A Sixth-Twelfth Grade Engineering Summer Camp – Drawing, 3D Printing, and Building a 4 Cylinder Combustion Engine Model

Georg Pingen, Betsy Pingen
Union University, Jackson, TN

Abstract

In order to reach out to our local community and encourage students to consider careers in engineering, we developed a 3D printing focused summer camp geared at 6th through 12th grade students. The authors' goal was a camp that would be challenging, relevant to engineering, and exciting for the students. During camp week, students with no prior knowledge of CAD learned how to draw 18 different engine parts in PTC Creo, using tutorials specifically developed for the summer camp and receiving help from faculty and student workers. Students then learned how 3D printing works and observed the printing of their parts, culminating in the assembly of a working engine model for each camper. The response to the summer camp was overwhelmingly positive and has led to the planning of an extended summer program for 2020 and the installment of monthly themed 3D print nights for students 5th – 12th grade.

Keywords

K-12 outreach, 3D printing, engine design, thermodynamics, solid modeling

Introduction

Over the years, requests have been made for our engineering department to provide a summer camp option for children in the community. In order to address this demand and encourage children to consider careers in engineering, we developed a 3D printing focused summer camp geared at 6th through 12th grade students. The authors' goal was a camp that would be challenging, relevant to engineering, and exciting for the students. We centered our camp around the 3D printing of a 4-cylinder air powered combustion engine model that was developed by one of our Union University students. During camp week, children with no prior knowledge of computer-aided design (CAD) learned how to draw 18 different engine parts in PTC Creo, using tutorials specifically developed for the summer camp and receiving help from faculty and student workers. Students then learned how 3D printing works and observed the printing of their parts, culminating in the assembly of a working engine model for each camper (see Figure 1 for a full model as well as a partial model of the engines built by the students). We further engaged students through a range of related activities including demonstrations of the combustion process using hydrogen/oxygen balloons in the chemistry lab, an engineering themed scavenger hunt, a 3D printing based escape room, a presentation by engineers from a local Toyota plant, campus tours, a LEGO bricks design challenge, the printing/designing of multiple fun items, and a culminating end-of-week open house in which students presented their designs to their parents.

In the following sections, we will discuss the motivation for the camp, provide details of the main camp project (the design, modeling, and construction process of the 4-cylinder engine), outline additional related activities that we performed with the camp attendees during the week, and finally, we will briefly reflect on the success of this engineering summer camp.

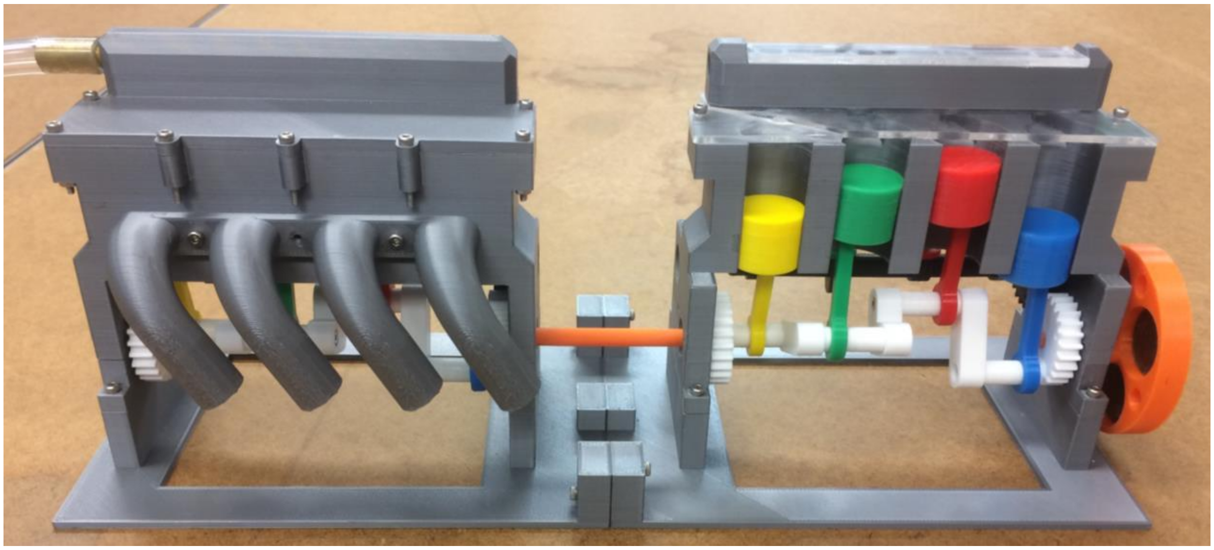

Figure 1: Full model (left) and partial/visible model of the 4-cylinder engine (right)

