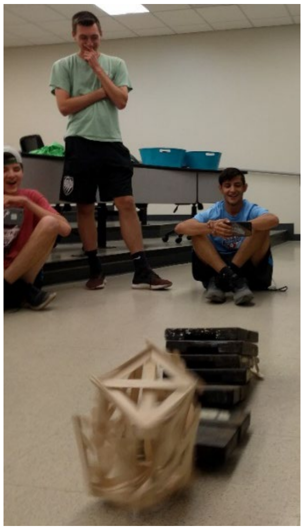


Figure 3. Images of 2019 Summer Popsicle Tower Challenge

Civil Engineering: The Civil Engineering hands on activity is designed to introduce students to structural components used in the buildings and infrastructures. After a brief introduction to truss structures, students were asked to design, build and test a bridge that spans 18 in. long, at least 2 ½ in. wide and is subjected to a concentrated force at the mid-span. Students are split into different team, each team is provided with a pack K'Nex that includes plastic rods, stems and connectors. The snap-fit pieces stick together securely and carry a limited amount of load in tension, compression and flexure. Students can attach the plastic parts together to create a variety of bridges. All connections are snap-fit that eliminates the use of glue or other connecting materials; also allows for testing and reconnecting to find out the weak point in the design and fine tune it before the final test. The challenge lies in the understanding as how the forces are transferred from the mid-span to the side supports, what is the best span structural geometry to carry the load and how to optimize the connections to achieve the maximum capacity of the bridge with the least amount of materials. In average, students spent 1.5-2 hours for design and building the bridge.

The bridges were tested for three-point bending with a concentrated load at the middle of the beam up to failure. A typical test setup is shown in Figure 4. The structural efficiency is measured using equation (1)

$$SE = \frac{F_{max}}{w} \qquad (1)$$

where F_{max} is the maximum load before failure and w is the weight of the bridge.

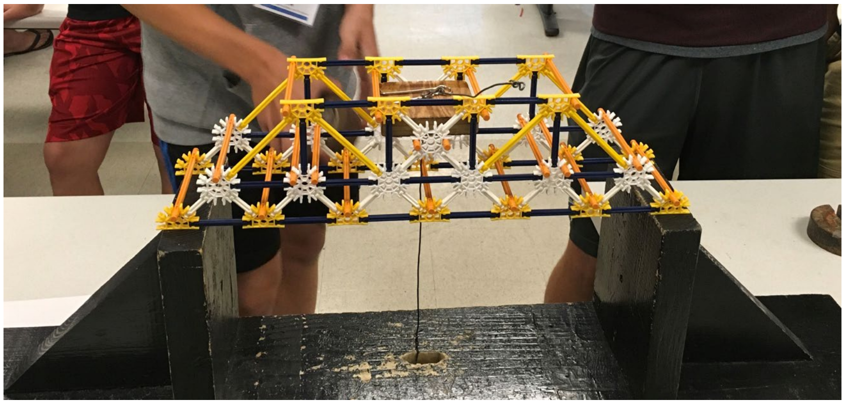


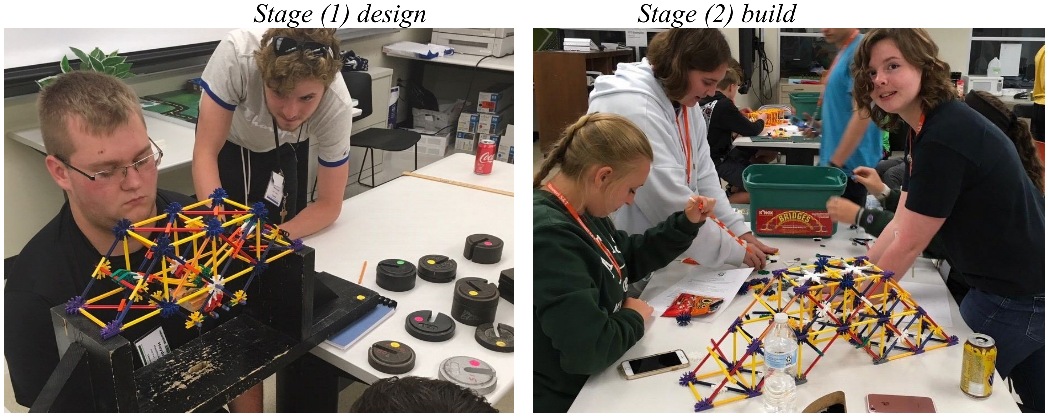
Figure 4- Test setup for bridge loading test

Observations:

During the hands on activity, students had the opportunity to practice an engineering problem in a smaller scale. One of the main challenges for high school students who are playing a role of novice engineer, is to come up with an optimum design given the limited time also discussing their design with the other team members. It was observed that the initial discussion stage is typically very short (less than 5 minutes) and students quickly start assembling different parts and testing their bridge. The first bridge is typically made in about 30 min after starting the activity. The third stage is the optimization process where, the teams test their bridge to optimize their design by adding or replacing some parts. The design/build/test/optimize stages are shown in Figure 5.

