Board 113: Teaching Hands-On Racecar Design in a Summer Pre-College Program

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George has also been an instructor in this program since 2006, mentoring students as they design, analyze, build, and test solutions to engineering problems they pose. He teaches undergraduate design, thermodynamics, and engineering experimentation and is the faculty adviser to both the Formula SAE Team (Cooper Motorsports) and Pi Tau Sigma Honor Society.

Mr. Estuardo Rodas, Cooper Union

Estuardo Rodas is Adjunct Professor of Mechanical Engineering at the Cooper Union for the Advancement of Science & Art where he is also Project Coordinator of the Mechanical Engineering Lab. He is adviser for Cooper's Formula SAE team and a Lead Instructor for the summer STEM program for high school students. Among his other projects, Prof. Rodas designed the Ike Heller Center for Integrated Manufacturing and Robotics at Brooklyn Tech, collaborated in construction and design of the Tokamak at Columbia University, and created a full-scale model of NASA's Mars Rover for Honeybee Robotics. He is especially interested in design elements and the mechanics of failure. Prof. Rodas is currently planning a workshop course in universal design for disability.

Teaching Hands-On Racecar Design in a Summer Pre-College Program

Abstract

Competitive motorsports at the undergraduate level has become an increasingly popular extra- and co-curricular activity at universities throughout the world. The importance of these experiential, industry-centered projects has long been understood by serving as a true proving ground for students while giving them the upper hand with industry recruiters.

Competitions sanctioned by SAE International (formerly the Society of Automotive Engineers) generally occur at the end of the school year (May/June), thereby making the summer months a critical time for student teams to reflect on their previous designs and to start proposing innovations for the subsequent season. The Formula SAE (FSAE) team at The Cooper Union in New York City has used this time to immerse high school students in this real-world activity in their college's summer STEM program.

This 6-week intensive summer program is separated into two main modules. The first module focuses on teaching students the fundamentals of engineering experimentation that culminate in oral presentations detailing their findings. These experiments include the study of cantilever beams, electric motors, water pumps, flame speed vs. air-fuel ratio, and basic electronics and microcontroller exercises.

After the first week of experiments, students develop a design project that is inspired by an urgent research problem the FSAE team needs to solve. During the past three years, these have included: 1) rebuilding, instrumenting and using a torsion rig to characterize the torsional rigidity of the vehicle's frame, 2) building and using a dynamic impact attenuator test rig, 3) aggressive use of carbon fiber for weight savings in the steering wheel, suspension, pedal system, impact attenuator, and body, 4) novel techniques for the design and manufacture of aerodynamic features, 5) electronic data acquisition system, or DAQ and 6) building a brake dynamometer. Weekly design 'sprints' were given by each team where they presented an update of their project to the entire class and were then critiqued on their engineering method as well as their technical communication skills.

In addition to exposing the STEM fields to high school students as they explore college and career choices, this program was also a critical learning environment for the teaching assistants who mentored these students. Entry and exit surveys were used as assessment tools to gauge the efficacy of the program in providing the students with a better appreciation for the opportunities available in the STEM professions and if the program itself changed their desire about what profession they would want to explore in college.

Introduction

Undergraduate student competitions have proven to be effective learning tools for many years and have introduced themselves in college-level engineering curricula in a variety of formats. These authentic engineering experiences regularly appear in senior capstone design courses which include projects that generally focus on electro-mechanical systems design and optimization. For over three decades, the most commonly described competitions in the engineering education literature are FormulaSAE (FSAE) [1], BajaSAE [2][3], Supermileage, Steel Bridge, Solar Decathlon, and Concrete Canoe, with abundant ASEE conference papers on the automotive projects alone.

The benefits and challenges associated with managing these teams from both administrative and student learning perspectives are described succinctly by Schuster et al, 2006 [1] which include themes that continue to resonate today at the predominantly undergraduate institution (PUI) described here: The Cooper Union for the Advancement of Science and Art. To address the particular challenges of institutional memory, maintaining a continuous stream of core students (with a focus on compositional diversity) [4], and time/project management, faculty give students the agency to leverage their extracurricular competition activities into courses throughout the curriculum, as well as in STEM outreach events and programs that occur throughout the year. One such example by Chambers et al [5] illustrates how an undergraduate project in an experimentation course was used for the school's FSAE team and then implemented in a summer high school program.

For over 30 years, the Cooper Union's summer STEM program has been attracting students in an effort to expand the STEM pipeline in the institution's urban setting of New York City. The program has also served as a recruiting tool whereby nearly 10% of the incoming first-year undergraduate class has participated in the the summer intensive. The program is designed for rising juniors and seniors in high school who are enrolled following a selective admissions process that includes an essay, a letter of recommendation, high school transcript, and demographic information.

The focus of this work is to describe the class structure and deliverables of a 6-week pre-college summer STEM program that occurred at The Cooper Union during 2018. The program operated from July 9 through August 16th and met daily from 9:30am - 3:30pm on Monday through Thursday, representing a total of 120 contact hours. This sustained effort has been shown to increase student retention in STEM, particularly if the interventions are scaffolded and long-term [6]. Though fee-based, donations and revenue allow for nearly 40% of the students to receive full funding to attend, thereby providing access to needy students. In addition to financial considerations, best practices for a successful summer camp is described by Barger and Gilbert

[7]. Student and teaching staff selection will be addressed along with project identification, scheduling, and the presentation of outcomes.

During the admissions process, students are divided into sections that range from 16-24 students each. Every section has a different theme in the STEM fields, centered in the area of expertise of the faculty lead instructor, which can range widely in subject. Students rank their top two section topics in the application and nearly 80% of students are offered their first-choice section. Since 2014, a section entitled, 'Racecar Design through Engineering Experimentation,' or *Racecar*, has been offered with section enrollment around 25 students, which represents classroom and laboratory capacity. Unlike most other sections, *Racecar* is taught primarily by the undergraduates themselves, while the FSAE faculty advisor and student project coordinator (laboratory staff member) serve supporting roles in the instruction.

Overview of Summer Program

The Summer STEM program is a six-week intensive program for rising juniors and seniors in high school. Recruitment for this program starts in the fall semester with the advertisement of the program through printed matter (sent out to more than 600 NYC high schools) and social media outlets. Through its 30+year history, the program has been regarded as technically rigorous and has catered to students from all socioeconomic and racial backgrounds. A challenge for the program was to perform outreach to schools from which students did not traditionally apply, thereby increasing the compositional diversity of the program. That is, students from the New York City magnet school as well as well-funded private schools were generally more knowledgeable about the program and therefore, a high number of applicants came from those schools. Moreover, the racial/ethnic diversity among the students in these populations do not represent a cross-section of New York City. In order to address compositional diversity, the program performs outreach to schools with high-potential students from under-represented minorities, along with foundations who have pre-selected candidate students that are already on a college trajectory. This strategy was similar to that proposed by Villers et al [8]. During the admission process, diversity of thought and life experience are taken into account through essay and recommendation screening.

