Roll-The-Roller 3D Printing Design Contest: The Experience-based Summer Bridge Program to Improve the Success of Incoming Engineering Freshmen Students. (Work in Progress)

Dr. Hitesh D. Vora, Oklahoma State University

Dr. Hitesh D. Vora is an Assistant Professor in Mechanical Engineering Technology. He received his Ph.D. and Masters' from the University of North Texas in Materials Science & Engineering (in 2013) and Mechanical Engineering Technology (in 2008), respectively. Dr. Vora is a Director of the Industrial Assessment Center (IAC) at Oklahoma State University, which is funded by the US Department of Energy (DOE) for the year 2016-2021 with total funding of $1.8 million. For those not familiar, the Industrial Assessment Centers help small and medium-sized U.S. manufacturers to save energy, improve productivity, and reduce waste by providing no-cost technical assessments conducted by university-based teams of engineering students and faculty. He is actively teaching several courses and pursuing research in advanced (smart/cyber) manufacturing and energy management to improve energy efficiency (reduced energy, cost, and throughput) for small to medium-sized manufacturers. In addition, he is a Matrixed Professor in the ENDEAVOR Digital Manufacturing Maker Space located in the new ENDEAVOR building, which is a 72,000-square-foot and $30 million building. This maker space provides additive manufacturing support for design courses, laboratory courses, and entrepreneur initiatives. This facility houses several different technology 3D printers that capable of printing parts from polymers, fibers, composites, and metals as well as 3D scanning and subtractive manufacturing equipment. His research focuses on machining and manufacturing with a specific concentration on the use of additive manufacturing processes for advanced materials. He emphasis on design for additive manufacturing (DfAM), topology optimization, lightweight applications, and finite element analysis in additive manufacturing processes. Dr. Vora extensively teaches the additive manufacturing technology through the dedicated undergraduate (MET 4173) class as well as through the hands-on training sessions and certification (level 1 to 4) in the Endeavor Digital Manufacturing Maker Space.

Mr. Aaron Alexander, Oklahoma State University

Aaron Alexander is an Associate Professor in the Department of Mechanical Engineering Technology at Oklahoma State University. He received his BSE from Messiah College, his MSME from Purdue University, and his PhD from Oklahoma State University. Before entering academia he spent eleven years as an Acoustical/Noise Control Engineer in industry and still continues to consult in that field. His research interests are fluid flow, wind turbines, noise control, and computational fluid dynamics.

Dr. Ilchung Park, Oklahoma State University

Ilchung Park is an assistant professor in the Division of Engineering Technology at Oklahoma State University, Engineering North, Room 563, Stillwater, OK 74078; ilchung.park@okstate.edu.

Dr. Chulho Yang, Oklahoma State University

Professor Yang received a Ph.D. degree in Mechanical Engineering from Purdue University at West Lafayette, IN, USA as well as M.S. and B.S. degrees from Hanyang University in Korea. Before joining OSU in 2008, he acquired 11 years of industrial experience with ArvinMeritor technical center, IBM Korea, and KIA Motors R&D Center. Much of his work focused on structural design and optimization, vehicle NVH test, sensitivity analysis, structural health monitoring, human body protection, and design methodologies. He registered many patents in the USA, Europe, Japan, and Korea. He received an "Innovation and Achievement Award" from ArvinMeritor, Inc., a "Best Paper Award" from the International Symposium on Advanced Material and Mechanical Application, an "Outstanding Presenter Award" from the International Symposium on Green Manufacturing and Applications. He also served as a keynote speaker or a session chair for multiple international conferences.

Dr. Avimanyu Sahoo, Oklahoma State University

Avimanyu Sahoo received his Ph.D. and Masters degree in Electrical Engineering from Missouri University of Science and Technology, Rolla, MO, and Indian Institute of Technology, Varanasi, India, in 2015 and 2011, respectively. He is currently working as an Assistant Professor at the Division of Engineering Technology, Oklahoma State University, Stillwater, OK, USA. His teaching interests include mechatronics, control systems, electrical engineering. His current research interests include event sampled control, adaptive control, neural network control, networked control system, and optimal control.

Dr. Young Bae Chang P.E., Oklahoma State University

Dr. Young Chang is a Professor and the Head of the Division of Engineering Technology. Since 2000 he has taught Mechanical Engineering Technology courses, particularly on hydraulic, electrohydraulic, and pneumatic fluid power. Prior to 2000, he worked as an adjunct faculty and a research staff of the Web Handling Research Center, supported by a consortium of American companies. He previously worked at Korea Atomic Energy Research Institute characterizing flow-induced vibration and thermo-fluids problems of nuclear power plant components, mainly related to the safety of pressurized-water reactors.