Team collaboration: It was observed that most of the teams kept the initial design and changes were limited to adding some components to increase the capacity or replacing the weak connectors at the failure points. The number of radical changes in the design was very limited even in cases where students had some extra time to redesign the bridge. Some teams started with different ideas and choose the best based on the performance in the loading test. Even though the teamwork seemed to be demanding, many teams collaborated effectively in various stages. Many students interacted with the peers enthusiastically and contributed in designing and making the bridge; there were very limited students who didn't contribute or made their own bridge as individuals.

Stage (1) design *Stage (2) build*



Stage (3) test *Stage (4) optimize*

Figure 4- various stages in the bridge hands on activity

The most fun part of the activity for many students was the final test where each team had one chance to test their bridge. The friendly environment of competition had a positive impact on students' performance. During the past three years (nine camp sessions) there was just one incident where a team showed displeasure against the other team during the final test that required the advisor to ask the members to calm down. Many teams got inspired by observing other design approaches that helped them to fine tune their design. Figure 5, show some of the creative bridge designs made by students during the 2019 camp sessions.

<u>*Team performance:*</u> The performance of 49 teams in 6 summer camp sessions were recorded to provide more insight on member's interaction, team functioning, and students learning. The overall average structural efficiency of all teams is SE = 62.2 with the standard deviation of 27.3. The minimum and maximum values were 23.3 and 133.0. Figure 6 shows the histogram distribution of all results with the bin size of 10. The results distribution is not a regular normal distribution; but it is more like a bimodal histogram with two peaks. The first peak bin with the most often SE values is the bin 30-40 and the second peak is 70-80.