The application for the summer STEM program is published online in early January and application deadlines are around early to mid-March. The program website contains the descriptions for all the sections (classes) in the program and students are asked to rank their top two choices when applying. The selection process is dependent on the following:

1. Student essay describing why they think this program would be beneficial to them
2. Recommendation letter by a reference who can talk about the student's academic performance, character, resilience, and other traits

3. STEM impact which considers the student's personal and professional trajectory through the lense of the access and opportunity s/he has had
4. Transcript
5. SAT, PSAT, etc (optional)
6. Financial statement (optional)

Although academics are part of the highly-selective admissions process, GPA and standardardized tests scores are only two of many dimensions of student achievement and potential that are considered. The essay letter indicates passion, creativity, and initiative while a strong recommendation letter describes first-hand details of the student's character, ability to learn, and perseverance. Applicants with near-perfect test scores and GPA's are certainly not guaranteed entry into this program. Additionally, the program staff work with guidance counselors and program administrators to recruit students for whom this program would be transformative in their personal lives and academic careers. These students are generally identified early in high school (if not in middle school) as high-potential scholars for whom access to opportunities like this STEM program are not common in their own school or community centers. Effectively, the academic and social characteristics of each section are designed through this admissions process.

Section instructors are asked to recruit teaching assistants for their projects with a target of one TA per 4-5 high school students where classes ranges in size between 16 and 25. This class size is dependent on room size and/or laboratory capacity. These TA's are drawn almost entirely from the undergraduate engineering population at The Cooper Union. Though some art and architecture students have been employed in the past, the TA staff is normally composed entirely of undergraduate engineering students. There have been a number of STEM alumni who have gone onto college elsewhere but who have returned to The Cooper Union to teach in the STEM program themselves. In the 2018 program, the teaching assistants were 30% female while the high school STEM student were 40% female and 28% under-represented minority.

Overarching STEM and college/career planning skills were developed through a series of workshops and seminars, along with a college fair, that were common for all sections. These touchpoints occurred on a weekly basis and were delivered in both full auditorium (~225 students) and workshop (in class, ~20-25 students) form.

Starting in 2014, an assembly has been offered around the midway-point of the program in which invited panelists discuss their path to STEM careers. Speakers are generally women or people of color and have included Tuskegee Airmen, New York City's Chief Technical Officer, designers who have linked STEM and art, and institution alumni. In 2018, a communication seminar was delivered by a transgender male bringing attention to the LGBTQ+ community, a workshop on design thinking was delivered by a female African American activist who creates anti-racist technology for her graduate thesis work, and one keynote speaker at the midway symposium panel was an African American woman who discussed interdisciplinary design, art, activism, and engineering, culminating in a DJ/VJ set. Students were also engaged in weekly career and college planning activities where they reflected on their interests and career goals through vlogs on websites they created. In addition, seminars were given on resume-writing by our college admissions team along with advice on how to ask for recommendation letters (and what should be in them). These activities were common among all sections and have been offered to better prepare students for the college and career planning process and to place engineering in a broader, social context, particularly in endeavors championed by people that looked more like them.

Racecar **Section Description**

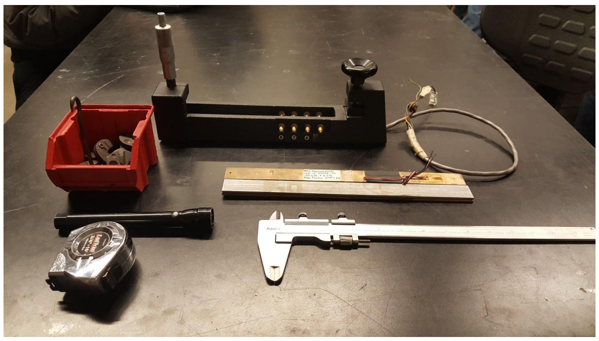
The Racecar section was composed of 21 students who were mentored by 6 teaching assistants (TA's). The students were 29% female (6 of 21); the six TA's were all male and were composed of students rising into the following years: 1 sophomore, 4 junior, 1 senior. The section activities were composed of two main modules. The first immersed students in learning experimentation techniques, measurement basics, teamwork, technical writing, and presentation skills. The second module, which started at the end of the first week, involved the immersion of the students in a project the FSAE Team identified before the program started.

Module One Labs: Building Foundational Knowledge

This module allowed all students to experience a series of laboratory exercises that were fundamentally linked to the projects the FSAE team selected for the second module. Module one experiments included the following and are pictured in Figure 1:

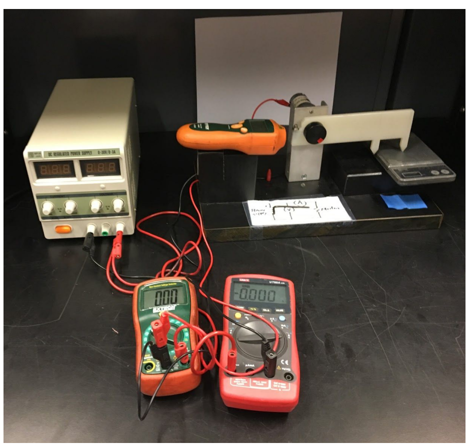
A. Cantilever Beam: using force-deflection curves to identify the materials that composed different cantilever beams.
B. Sump Pump: measuring electrical power input and mechanical (hydraulic) power output of a commercial sump pump to determine efficiency.
C. DC Motor Dyno: sweeping through the performance range of a DC motor used in mechatronics applications, determining speed, torque, and power output through a prony-style brake mechanism.
D. Flame Lab: igniting fuel-air mixtures in a flame tube at different fuel-air ratios to measure flame speeds and relate maximum flame speed to equivalence ratio.
E. CAD lessons: fundamental skill-building in CAD software in preparation for the student design project.
F. Arduino-style microcontrollers and electronic sensors workshop

After performing a rotation through all of these experiments, students would give successive presentations as they refined their understanding of the fundamentals of energy conversion, efficiency, mechanics of materials, and computer-aided drafting. They were critiqued when they presented whereby students and TA's gave input on what they thought worked in the presentation along with suggestions for improvement. During these discussions, the audience debated these themes thereby developing critical thinking skills among the students.



(a) Cantilever Beam

(b) Sump Pump



(c) DC Motor Lab

(d) Flame Tube Lab

Figure 1: Four of the Module One test stands

Module Two: Real-World Design and Research

Module Two was then initiated in the following manner. First, the list of projects was presented and discussed by the TA's, each giving a 'pitch' for each project. The selected projects and a brief description are provided here:

1. **Steering Wheel:** after several years of purchasing off-the-shelf aftermarket steering wheels, the team elected to produce their own which contained integrated electronics, paddle-shifting, and better ergonomics.

2. **Active Aero Wings:** this exploratory study challenged students to build and test a scaled prototype rear wing with an integrated lateral thrust mechanism, thereby allowing for more nimble turning.
3. **Brake Dynamometer:** to initiate the design of a brake testing machine in the laboratory to perform energy dissipation and thermal examinations of different brake pad, caliper, and rotor material combinations to inform system selection
4. **Carbon Fiber A-Arms:** a continued investigation to improve the design and refine the manufacturing process of suspension members that would replace the steel designs that have been used since the beginning of the team's history
5. **Impact Attenuator:** to improve a dynamic test rig, refine an experimental method, and create a series of geometric shapes that would inform the future designs of carbon fiber alternatives to the current aluminum honeycomb crash structure (impact attenuator)
6. **Forged Carbon Fiber:** to explore the use of forged carbon fiber (non-woven strands) as an alternative material for a number of non-structural vehicle elements.