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Abstract

College of Engineering, Architecture, and Technology (CEAT) at the Oklahoma State University (OSU) annually offers a 3-week high school-to-college transitional program called Summer Bridge for incoming engineering freshmen. The summer bridge program is a hands-on, experience-based learning program that gives engineering freshmen a good head-start to their college careers and greatly increases their likelihood of success. Various engineering departments actively participate in this program by offering a discipline-specific hands-on experimental or simulation-based design modules to provide exposure to engineering disciplines through active experiences. In this summer bridge program, the Mechanical Engineering Technology (MET) department of the Division of Engineering Technology (DET) offers a design module: Roll-The-Roller 3D Printing Design Contest. The is a six-hour-long event that is spread over three days with two-hour sessions each day. The objective of this design module is to provide an opportunity to study and expand the abilities of 3D design and manufacturing with experimental hand-on learning. The main goal is to design, print, and test a 3D-printed roller that rolls faster than the designs by the other competitors. Here, a 3D structure (roller) will be first conceptualized and designed with strict design constraints and tested on a ramp for maximum acceleration. To achieve this goal, the team will first start making the 3D roller physically by using modeling clay and/or 3D pens, then the finalized design translates into 3D CAD model for 3D printing. The team will learn the concept of physics, lightweight structures, and 3D printing through this exercise. This 3D printed roller will be later tested on a ramp for speed. The roller that completes the race first wins. In summary, this article shows a step-by-step procedure for creating an experience-based summer bridge program to improve the success of incoming engineering freshmen students.

Keywords:

Summer Bridge Program, Incoming Engineering Freshmen, 3D Printing

1. Background

The American Society for Engineering Education (ASEE) published a special education research project dedicated to retention related issues of engineering students in 2012 [1, 2]. This ASEE retention project collectively invited around 60 universities to share their perceptions on this topic and, specifically, asked for a focus on exploring the best practices and strategies for retaining students in Engineering, Engineering Technology and Computing programs [1, 2]. The main focus of this study is to find the reasons why 40 to 50% of engineering freshmen had either switched or withdrawn from the engineering major. The study indicated that it is mainly due to poor teaching and advising, difficulty of the engineering curriculum, and lack of "belonging" within engineering [2, 3]. Furthermore, these findings also linked this with the self-value and self-confidence of freshman students to accomplish satisfactory progress in engineering majors [2, 3]. To tackle these issues, the list of best practices and strategies from schools were collected under this ASEE "retention" project [2, 3]. This investigation categorized the findings and asked educators to focus on (i) student learning through tutoring/mentoring; (ii) student programs and financial aid; (iii) student academic enrichment programs; (iv) student research/work experience; (v) curriculum and class enhancements; (vi) institutional/educational research; and (vii) change in institutional/departmental policy [2, 3]. Specifically, this study recommends developing and implementing more focused freshman education on teaching mechanisms that emphasize providing extra help by tutoring at early stages as well as providing the extra academic enrichment methods through dedicated bridge programs for pre-college and/or pre-engineering freshman students [3].

In particular, several other researchers developed and implemented several teaching strategies through summer camps to effectively tackle these issues [4-12]. Davari et al. investigated and tested some strategies for recruiting and retention of science, technology, engineering, and math (STEM) majors [4]. Elam et al. advocated the engineering summer camp for underrepresented students from rural school districts [5]. Zhou et al. demonstrated through the intensive summer bridge program to condense the mathematics related gap for pre-engineering students [6]. Bottomley et al. demonstrated a strategic model for engineering summer programs to teachers and students [7]. The results were collected from the summer bridge programs offered for the last 20 years. Krapcho et al. showed the results based on the lessons learned by offering the engineering summer camps [8]. In addition, Kittur et al. provided a novel idea for a multi-disciplinary engineering summer research program for high school seniors. They showed the overview, usefulness, and possible outcomes of the summer camp [9]. In regard to pre-freshman, Glenn et al. demonstrated matriculation and summer bridge programs to improve the retention and graduation of minorities in engineering [10]. White et al. offered a summer bridge program with emphasizing the pre-freshman accelerated curriculum in engineering (PACE) [11]. Wischusen et al. shows the impact of a short pre-freshman summer program on retention [12]. In addition, Reisel et al. provided the possible assessment factors that can impact the success of incoming pre-freshman engineering students [13]. While, Kallison et al. showed the summer bridge program as an effective tool in enhancing college readiness [14].