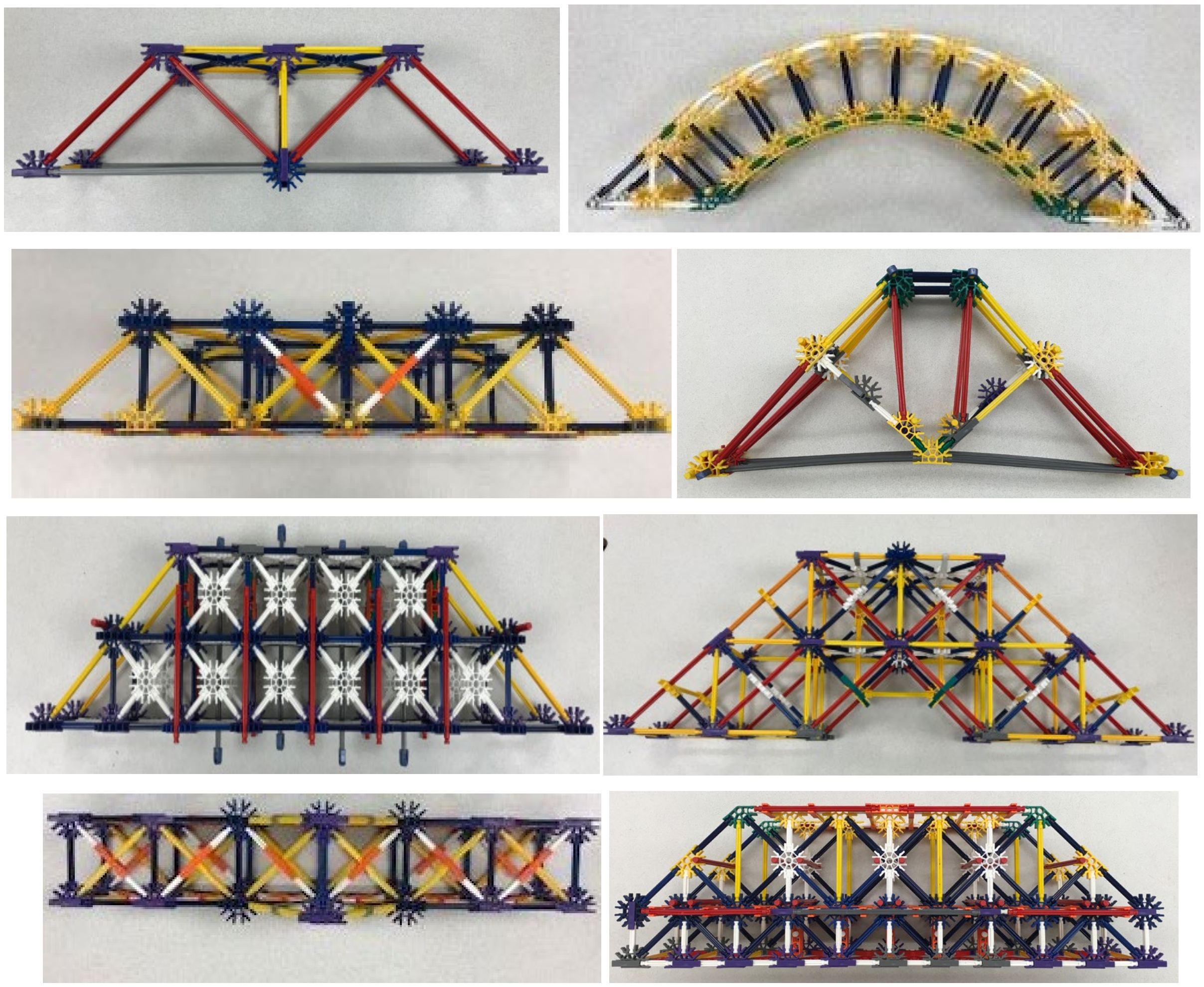


Figure 5- Some bridges made by students

Another interesting finding is the performance of teams with different number of members. Figure 7 shows the boxplot of structural efficiency of the bridges made by teams with different number of members. Based on the statistical analysis, the optimum number of members in a team is 4 that showed the highest median of SE=70. The median of SE for the teams with 5 members has dropped to SE=64.1. Regarding the limited time and the given activity, an explanation for the drop is the lack leadership that prevents the efficient utilization of the fifth members in the team. The teams with 3 members showed the lowest performance with the median of SE=43.1. An interesting finding is the team with only 2 members. Even though the median value is SE=55.8, this category showed the highest average among all teams with SE=69.1. This is attributed to the excellent performance of few teams with the SE>100. The results confirm that a small team with quality members could over perform other teams with more number of students (higher available resources) at least for small tasks with a limited time.

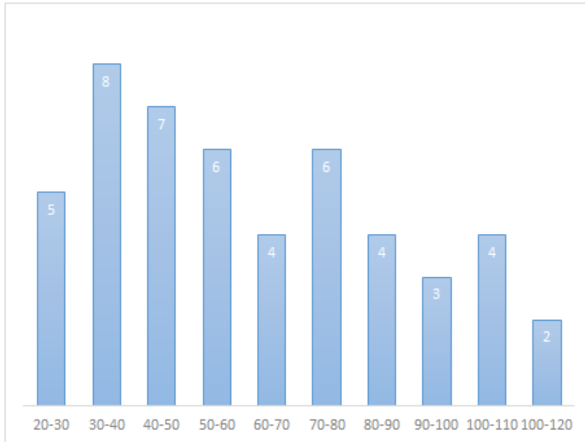


Figure 6- Histogram distribution of structural efficiency of all teams (n=49)

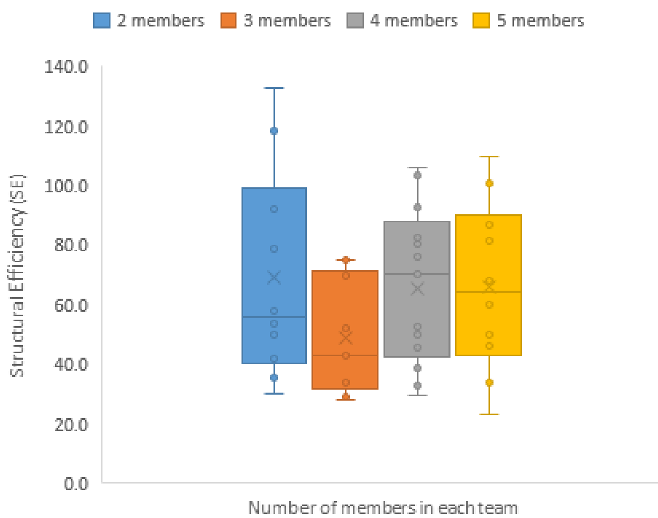


Figure 7- Performance of teams with different number of members

Student's feedback and future work:

After the exercise, we asked the students what are some of the lessons learned from this challenge. The responses focused on the importance of team collaboration, understanding basic engineering principles in terms of both materials and their assemblies as a whole, and the appreciation of the profession.

Overall the Intro summer camp was very positive for both the participants and their mentors. Many students appreciated the hands-on activities and mentioned they enjoyed working in a team to solve a problem and being able the make and test structural components. The word cloud of student's response the question on what they liked about the hands on activity is shown in

Figure 8. Recommendations for future years were largely operations and included the suggestions to spend more time for the lab. Here are some representative feedbacks:

> *" I liked that I could see what was happening right away. I liked that I could manipulate a material to do what I needed it to do."*
>
> *" I liked how we had to work as a team in order to complete a common goal."*
>
> *" It involved trial and error until we came about the bridge we wanted."*
>
> *" The great professors and students taught be the importance of civil engineering"*
>
> *" I enjoyed creating the bridge and making something with ideas that we all contributed and combined to create something cool."*

Figure 8- Word cloud of students' response to what they liked about the hands on activity

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