Design Narrative of Final Projects

Before the students started their group work on Module Two, they were all introduced to the engineering design process whereby they were exposed to the concepts of: 1) problem identification, 2) information gathering, 3) problem formulation, 4) generation of design alternatives, 5) design ranking systems and implementation, 6) design selection and prototyping, and 7) testing and refinement. Groups were asked to document their work on a daily basis such that they would be prepared for every week's design sprint, normally occurring on Tuesday. This sprint was an informal presentation in front of the entire class that allowed students to work out ideas with the audience as the audience would give pointers, ask questions, and help the presenters critically assess and strategize the next steps in their design process.

The feedback from students regarding the design sprints was that it also gave them a short-term goal; they served as a stopgap, in that if things were not going as expected or desired, process changes could be made, mechanisms were re-designed, and even workload could be redistributed. This interaction was important in improving the group's presentation skills and allowed every student to present publicly. In contrast, the final day of the program only afforded the entire section a limited amount of time (20 minutes) and therefore, not all students would have been able to present then.

Each team implemented the design process in their work and followed a different path through this process. That is, one group may have spent more time in the information-gathering phase as they were learning how the current machinery worked and what the state-of-the-art related to their project. At the same time, a different group may have jumped quickly into the design alternatives and prototyping phases since they joined the project much later on in the project's design cycle (ie some were ongoing projects within the FSAE team while some were completely new). The importance of developing multiple design alternatives, the importance of the iterative process, and the continuous communication between group members was highlighted throughout. The following section provides greater detail regarding the projects selected, the evolution of each project, and a description of the final results.

<u>Steering Wheel</u>

The 2018 season marked the first introduction of a student-built steering wheel and it received resounding favorable feedback from the design judges at the competition. This steering wheel was a molded carbon fiber base with integrated electronics and paddle shifters for the transmission; this steering wheel is shown in Figure 2. The STEM group that selected this project needed to address two subproblems in the design of this system: 1) ergonomic design to allow for better gripping and turning by a gloved hand for a range of driver hand sizes and 2) a shifting lever system that would more precisely read driver demand and retract fully to prevent missed and inadvertent double shifts.

(a) Front (Driver's View)   (b) Back

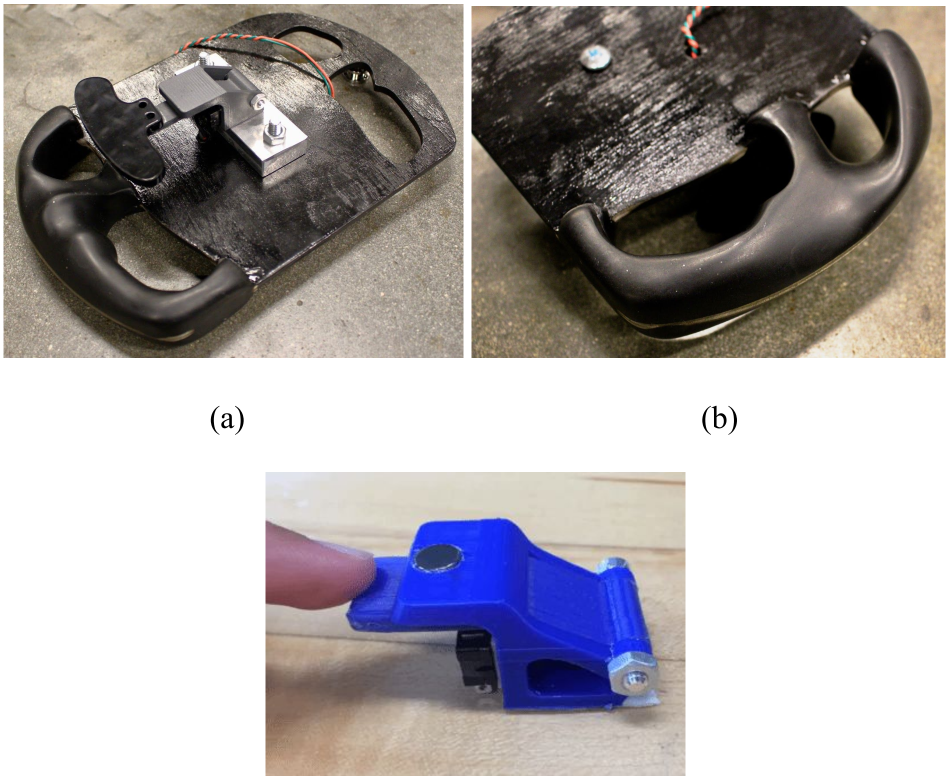
Figure 2: Front (a) and back (b) Images of 2018 steering wheel.

After their first meeting with the TA, the group began developing design alternatives for both these problems as they were continuing to learn about the problem itself. This process was very common among the groups and illustrated the iterative stepping between the design process stages. Figure 3 shows two examples of these design alternatives for the handle and the shifter, respectively.

(a) Steering wheel handle (b) Paddle shifter

Figure 3: The first design iteration in re-imagining the steering wheel ‘handle’ and the paddle shifting mechanism.

The images in Figure 3 show the importance of having a CAD lesson during the foundational learning module as these subsystems were first prototyped virtually and then physically. This process was not the same with other projects. Some started with the physical prototype and then progressed to the virtual design; others worked on both prototyping styles concurrently. The next stage for the steering wheel group was to physically prototype their concepts such that the TA’s could give feedback about their design’s possible effectiveness. The results of the next stage of this process are shown in Figure 4, which shows the team’s progress toward understanding the problem better and testing out new concepts for handle molding, along with paddle placement and actuation. Interestingly, the hand-molded design (from clay) was subsequently scanned and 3D printed in the Fall 2018 semester by a group of first-year students at The Cooper Union.



(a) (b)

(c)

Figure 4: Physical prototypes showing the overall system (a), a close-up of the hand-molded grips, and (c) a shifter mechanism.

After continued work and refinement, the team concluded with the following design shown in Figure 5.