In summary, short summer camps are one of the possible solutions to engage student at early stage of engineering education for incoming freshman students. In light of this, the College of Engineering, Architecture, and Technology (CEAT) at the Oklahoma State University (OSU) annually offered an intensive 3-week high school-to-college transitional program called the Summer Bridge program for incoming engineering freshmen. Hence, this paper will demonstrate the structure and projects of this Summer Bridge program on the sessions hosted by the Mechanical Engineering Technology (MET) department of Division of Engineering Technology (DET) at CEAT, OSU.

The Summer Bridge program is a full hands-on, experience-based learning program that gives the freshman engineering students a head starts to their college careers and greatly increases their likelihood for success. Various engineering departments actively participate in this program by offering discipline-specific hands-on experimental or simulation-based design modules to provide exposure to engineering disciplines through active experiences. Specifically, the Mechanical Engineering Technology (MET) department offered a design module called "Roll-The-Roller 3D Printing Design Contest" in the Summer Bridge program. This is a six-hour long session spread over three days with two-hour sessions each day.

The objective of this design module is to provide an opportunity to study and expand the abilities of 3D design and manufacturing with experimental hands-on learning. The main goal is to design, manufacture (through 3D printers), and test 3D-printed roller that travels faster than the competing designs. Here, a 3D structure (roller) will be first conceptualized and designed with strict design constraints and tested on a ramp for maximum acceleration. The roller design that completes the race first wins. To achieve this goal, the team will first start making the 3D roller physically by using modeling clay and/or 3D pens, then the finalized design translates into a CAD model for 3D printing. The team will learn the concept of physics, light weight structures, and 3D printing through this exercise. This 3D printed roller is then tested on a ramp for speed.

2. **Methodology**

Every year, different learning modules are offered by the various departments. Summer Bridge program coordinators schedule an event the day before the Summer Bridge program where all the offered modules are presented in front of the students. Later, students choose modules based on their interests and submit this information to the program coordinator.

In particular to the authors' design module, Roll-The-Roller is intended to provide the students with an opportunity to learn basic mechanical engineering concepts and expand their abilities in design and prototyping a roller with 3-D printing technology. The students are provided with hands-on experience involving design and manufacture of a 3D roller with their independent design ideas that can be tested on a ramp for maximum acceleration. The event is six hours long and spread over three days with a two-hour session each day. The general flow of this design module is as shown below in Figure 1.

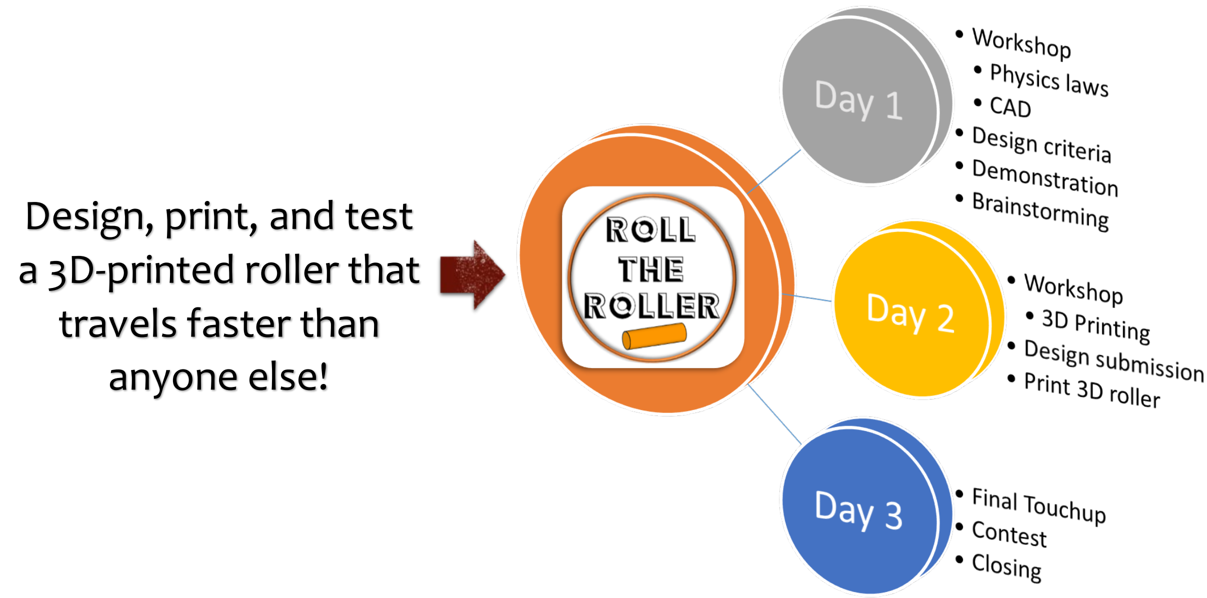

Figure 1: Flow diagram of Roll-The-Roller design module

2.1. Instruction and Calculations

The students enrolled in the summer bridge program come in with a wide range of engineering preparation. Some students have barely had any science or math classes in high school. Other students have had three years of pre-engineering instruction with preparation in CAD. In order to help all students and get the most out of the activities, several short lectures are given on 3D printing, CAD usage, and basic dynamics.