Starting a New Engineering Summer Camp – From Identified Need to Camp Idea

Having spent multiple summers in Boulder, Colorado, the authors' family has experienced first-hand the value and breadth of the summer programs offered by the University of Colorado at Boulder, as well as the general Boulder, Colorado community. We have seen the need to have more STEM-based summer camps in Jackson, TN but have lacked the resources as well as a good idea for an engineering summer camp. Having spent a sabbatical doing computational engineering research in the MathCCES center of the Aachen Institute for Advanced Study in Computational Engineering Sciences (AICES) at RWTH in Aachen, Germany, G. Pingen observed the department wide engagement in the outreach education lab CAMMP (Computational and Mathematical Modeling Program)[1]. While Pingen was not involved in CAMMP, the time at Aachen further illustrated the value of and need for STEM summer camps in the authors' home community. The initial seed for an engineering summer camp at Union University was planted, but the idea for a specific camp was still lacking.

The project idea came unexpectedly through a project assignment in the sophomore level thermal-fluid-science class at Union University. The author gave student teams the assignment to each produce a teaching model for one of the concepts covered in the course. Two students – Gavin Hamann and Ethan Morris – submitted the 3D printed engine model shown in Figure 1, a modified version of a "Working 4-Cylinder Air Engine Model" that had – unbeknownst to us – been designed and uploaded to Thingiverse by our former student Eli Smith[2]. At the same time our department updated its 3D printers from older Wanhao Duplicator 4s to new Prusa MK3s printers. This upgrade in printers made 3D printing much more turn-key in our department, providing us with adequate facilities to initiate the first 3D printing summer camp at Union University during summer 2019.

Engineering Summer Camp 2019 - 4-Cylinder Air Engine Design and 3D Printing

The goal of our summer camp was to introduce students to 3D printing while teaching them about internal combustion engines, hoping to provide K-12 students with a feel for the many exciting career opportunities in engineering. We felt that using the 4-cylinder air engine provided a fascinating and doable, while at the same time very ambitious project for children without prior CAD or 3D printing experience. In order to ensure a basic background with computer skills as well as the ability to follow multi-step instructions, we limited the camp to children in 6th – 12th grade. Further, we were limited to 20 camp participants due to the size of our computer lab.

Figure 2: Engine Tutorial

Starting with the CAD model and STL files provided by our former student[2], we developed a 200+ page detailed PTC Creo tutorial (see Figure 2) of all 18 parts (see Figure 3) required for the engine. Each tutorial starts with a brief introduction of the purpose of the particular part and is subdivided into multiple "Missions" of manageable size. An example of 2 pages of the CAM Gear tutorial is shown in Figure 4.