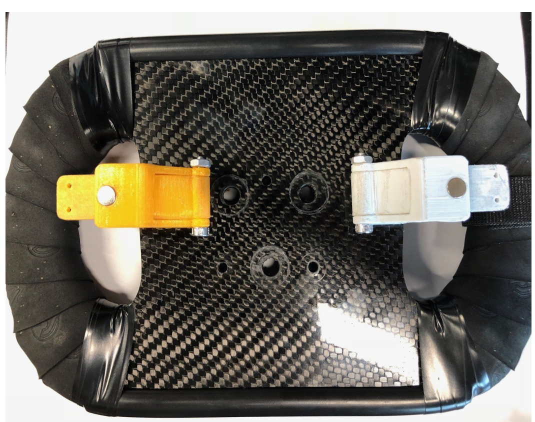
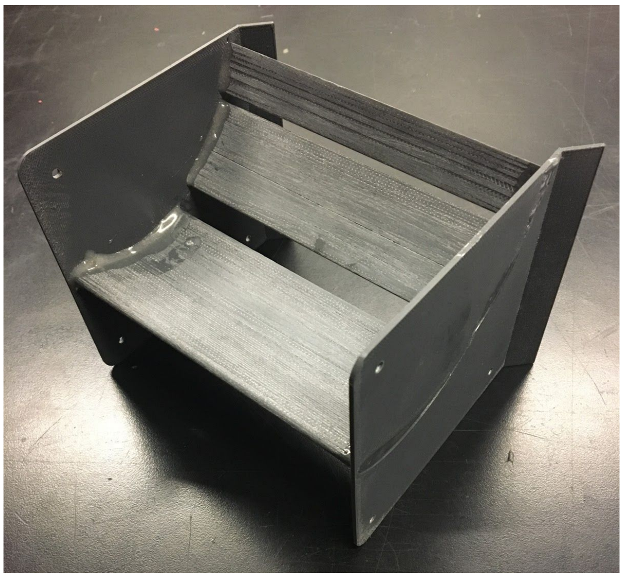


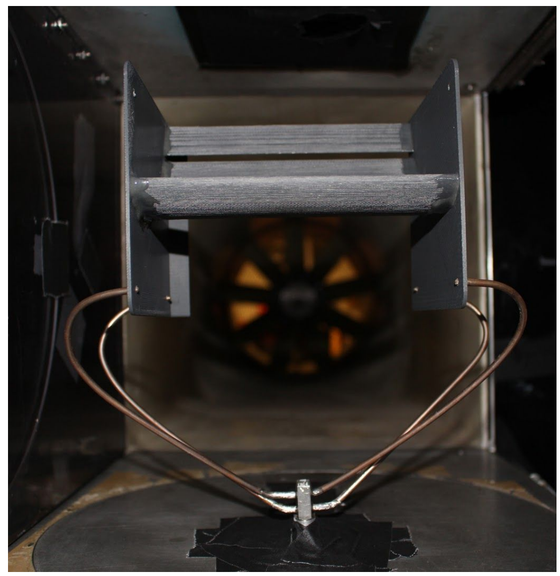
Figure 5: Final steering wheel design iteration

Active Aero Wings

The use of aerodynamic packages in FSAE vehicles has become very popular among the top-performing teams since this feature allows for increased tractive ability due to downforce provided to the driven rear wheels. This team elected to explore the use of deflectors on the rear wing, shown in Figure 6 (a), which could actively divert fluid momentum thereby allowing for nimble turning of the vehicle. This project, though not intended for immediate implementation on a vehicle, was a project that engaged the students in a feasibility study.



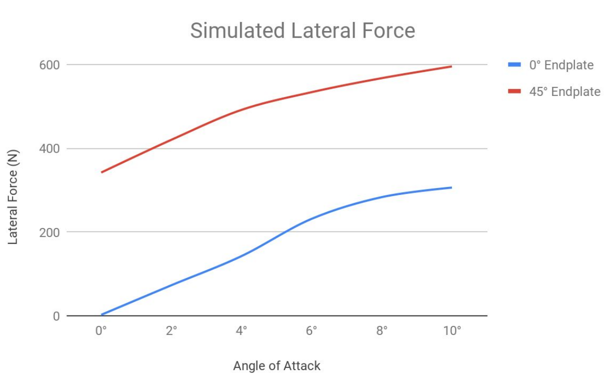
(a) 3D printed prototype (note rear flaps)



(b) Rear wing in wind tunnel

Figure 6: Rear wing prototype (a) and its implementation within an education wind tunnel (b).

The students produced 3D CAD renderings of the rear wing assembly which were 3D printed and attached to a test rig (Figure 6 (b)) within the institution's wind tunnel. The test section was approximately ⅓ meter x ⅓ meter and the rig was attached to a balance that measured resulting downforce. The students also performed a CFD study and compared their physical and virtual prototyping results in Figure 7.



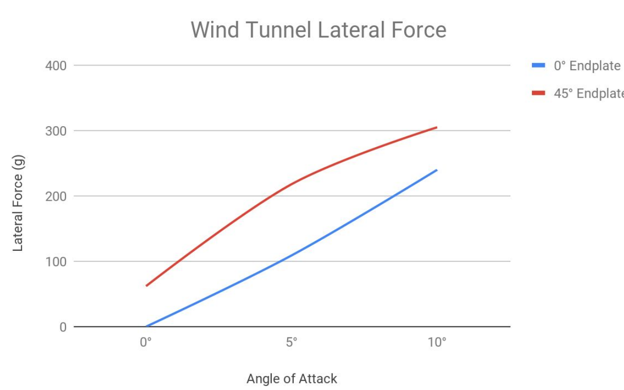


Figure 7: Samples CFD analysis performed (a) compared with experimental results (b).

The second part of this project included the development of an electronic actuation device that would change the rear geometry of the wingflaps on-the-fly to produce the side force needed for cornering. This microntroller-based system is shown in Figure 8.

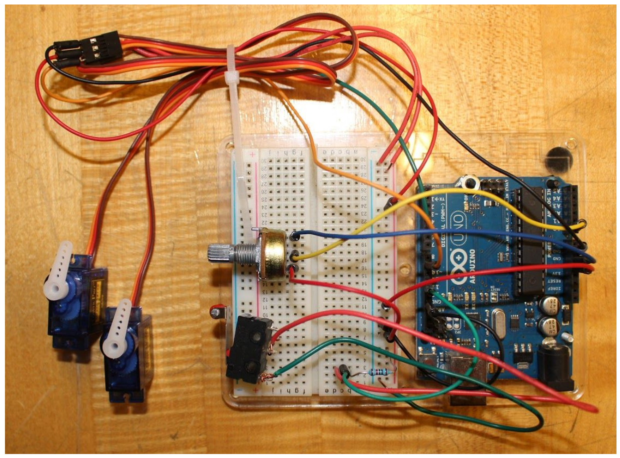


Figure 8: The aero wing team's prototype for the electronic flap actuation system.

Brake Dynamometer

Much like all of these projects, the need to fully validate and verify subsystem designs is critical in improving overall vehicle performance but also to incur higher design scores at competition. A team that is able to fully characterize subsystem designs and inform the next iteration in design through rigorous and systematic experimentation is considered more favorably from a design perspective. Brake development follows this same philosophy and for the first time, systematic testing is beginning to be addressed. One method that allows teams to isolate the brake system and test it in a highly-controlled fashion is through a brake dynamometer (or brake dyno).

This team started with a decommissioned frame from an unrelated project, which is shown in Figure 9. Their goal was to first simulate ¼ of the car's inertia and then supply adequate braking force to this inertia such that the necessary deceleration rate was achieved while also maintaining a workable system temperature.