The basic dynamics is really the most important section to cover as it is the one area in which the students can't quickly get up to speed with pure experimentation. So, the lecture begins by defining the moment of inertia given by:

$$I = \int_m r^2 dm = \int_V r^2 \rho dV \qquad \textit{Eqn. (1)}$$

with a typical cylinder resulting in:

$$I = \frac{1}{2} mr^2 \qquad \textit{Eqn. (2)}$$

where ρ is the density, r is the radius, m is the mass, and V is the volume. The students are then shown a free body diagram (Figure 2) and the acceleration of the center of mass (a_{cm}) is developed per:

$$a_{cm} = \frac{g \sin \theta}{1 + \frac{I}{mr^2}} \qquad \textit{Eqn. (3)}$$

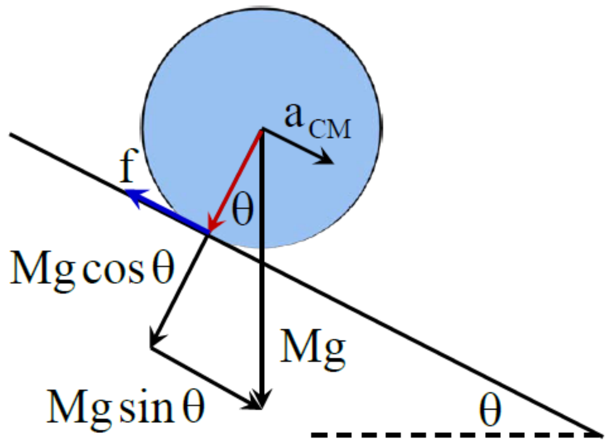

Figure 2: Free Body Diagram of the Roller

2.2. Program Schedule

The roll-the-roller design module is spread over three days according to the following schedule:

- **Day 1**: On the first day of meeting, all students participate in a faculty-led workshop to understand the various engineering concepts that are useful to succeed in this contest. Later, the team building activities are carried out. Each team then have brainstorming activities to conceptualize the design ideas and come up with some unique roller designs. Students need to hand over their hand-drawn design or design idea to the instructors before concluding Day 1.
- **Day 2**: During the second day, teams will translate hand-drawn designs into 3D CAD modeling. Each team must submit a final design drawing and 3D CAD model to start 3D printing. The 3D printing is started as soon as the design is submitted to instructors. In instances with especially complicated designs, the print will not be completed before the end of day 2. In this case, the printers are left running under the supervision of instructors or teaching assistants.
- **Day 3**: On the third day, the 3D printed structures (roller) are given back to the teams. All teams are now allowed to perform the final touchup on the rollers and get ready for the contest. Later, winners will be determined, and awards given to the winning team. During the closing meeting, faculty mentors explained the scientific reasons why the particular design won the contest so that students fundamentally understand the finding and take these key findings with them.

2.3 Program Rules

For the Roll-the-Roller design module, the following rules and specified:

- **Team formation**: Individual teams shall be composed of no more than five students including one team leader.

- **Design and fabrication of 3D structure (roller)**: The students are encouraged to solicit advice, instruction, and training from faculty and peers during the duration of the project. However, all work involved in design and fabrication of the 3D structure (roller) shall be done by the team members without assistance from any other parties. For the convenience of the students and time limitation, 3D printing will be carried out by student assistants, but design should be submitted before the deadline.
- **Unique design**: Each team must develop a unique design.
- **Geometric constraints**: The geometric constraints are normally varied in each summer program in order to generate unique designs. Usually, the outer diameter of the roller should not exceed 2-inches and its length is limited to 2-inches. However, the team can design any internal and external surfaces of the roller. The infill structure of the roller should be no more than 70%. Any deviation in geometric criteria will not be acceptable and may disqualify the team. A few examples of such rollers are shown in Figure 3. The infill structure of the roller should be no more than 70%. The faculty mentors and student assistants should guide the student to trigger the creative thinking process.

- *Figure 3: Examples of Potential Rollers (ref: Google images)*

- **Ramp specifications**: A predesigned ramp will be provided for the contest. General specifications of the ramp are shown in the Figure 4.