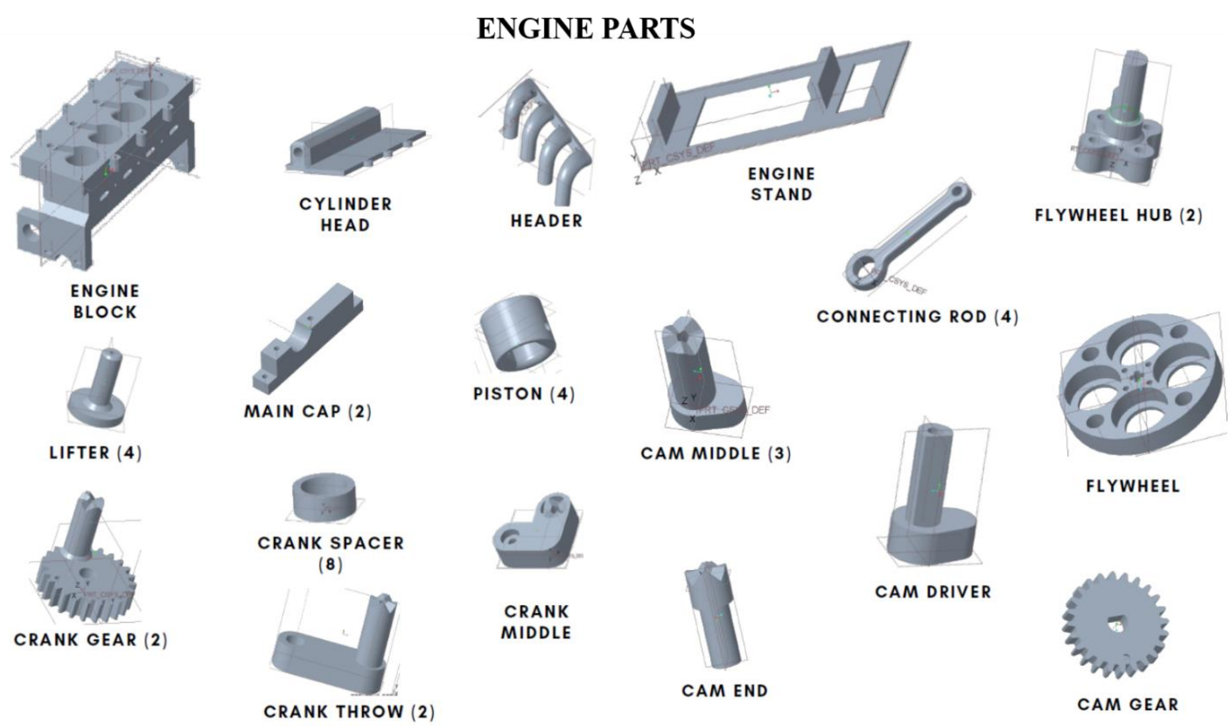

Figure 3: Summary of all 18 Engine Parts

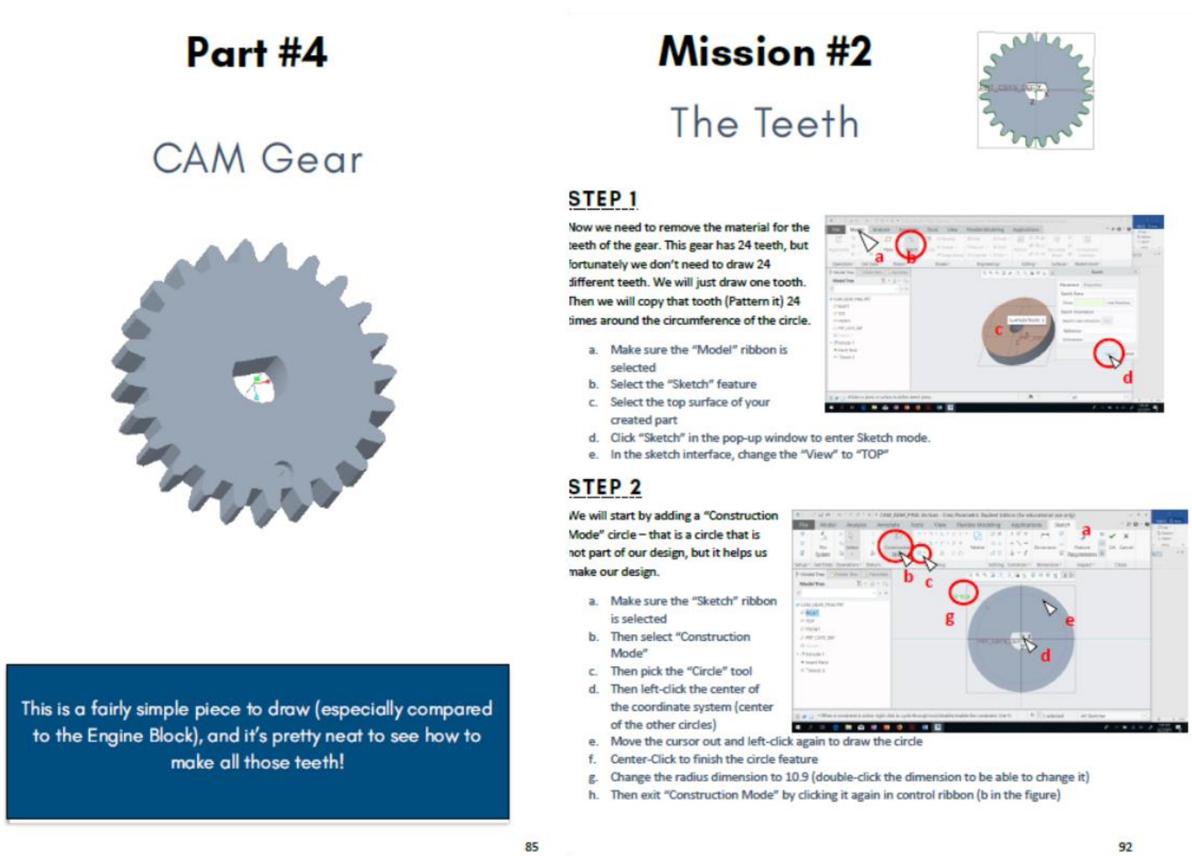

Figure 4: CAM Gear Tutorial Example

While we gave students a first introduction to 3D printing using Tinkercad – students designed and 3D printed their own name-tags to be used during the remainder of the camp week – students modelled all engine parts using PTC Creo. Having a full-day camp (8am-5pm) we limited engine modelling activities to approximately 2 hours in the morning and 2 hours in the afternoon during the first four camp days. The modelling of the parts was subdivided into smaller "Missions" that we demonstrated on the overhead projector and that students then followed by using the PDF tutorial while faculty and one student worker assisted the students. Using this teaching model, a few students completed all parts of the engine while the remaining students completed the majority of the engine models during the allotted time (unfinished parts were provided to the students for 3D printing). It was amazing to see how students with limited prior computer/design experience were able to learn how to model complex engine parts within the short timeframe of the camp. The students were persistent and learned to use a host of CAD features that included: sketching, extruding, chamfering, rounding, revolve, pattern, and sweep operations. Upon completion, the student-designed parts were 3D printed on the department's 4 Prusa MK3s printers (one with a multi-material unit – MMU2). Each student was able to customize their engine by choosing the colors in which their parts were printed.

While students assembled some parts of the engines throughout the week, we set aside the morning of the last camp day for engine assembly (Figure 5). Detailed instructions for the assembly were included in the tutorial. We found that while the assembly of the engines can be tricky at times – in particular the sanding of the pistons and engine block to ensure smooth movement, as well as the correct timing/alignment of the cam shaft and lifting rods – performing the assembly of the engines provided students with hands-on experience with all of the parts of a combustion engine. At the end of the week, all camp participants had functioning 4-cylinder air engines.