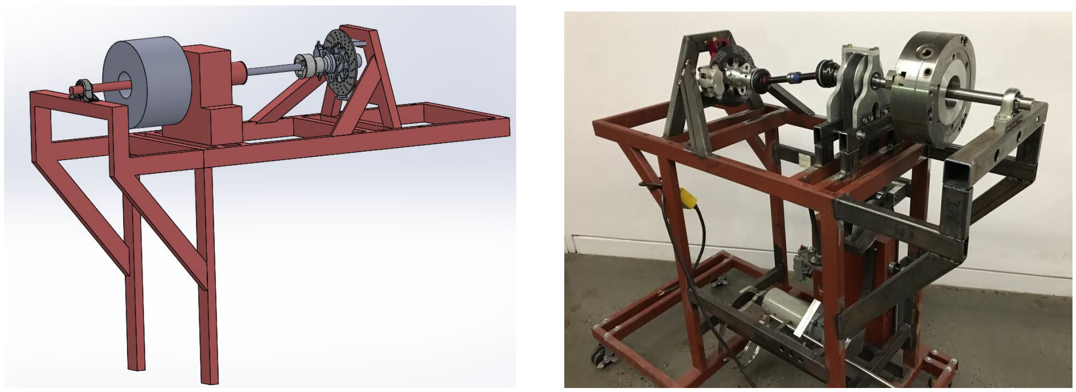
Figure 10 contains images of a typical brake rotor and caliper which exist at each of the four corners of the vehicle. This brake rotor is attached to a system called a hub that physically grounds the rotor to the wheel. If a retarding force is applied to the rotor, the wheel would also slow down. An upright (shown in b) attaches the hub to the rest of the suspension system and had to be integrated within the dyno system. Finally, an inertial equivalent to the ¼ car model appears in Figure 10 (c) which coincidentally is a tooling chuck used in lathes. All these materials were procured from previous or decommissioned projects and therefore did not impact the section’s overall budget.

Figure 9: Original decommissioned frame used for the brake dynamometer.

(a) (b) (c)

Figure 10: Example of a brake rotor and caliper (a), an upright that holds the hub, and brake rotor (b) and a tooling chuck used as inertia (c).

In Figure 11 below, the team showed how they started with a virtual model of the overall system including the parts shown above and a driveshaft that they procured that connected the inertia-end to the driven end of the dyno.



(a) System rendering (b) Dyno prototype

Figure 11: Virtual rendering and subsequent design iteration of the brake dyno.

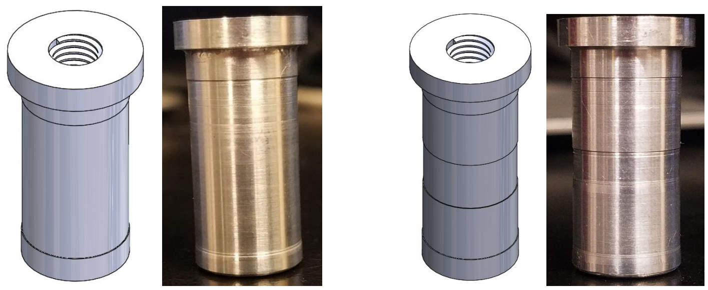
Note that this team's duties were mainly based in CAD modeling and system synthesis. Summer STEM students cut and prepared the structural members to support flywheel and bearing pillow bearings as well as coordinated with the shop technician to weld the frame extension. They assembled the flywheel subsystem and reassembled the pulley and tested various motors found in the lab and shops. The next stage of this prototype was continued by first-year students at the institution who subsequently procured an electric motor and controller while using all the components the STEM students built and procured.

<u>Carbon Fiber A-Arms</u>

For years, The Cooper Union FSAE team has been contemplating and exploring the replacement of its steel suspension members with carbon fiber. Great progress was made, but the replacement carbon fiber parts, although very lightweight and strong, were not implemented. The main reason was that the team leaders at the time believe that the carbon fiber members would fracture under impact loading from the orange cones used to mark off the lanes on the racetrack. The inexperienced drivers have had a long history of hitting this cones.

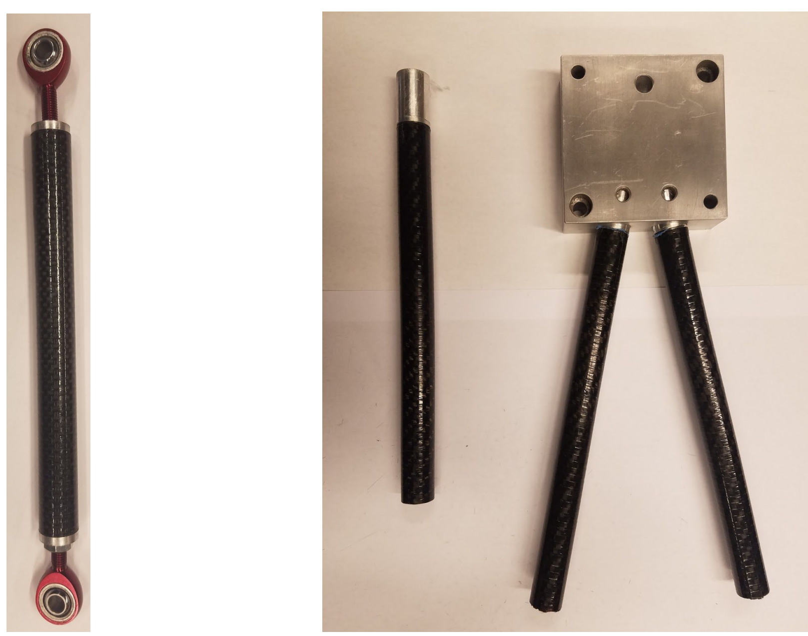
This project attempted to reintroduce this replacement concept to the team and prove, through experiment, the strength of the members under impact loading. The project began with an assessment of the loads that were experienced by the steel suspension members in previous years' racecars. These numbers were then used in statics calculations to size the diameters of hollow carbon fiber tubes that were then purchased and prepared in the following manner.

First, rod-end bearings were to be applied to each end of cut tube. In order for the threaded ends of these bearings to be attached, custom aluminum inserts were machined and epoxied into the tubes. The students experimented with surface roughness preparation as well as the tolerances between tube and aluminum insert. Optima exist in either case which would render the tube material itself the weakest part of the system. Examples of these inserts are shown in Figure 12.



(a) Single groove (b) Multiple groove

Figure 12: Aluminum insert surface preparation with a single groove (a) and several grooves (b) for epoxy retention.



(a)Two-force member (b) A-Arm jig

Figure 13: Two-force member (a) and A-arm jig (b).