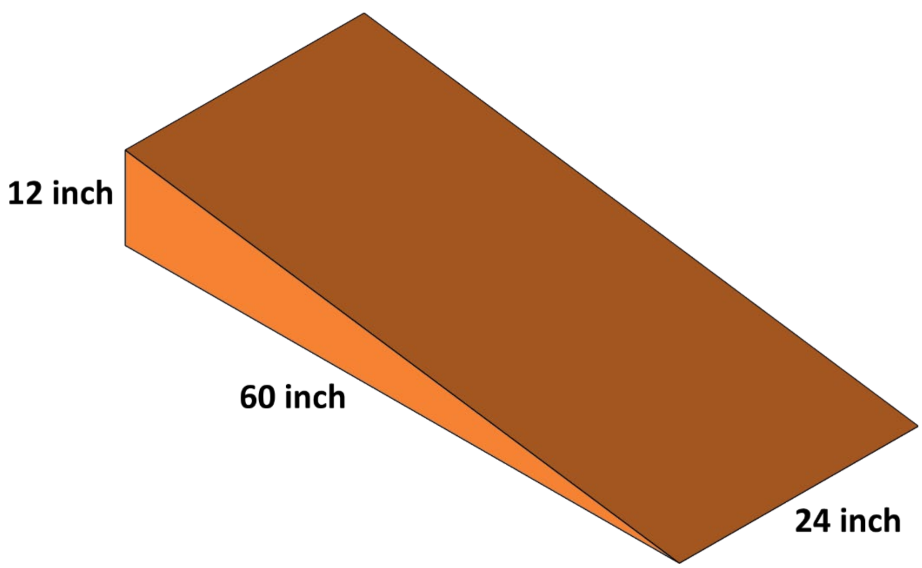

Figure 4: Typical Ramp Dimensions

2.4. Procedure and Evaluation Criteria of the Contest

All the 3D printed rollers will compete in the contest. The contest will be conducted based on the following procedure and criteria:

i. The 3D structure will be put on the ramp, the gate will be open, and clock will start. The one that completes the race first wins. The same structure will be tested three times and the average will be considered as the final time.
ii. The contest winner will be announced, and the first place, the second place, and the third place will be awarded.
iii. In the event of a tie, the team with the lighter structure wins.

The overall procedure is depicted in Figure 5.