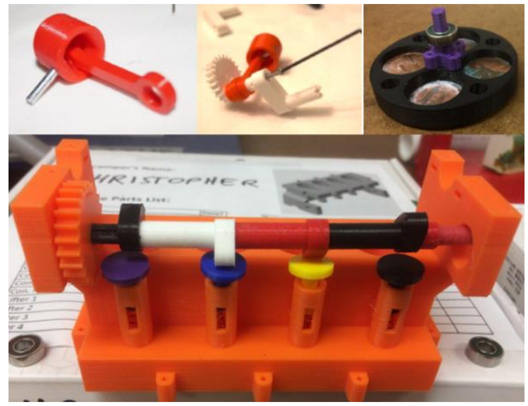

Figure 5: Engine Assembly

Engineering Summer Camp 2019 – Supporting Activities

In addition to the camp activities directly pertaining to the modelling and assembly of the 4-cylinder engine, we planned a multitude of supportive activities that either taught students additional details about engine design, exposed them to the many opportunities that a career in engineering provides, or introduced them to life on a college campus. Those activities were an integral part of the week long camp experience and are outlined here:

1. Campus Tour – Students went on a campus tour, including a tour of the student dorms to provide them with a glimpse of college life.
2. Cafeteria Lunch – Students had daily lunch in the campus cafeteria.
3. Engineering/3D Print Scavenger Hunt – To expose students to various aspects of our college campus as well as aspects of engineering, we designed an engineering-related scavenger hunt.
4. 3D Print Escape Room – We implemented a 3D Print Escape room[3] designed by Karissa Fast, a children's and teen librarian in Ontario.
5. Combustion Process Demonstration – For an impressive demonstration of the energy released during combustion processes, we visited the Chemistry Department and ignited hydrogen and hydrogen/oxygen balloons (see Figure 6).

Figure 6: Hydrogen Balloon Combustion

6. Toyota Bodine Presentation – Toyota Bodine is a subsidiary of Toyota that produces engine blocks in our city. Toyota provided us with an engine block to display for the duration of the summer camp and a representative from Toyota Bodine gave a presentation to students about how engines are manufactured in the plant.
7. Fun 3D Print Designs – In addition to the engines, students had opportunities to design and print fidget spinners, Christmas ornaments, and fun objects from Thingiverse.
8. LEGO brick egg challenge – Students were placed in teams and challenged to use LEGO bricks to design cars that could safely transport an egg down a ramp.
9. Open House – Students designed and built mechanisms to power with their engines and demonstrate their engines to family and friends during an end-of-week open house.