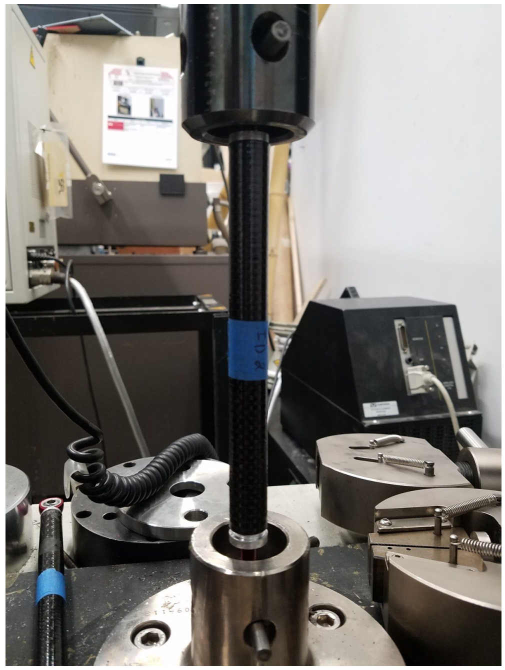
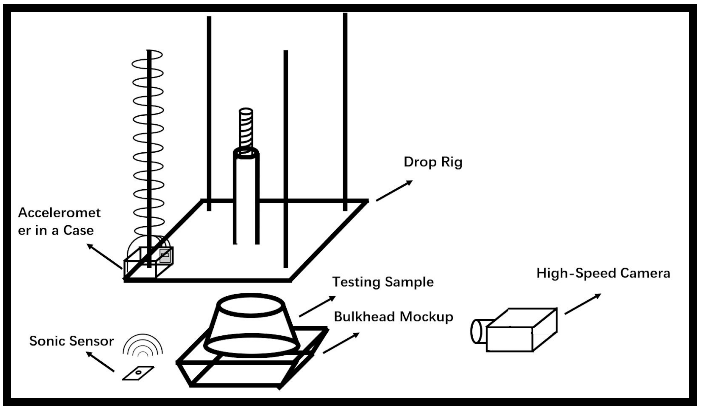


Figure 14: Application within an ultimate tension test machine.

<u>Impact Attenuator</u>

Every FSAE team must provide a series of technical reports before they are allowed to compete. One such report involves the impact attenuator (IA) that is placed in front of the driver's feet, within the vehicle body. As defined in the FSAE rules, in order for an IA to qualify for competition, it must sustain an overall kinetic energy of 7350 J and sustain maximum and average forces equivalent to 40g and 20g, respectively.

A schematic of the test rig employed in this study is shown in Figure 15 along with a series of pre- and post-practice tests on cardboard designs that the students made. The test rig uses an accelerometer to measure the rate of deceleration, which is then integrated to yield velocity. This change in momentum is used to calculate force and the integral of this force over respective distance yields energy absorbed. An oscilloscope with an adequate sampling rate was used to collect accelerometer data and saved for post-processing.



(a)

(b) Pre-test (c) Post-crush

Figure 15: Schematic of overall drop-rig test system (a) and mock-up geometric designs before (b) and after (c) crushing tests.

A photograph of the test rig is shown in Figure 16 and a characteristic acceleration curve is shown in Figure 17.

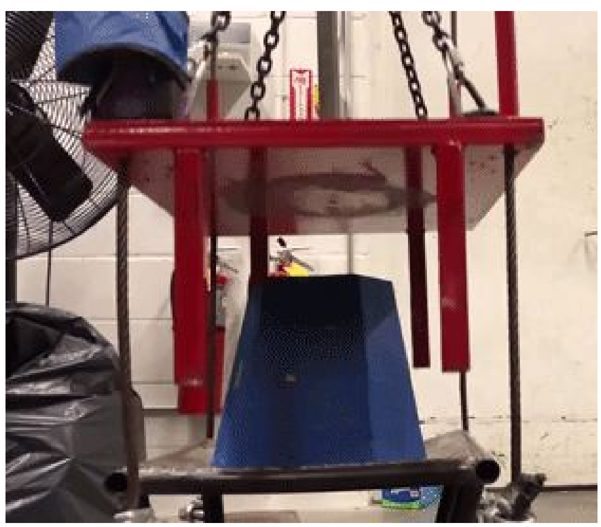


Figure 16: Test rig with sample impact attenuator

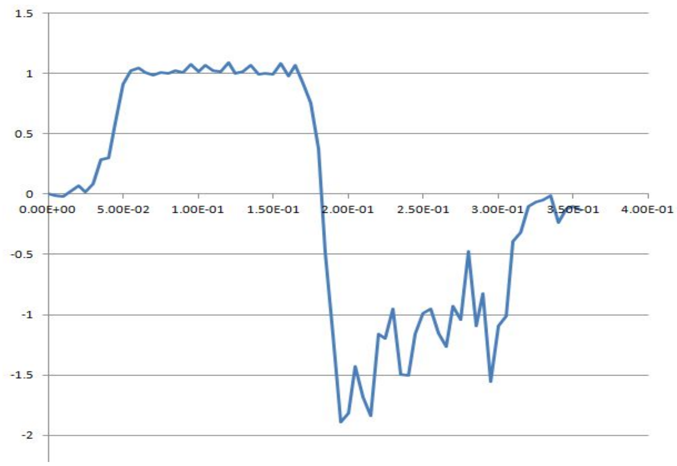
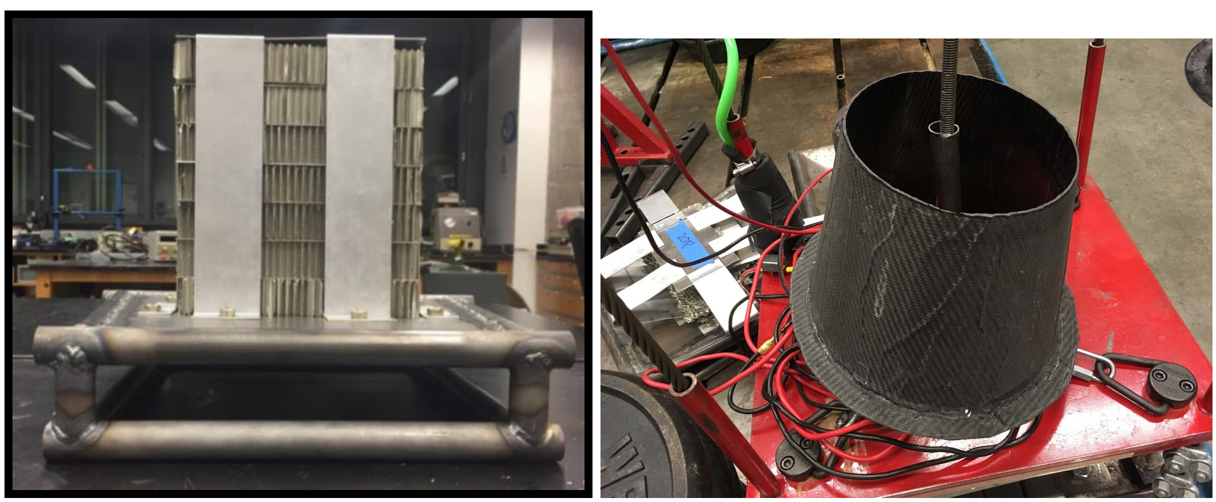


Figure 17: Sample acceleration data from drop-test

The students then continued their study by designing a mold and laying up carbon fiber for a new IA design resembling the one shown in Figure 18. Note the comparison between the traditional, multi-layered aluminum honeycomb design versus the new ‘stovepipe hat’ design in this figure.



(a)Aluminum (b) Carbon Fiber

Figure 18: Traditional multi-layered impact attenuator made of aluminum (a) and the STEM design on the test rig (b). The latter is completely hollow.