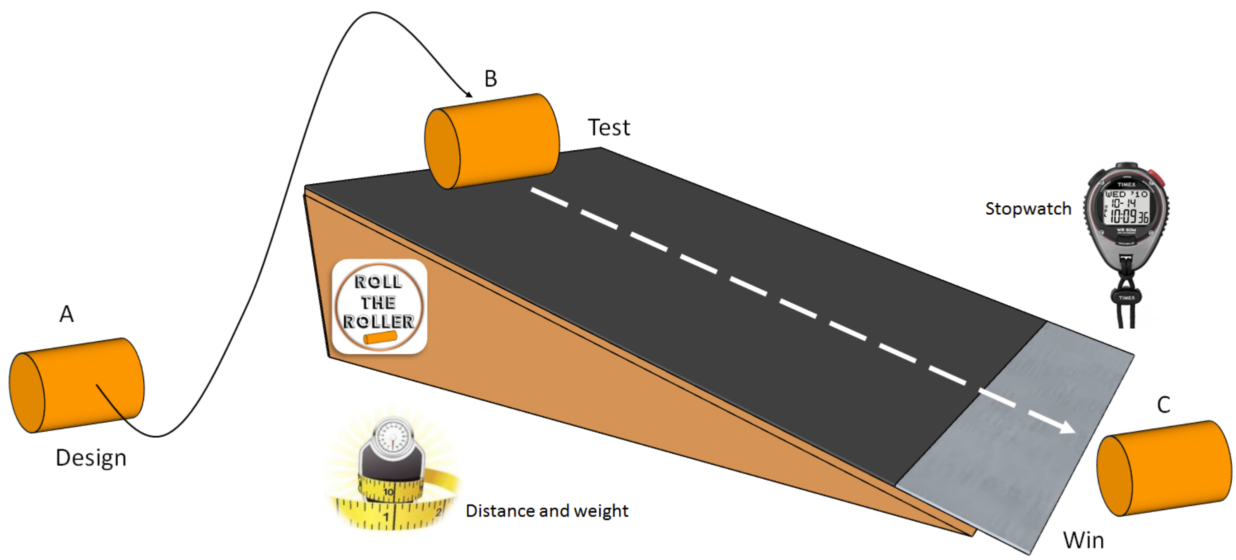

Figure 5: Ramp Set-up

3. Results & Discussion

Figure 6 shows students' conceptualized designs for the 2019 summer bridge program at the end of Day 1. The students were instructed on the use of engineering paper in order to give them a taste of "official" engineering work. Examples of the resultant 3D prints are shown in Figure 7. These prints are actual student results from the 2019 Summer Bridge program and demonstrate the diversity of possible design solutions. In different iterations to add more complicity to this design module, the contest has been conducted using either only the angled track (winner at the end of angled track) or also using a level track after the angle section (winner after the end of level track). The Figure 8 shows the finishing line for both the cases. Using only the angled track is a simpler arrangement as the performance is dominated by the mass and moment of inertia. Adding the level section results in issues where rollers may not track straight and reach the predetermined distance and time. Also, designs with a smaller moment of inertia, which was beneficial in the acceleration phase on the slope, can slow down faster due to the rolling resistance that now becomes a dominating factor.