Materials and Resource Requirements

To design and construct the 3D printed 4-cylinder engines, the following minimum resources are required:

1. 3D printers and PLA filament
2. A computer lab (one computer per student)
3. Hardware (1 set per engine) – complete hardware kits can be purchased from Eli Smith, the student who originally designed the engine[4]
4. Precision screwdrivers, small files, pliers, super glue, and a compressor

Reflections

The response to the summer camp was overwhelmingly positive from both students and their parents. Unfortunately, we neglected to give camp participants a formal end-of-camp-survey and are thus unable to document/quantify those responses. However, given the good feedback received for the summer camp, we have started monthly themed 3D print nights for students 5^{th} – 12^{th} grade. Initially those nights were planned once a month but due to high demand, we have been offering two workshops each month, exposing 80+ different children to 3D printing, solid modeling with Tinkercad, and engineering at Union University during the fall 2019 semester. Further, we have expanded the summer program for 2020 and are currently planning 3 weeks of engineering related summer camps. This will include the one week 4-cylinder engine camp, a camp geared towards younger children (3^{rd} – 5^{th} grade), and a more advanced camp that will probably combine 3D printing and Arduino micro-controllers. Further, B. Pingen has developed a simplified version of the 4-cylinder engine camp as a Tinkercad Instructable for teachers[5]. The tutorial was awarded the "Judge's Prize" in a recent Instructables "Teacher Contest".

Overall, the camp was a great success, but it was also exhausting and the authors recommend the following improvements for future years. For the 2019 camp, we had 4 Prusa MK3s printers. In order to ensure that all 20 engines could be printed for the students, we pre-printed some parts and had to ensure that the printers were running around the clock, often requiring one of the authors to remain in the lab until after midnight. While we have since upgraded to 8 printers, we recommend a 2-to-1 student-to-printer ratio such that sufficient printer time is available. This would allow students to immediately set up their prints upon completing a part in PTC Creo, rather than having to place completed parts in a print que and having to wait until the following day to see their completed parts. Further, we had one student worker in addition to the two authors. We recommend having at least two student workers with one person designated for setting up and monitoring the prints with the students.

Conclusions

The authors have developed an engineering/3D printing camp for students from 6^{th} – 12^{th} grade. The camp introduces students to 3D printing while teaching them about internal combustion engines, having each camp attendee model, print, and assemble a 4-cylinder air engine. The camp was well received and has inspired other 3D printing related outreach activities at Union University. A simplified version of the camp project has been published as an Instructable[5], additional materials can be made available upon request.

References

1 Frank, Martin, Nicole Faber, Christina Roeckerath, and Sophia Wrede, "CAMMP", https://blog.rwth-aachen.de/cammp/info/, (accessed Dec. 2019).
2 Smith, Eli, "Working 4 Cylinder Air Engine Model", https://www.thingiverse.com/thing:3968961, Nov 2019 (accessed Dec. 2019).
3 Fast, Karissa, "3D Printing Escape Room at the Library", https://ontarianlibrarian.com/2018/07/31/3d-printing-escape-room-at-the-library/, 2018, (accessed Dec. 2019).
4 Smith, Eli, "Hardware Set for 4-Cylinder Engine", https://compressedcreations.bigcartel.com/product/hardware-set-for-4-cylinder-engine, (accessed Dec. 2019).
5 Pingen, Betsy, "3D Print Your Own Engine", https://www.instructables.com/id/3D-Print-Your-Own-Engine/, 2019 (accessed Dec. 2019).

Georg Pingen

Georg Pingen is a tenured Associate Professor of Engineering at Union University. He has been teaching mechanical engineering for more than ten years with a focus on thermal-fluid-sciences, mechanics of materials, and engineering design. Pingen co-leads a 5-12 grade outreach program, introducing kids to engineering through 3D printing. Technical research interests are in the area of topology optimization for fluid flows and computational engineering. Membership: American Society of Engineering Educators, American Society of Mechanical Engineers.

Betsy Pingen

Betsy Pingen is an Adjunct Instructor at Union University. She has been teaching K-12 children for 18 years in various capacities and co-leads a 5-12 grade outreach program, introducing kids to engineering through 3D printing.