<u>Forged Carbon Fiber</u>

One exploratory study that was initiated in the Spring 2018 semester in the junior-level mechanical engineering course ‘Engineering Experimentation’ was to investigate ‘forged’ carbon fiber as an alternative material to help achieve lightweight parts. The FSAE team was increasingly performing aggressive weight-savings strategies throughout the vehicle and were considering woven carbon fiber for some time. Some issues with that material selection were: 1) overall cost, 2) skill level needed by the student manufacturers.

Forged carbon fiber consists of strands of the material (not woven cloth) infused with epoxy and pressurized within a mold. Though the team was given strands that were a specific length, future studies would investigate how different strand lengths affect material strength. These strands are shown in Figure 18.

Figure 18: Carbon fiber strands used in this study.

The students learned about the costs of each, were trained on laying up carbon fiber parts (the traditional way), used CAD and rapid prototyping machines to build the molds, and then developed and implemented a material testing protocol for their prototypes. Figure 19 shows these test specimens before and after ultimate strength testing.

(a)Test sections (b) Tension test specimen

Figure 19: Examples of test sections that were produced from molds (a) and a sample from the destructive test (b) performed in a material testing machine (tension).

After the material properties were determined, the strength data were used in designing and prototyping a fuel pedal. Statics calculations were performed in addition to FEA to refine the geometry of this pedal before a mold was produced. Once the mold was finalized, the carbon fiber was forged and allowed to cure before testing was performed. The designs and final product are shown in Figure 20. The fuel pedal was selected as a trial part for this study because of the low structural strength requirement.

(a) Several preliminary design alternatives (b) Final design

Figure 20: Virtual design iterations (a) and the final product (b).

The students then subjected the final design to series of loading conditions and verified that it could withstand the impact and fatigue loads anticipated.

Survey Results and Discussion

The compositional diversity of the students was as follows:

Race/Ethnicity	N	%
Asian, Filipino or Pacific Islander	4	19.0%
White	8	38.1%
Black/African American and/or Latinx	9	42.9%
Total	21	100%

Of the 21 students, 10 were granted full scholarship to attend, one received a half-scholarship, and the remaining 10 paid the full amount. In addition, the gender composition is shown below:

Gender	N	%
Male	15	71.4%
Female	6	28.6%
Total	21	100%

The overall program demographics indicate a lower percentage of under-represented minority groups in STEM (28%) while the female population composed 36% of the population.

Of the 21 students enrolled in this section, 19 were given parental permission to take the exit (self-efficacy) survey administered by the program and 7 students completed it. Although these numbers are relatively small compared to the average of all the other sections, 15 students requested recommendation letters from the technical staff (technician and instructor) which indicates a connection to the program. Furthermore, the exit survey was administered the day before the final presentation. Because of this timing, and because students knew that it was a voluntary survey, they elected to work on their final project and presentation instead of taking the survey. The program administrators will consider changing this timing and have found that giving students the survey directly after the presentation may yield a greater number of surveys completed, as well as greater completion rates.

The exit survey questions were divided into the following themes and a Likert scale was used in each where student perceived strength and/or confidence level received highest scores. All post survey questions are provided in Appendix A.

1. What engineering skills and knowledge do you possess?
2. How confident do you feel about the following statements related to your transition to college?
3. What do you know about engineering jobs?
4. Is what you learned in engineering important?
5. Is what you learned about applying engineering skills important?
6. Did the program live up to your expectations?
7. What are you academic intentions after high school?

As depicted in the table below for theme 1, the students felt more knowledgeable about the design process, teamwork, and both oral and written communication skills. Since weekly presentations were given on a group basis, it seems intuitive that the student confidence was relatively high for this outcome. The design process was continually applied within the team and developed daily.

Theme	Question	Scale	Mean	Std Dev
What engineering knowledge and skills do you possess? (Indicate the extent that you agree with the following statements)	I am knowledgeable of the engineering design process.	Strongly Agree = 4	3.57	0.53
	I know how to use basic electronic tools (Examples: arduino, breadboard, circuit components, etc)	Agree = 3	3.29	0.49
	I know how to use basic fabrication tools (Examples: Laser cutter, 3D printer, machine shop, etc)	Disagree = 2	3.00	0.82
	I feel confident using the engineering design process to solve a problem.	Strongly Disagree = 1	3.71	0.49
	I feel confident giving oral presentations.		3.57	0.79
	I work well in teams.		3.57	0.53
	I feel confident writing about engineering concepts.		3.43	0.53
	Engineering is easy for me		2.86	0.38

We also notice that the students did not feel as strongly that they knew how to use fabrication tools. Although this section contained extensive fabrication projects, it is inferred that the respondents may have been the ones who took the lead on the electronics portions of the projects. We also see that the students felt that engineering was not easy for them, but still felt confident in their abilities. This result may suggest that they are developing resilience, particularly with the close support of near-peers who guide them through the projects.

A long-standing offering in the summer program has been a college admissions seminar and a college fair held at a neighboring university. In 2018, the students were given more workshops on the college admissions process with particular focus on how to ask for a recommendation letter. We have seen in past years that summer STEM alums would apply to our undergraduate program and not ask their instructor for a recommendation letter.

Theme	Question	Scale	Mean	Std Dev
How confident do you feel about the following statements related to the transition to college? (Indicate the extent that you agree)	I feel confident writing an application essay	Completely Confident = 4	3.29	0.76
	I feel confident creating a website or digital portfolio to demonstrate my knowledge and prior experiences.	Moderately Confident = 3	3.29	0.76
	I feel academically prepared for college.	Slightly Confident = 2	3.43	0.53
	I feel comfortable in a college environment	Not at all Confident = 1	3.57	0.79
	I feel comfortable asking for recommendation letters.		3.71	0.49

As an addition to the program, students were immersed in career planning sessions where they researched different STEM careers and learned about job opportunities, salaries, necessary coursework, and degrees needed. They were assigned a voluntary weekly reflection on a topic pertaining to this career action plan. From these outcomes, we anticipate adding an element of professional social media, job search advice, and company awareness.

Theme	Question	Scale	Mean	Std Dev
What do you know about engineering jobs? (Indicate the extent that you agree with the following statements)	I know about different kinds of engineering jobs.	Strongly Agree = 4	3.43	0.53
	I know where to find information about engineering jobs.	Agree = 3	3.43	0.53
	I know the steps to take to get an engineering job.	Disagree = 2	3.00	0.82
	I know of companies that hire people to work in engineering jobs.	Strongly Disagree = 1	3.14	0.69

Next, we gauged student sentiment regarding the importance of their work and how STEM learning relates to their ability to find a college or career. The students overwhelmingly indicated that STEM learning was very important to them. Although not all the students indicated that they were interested in a STEM career, they recognized the importance of analytical thinking and systematic problem-solving as a lifelong skill.

Theme	Question	Scale	Mean	Std Dev
Is what you learned in engineering important? (Indicate the extent that you agree with the following statements)	Engineering is important for me.	Strongly Agree = 4	3.71	0.49
	Engineering is important for what I want to study.	Agree = 3	3.43	0.98
	Engineering will help me find a job.	Disagree = 2	3.71	0.49
	I am interested in working in a career that allows me to use engineering-related skills or knowledge.	Strongly Disagree = 1	3.71	0.76

Finally, the students felt positively about their abilities to employ the engineering design process and electronics skills and much less in regards to entrepreneurial skills. Note that this exit survey was given to all the sections in the program and some focused primarily on this latter skill. A lower score in manufacturing skill confidence tracks with the fabrication skill question in the first theme and may have resulted because the respondents were mainly in charge of the electronics portions of their teamwork.