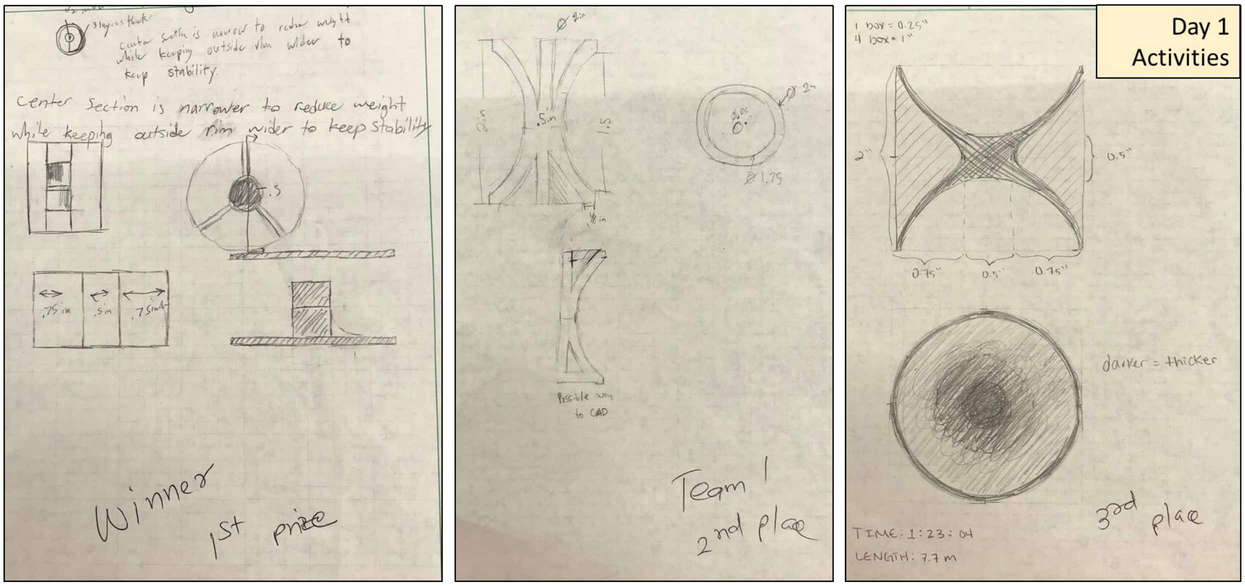

Figure 6: Day 1 activities – examples of design conceptualization

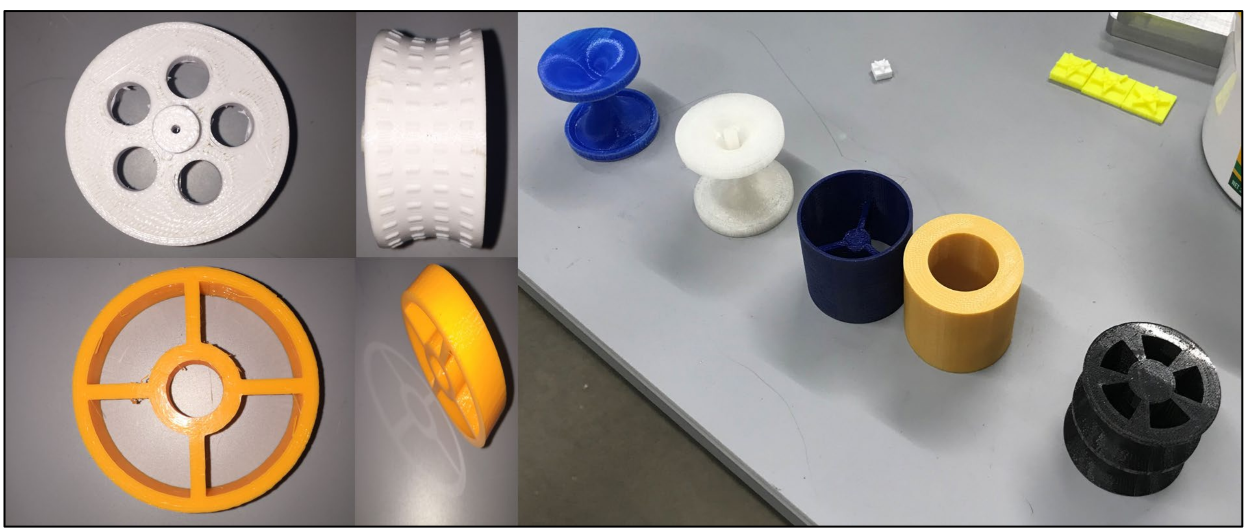

Figure 7: Day 2 activities – examples of 3D printed rollers

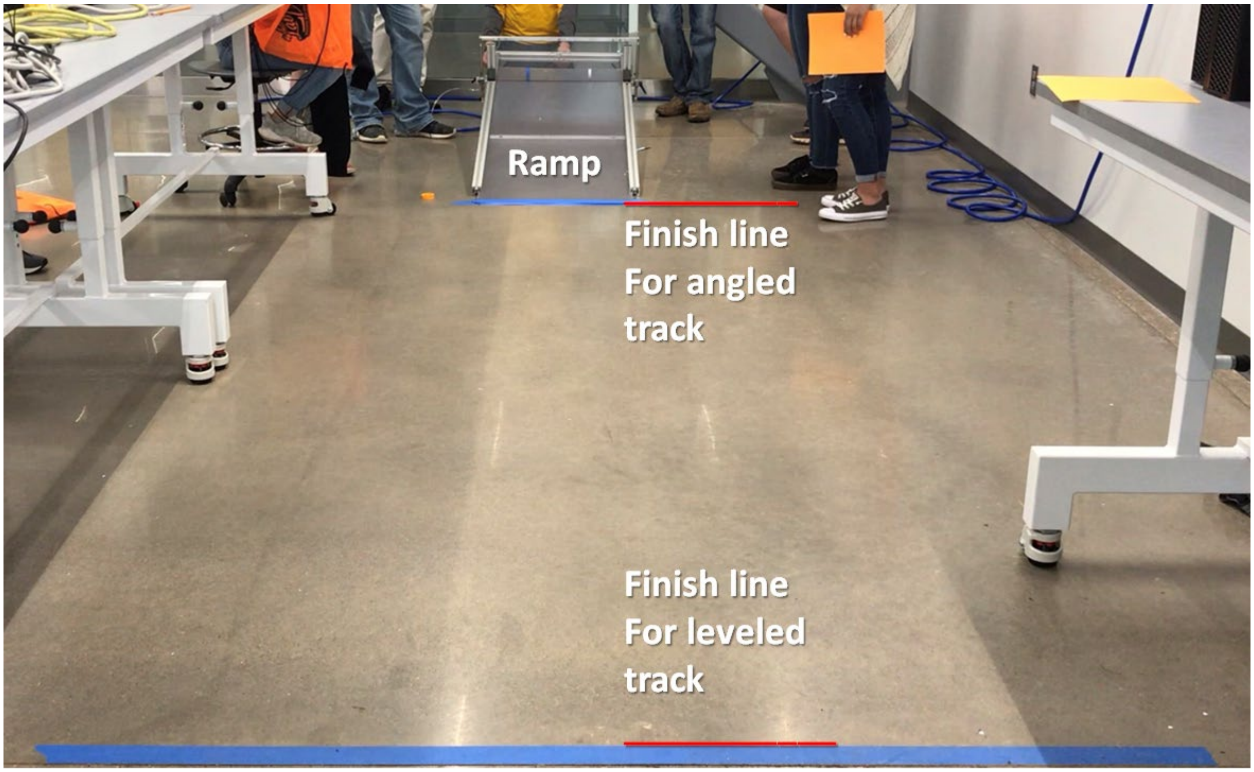

Figure 8: Day 3 activities – testing the roller designs through a contest

Although this paper has focused on project content, in future Summer Bridge iterations the authors and the Mechanical Engineering Technology department of College of Engineering, Architecture, and Technology (CEAT) at the Oklahoma State University (OSU) will be working together to establish measurables to determine the long term impact on student outcomes.