Theme	Question	Scale	Mean	Std Dev
Is what you learned about applying engineering skills important? (Indicate the extent that you agree with the following statements.)	I am confident in starting a project that uses electronic skills.	Strongly Agree = 4	3.29	0.49
	I am confident in starting a project that uses manufacturing skills.	Agree = 3	3.00	0.82
	I am confident in starting a project that uses entrepreneurship skills.	Disagree = 2	3.14	0.69
	I am confident in starting a project that uses design skills.	Strongly Disagree = 1	3.57	0.79

Although there were only 7 surveys completed, all students noted that the program lived up to and exceeded their expectations. The students responded to question 6 as follows:

A. *Yes, this program did live up to my expectations because I learned a lot about how many different aspects there are in engineering and what it takes to be an engineer. I came in expecting to build the entire race car but the program made me realize that's unrealistic. Considerable effort goes into each part of it and each part is well thought out. I thought it was very cool that so much effort could be put into a tiny part of the car and it may just give it that edge over a competitor.*
B. *This program exceeded my expectations. I did not know I was able to use so much fun while engineering a brand new part. I have learned a lot from this program*
C. *This program definitely went beyond my expectations. Not only did I make new friends and learn invaluable lessons from them, I also learned more about engineering in those past six weeks than I have ever. It broadened my perspective on the intricacy and complexity of the art that is engineering.*
D. *Yes and more than that, it allowed me to be one step closer to be my dream of becoming an engineer.*
E. *The program lived up to my expectation because I was able to get firsthand experience with working on the FSAE racecar and learn the inner mechanics of how the car works. I was able to experience what it is like to work as a mechanical engineer at Cooper Union and see what they do. I really enjoyed it.*
F. *This program went beyond my expectations. I learned how to use electronic tools like arduino to complete our project. Because of this program, I am certain that I want to pursue a career in engineering.*
G. *Yes, the program validated my desire to be an engineer. It is uncommon for students at such a young age to be exposed to possible work within their career of choice. Summer stem has allowed me to be confident in my pursuit of engineering through college and into a career. I am, however, not quite sure exactly what I will be doing with my degree after I graduate college.*

These responses are very encouraging and will be used as a basis for future study of this section. The final presentations for all six projects can be found at the end of this playlist:

https://www.youtube.com/playlist?list=PLmdAoua1GcPuaE_w6LeEq_xSKUA0VS5qe [9]

Conclusions

Through a series of hands-on modules based in experiments that serve a client (the FSAE Team), high school students were immersed in an authentic engineering design project that replicated professional industrial practice. A group of 21 high school students were mentored by 6 college undergraduates in the design, analysis, prototyping, testing, documenting and reporting of a project of their choice and greatest interest.

Efforts were made by the program administrators to assure compositional diversity of the entire class through the admissions process and through targeted recruiting. More effort could be made at the institutional level to attract more female students and under-represented minorities, thereby increasing the applicant pool for these TA positions.

The quality of work produced by these 6 teams was on par with the caliber of work output from a 25-student section of an introductory design course, taken by all incoming first-year students over 15 weeks, 3 contact hours per week. With no prior experience necessary, these students were able to learn the design process through application using the institution's FSAE project.

Although given a supply budget, the section did not use it all because they leveraged materials that were already in stock and that were used in previous years by the FSAE team, or even materials that were discarded from decommissioned projects. This fact would be very useful for other FSAE team considering this type of summer program.

The results were 6 projects that addressed diverse system needs throughout the vehicle and ranged from short- to long-term; the authors anticipate that some of these project will be directly used in the 2019 competition while others will take longer to fully mature to competition-readiness.

Though this program focuses on the skills development of the students, the teaching assistants also benefit in that they both deepen and broaden their expertise in the themes involved. But moreso, they have gained an appreciation and first-hand experiences in a teaching and learning pedagogy that has proven to be effective at The Cooper Union for years.

Exit survey data, though sparse, indicated that the students felt more confident in their ability to apply the design process to an open-ended problem, while also feeling very comfortable in a college environment. Areas of improvement include: 1) more fabrication work to improve their manufacturing skills, 2) enhanced college/career seminars to include occupation searches, and 3) recruiting and hiring a more diverse teaching staff.

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Appendix A: Program Exit Survey Questions

Theme	Question	Scale	Scale
What engineering knowledge and skills do you possess? (Indicate the extent that you agree with the following statements)	I am knowledgeable of the engineering design process.	Strongly Agree = 4	Strongly Agree = 4
	I know how to use basic electronic tools (Examples: arduino, breadboard, circuit components, etc)	Agree = 3	Agree = 3
	I know how to use basic fabrication tools (Examples: Laser cutter, 3D printer, machine shop, etc)	Disagree = 2	Disagree = 2
	I feel confident using the engineering design process to solve a problem.	Strongly Disagree = 1	Strongly Disagree = 1
	I feel confident giving oral presentations.		
	I work well in teams.		
	I feel confident writing about engineering concepts.		
	Engineering is easy for me		
How confident do you feel about the following statements related to the transition to college? (Indicate the extent that you agree)	I feel confident writing an application essay	Completely Confident = 4	Completely Confident = 4
	I feel confident creating a website or digital portfolio to demonstrate my knowledge and prior experiences.	Moderately Confident = 3	Moderately Confident = 3
	I feel academically prepared for college.	Slightly Confident = 2	Slightly Confident = 2
	I feel comfortable in a college environment	Not at all Confident = 1	Not at all Confident = 1
	I feel comfortable asking for recommendation letters.		
What do you know about engineering jobs? (Indicate the extent that you agree with the following statements)	I know about different kinds of engineering jobs.	Strongly Agree = 4	Strongly Agree = 5
	I know where to find information about engineering jobs.	Agree = 3	Agree = 4
	I know the steps to take to get an engineering job.	Disagree = 2	Disagree = 2
	I know of companies that hire people to work in engineering jobs.	Strongly Disagree = 1	Strongly Disagree = 1
Is what you learned in engineering important? (Indicate the extent that you agree with the following statements)	Engineering is important for me.	Strongly Agree = 4	Strongly Agree = 5
	Engineering is important for what I want to study.	Agree = 3	Agree = 4
	Engineering will help me find a job.	Disagree = 2	Disagree = 2
	I am interested in working in a career that allows me to use engineering-related skills or knowledge.	Strongly Disagree = 1	Strongly Disagree = 1
Is what you learned about applying engineering skills important? (Indicate the extent that you agree with the following statements.)	I am confident in starting a project that uses electronic skills.	Strongly Agree = 4	Strongly Agree = 4
	I am confident in starting a project that uses manufacturing skills.	Agree = 3	Agree = 3
	I am confident in starting a project that uses entrepreneurship skills.	Disagree = 2	Disagree = 2
	I am confident in starting a project that uses design skills.	Strongly Disagree = 1	Strongly Disagree = 1