4. Future Project Improvements

The original implementation of this project focused on introducing the students to three main topics; the theory of the moment of inertia, use of CAD software, and 3D printing technologies. Initially, each of these topics have been treated separately with specialized lectures. Yet, there are some interesting synergies that could be utilized to help the students grow their understanding.

The first of these is the measurement and simulation capabilities of current CAD software. While the dependence of the roller acceleration on the moment of inertia is developed theoretically, the complex roller shapes the students develop do not lend themselves to an easy paper-and-pencil analysis. Additionally, for the type of students that the Mechanical Engineering Technology (MET) department of Division of Engineering Technology (DET) is trying to recruit, an example is often a more powerful teaching tool. So, the students' depth of understanding can be strengthened by conducting a CAD activity in which the students draw 3-5 given shapes and use the measurement tools to output the moment of inertia. They can then use the moment of inertia to calculate the theoretical acceleration of the object. This will give them solid numbers to help them see the consequences of changing the mass, radius, and moment of inertia.

As an extension to this improvement, many of the popular CAD packages now include dynamic simulation and Finite element analysis (FEA) capabilities. While asking the students to set these models up from scratch would be overwhelming, having simulations set up and ready to run with the students' custom designs would give them another connection between theory and performance. This gives them instant feedback on how design changes impact the performance of their roller allowing them to improve their designs over multiple generations.

One limitation of the current methodology is that little time is allotted for physical testing. This is partially due to the time it takes to print the rollers at the current size specifications. It would be worth considering a reduction in the size specification that would allow the students to print and test multiple design iterations. This would allow the facilitators to instruct the students on how to evaluate physical performance and of the importance of physical prototypes.

Finally, two topics of relevance are not currently discussed in the theory modules. These are the impacts of stability and resistance. Many of the designs the students produce are slower because they do not run in a true straight line. This issue is exacerbated when a level section is introduced to the course (Figure 8). Finding a way to cover a more advanced topic like stability would be beneficial. This could be covered in a simulation module or with physical demonstrations of instructor designed rollers. Having a level section of the track also shows the impact of rolling resistance. Once this is demonstrated to the students, a follow up lecture developing the dynamics equations with rolling resistance would help them to understand how models can evolve in complexity and accuracy.

5. Long Term Goals

The present summer bridge program was offered in last three summers and efforts were made to collect relevant data. The preliminary data have shown encouraging results but are insufficient until more students have matriculated through the program.

The long term goals are:

- Increase a reduction in the roller size specification that would allow to print and test multiple design iterations.
- Increase the scope of this program by providing more instructions on design, printing, and testing.
- Include the failure analysis topic using finite element modeling and simulations.
- Include the topic on dynamics and rolling resistance to provide more stability to the rollers.
- Provide early engagement of pre-engineering students to STEM related activities.
- Provide hands-on experience of STEM related activities.
- Developed critical thinking skills to solve complex engineering problem.
- Provide advice on choosing engineering as a career.
- Collaborate with OSU Institutional Research and Information Management (IRIM) department to collect the useful data for this project.

- Analyze the revised data from IRIM and draw the conclusion.
- Communicate findings and results to the educational research community to inform the lesson learned through activities.
- Connect the outcomes of this program to overall university goals.

6. Conclusion

This paper has focused on the structure and implementation of the Summer Bridge program. The Roll-The-Roller 3D printing design contest has been offered during Summer Bridge programs to pre-engineering students to provide opportunities for a hands-on experience with engineering. It also has allowed the students to study and expand their abilities while learning the important engineering concept of "design-to-manufacturing" with hands-on learning. The main goal has been to create a competitive structure where the concepts of design and manufacturing are challenged and later targeted towards functionality. Particularly, a 3D structure (roller) was conceptualized and designed with given design constraints. Students began by creating hand drawings before directly jumping to CAD modeling. Later, student learn how to convert conceptualized design into physical model, oftentimes initially with the modeling clay and 3D pens, then with a finalized design manufactured using a 3D printer. In addition, important aspects of additive manufacturing/3D printing (3D printing technology, CAD model requirements, slicing, machine codes) are explored through this design module. The preliminary data shows that the offered design module has found interest among the students. In addition, this design module has provided students with early engagement to engineering designs, CAD software, manufacturing methods, and prototyping. The idea here is to offer this module for several more years and trace the students from the pre-engineering curriculum (summer camp) until graduation while collecting the appropriate data. This will allow a thorough investigation to the effectiveness of the experience-based design module. The data collection process has just started but in the future more data will be collected link the findings with retention and attrition rate. In summary, this paper shows a step-by-step procedure for giving a practical demonstration experience-based summer bridge program to improve the success of incoming engineering freshmen students.

7. Acknowledgment

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