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Reverse Engineering an Engineering Design Challenge with Low-Cost 3D Printing

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Reverse Engineering an Engineering Design Challenge with Low-Cost 3D Printing

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Abstract

The influx of low-cost 3D printing systems has resulted in substantial adoption of the technology by many K-12 school systems. There are several reasons for this adoption including the opportunities to expose students to various engineering related activities and the development of skills such as computer-aided design, reverse engineering and prototyping. Yet, many area high schools lack access or training in 3D printing systems. Engineering Design Challenge (EDC) 2022: Eagle-3D is a novel engineering design competition based on 3D printing. The goal of Eagle-3D is to develop the engineering design capacity, 3D printing infrastructure, and technical knowledge of high school teachers and students. EDC 2022: Eagle-3D provided high school teams with a 3D printer kit, associated supplies, software resources and training to facilitate more engaging Engineering Design Challenge (EDC) competitions in the future. The challenge included a reverse-engineering activity using their 3D printer. This paper will discuss the development, implementation, and results of EDC 2022: Eagle-3D.

Keywords

3D printing, design, challenge, high school.

Introduction

The recent 3D Printing revolution has introduced several low-cost 3D printing systems [1]. Integrating low cost 3D printers into the K-12 curriculum is a simple way to teach the Next Generation Science Standards (NGSS) [2]. The subsequent advancements in open-source 3D printing software has also propagated this revolution in the availability of these systems to a larger audience. Many high schools have access to a 3D Printer and use it for projects or embed its utilization in their curriculum. However, teachers continue to lack adequate training in 3D printing systems [3].

There are several outreach activities that can be integrated with 3D modeling. For example, 3D modeling has been integrated with robotics and implemented in a one-week-long summer camp by a team at the University of California, Davis [4]. The student responses show that being able to not only design their product, but also 3D print it and use it boosted students' confidence. In another program, a two-week summer camp at North Carolina A&T State University, high school students were introduced to advanced manufacturing and 3D printing [5] [6] [7]. In the summer of 2019, a similar two-week summer camp was held at Southeastern Louisiana University where students were introduced to 3D printing and design activities [8]. Oklahoma State University offers a 3-week high school to college transitional program for incoming freshmen which culminates in a student team contest [9]. Students are introduced to CAD modeling, the engineering design process and 3D printing in this program.

This paper presents the most recent version of the Engineering Design Challenge (EDC) that has been held at the Armstrong campus of Georgia Southern University since 2014. The EDC is an engineering design competition where student teams at local high schools design and implement a solution to a given problem. The teams are mentored by Georgia Southern University engineering students and a STEM teacher from the school. The program culminates with a competition held at the Armstrong campus of Georgia Southern University. In 2020, the EDC 2020: Eagle ROAR (Remotely Operated Aerial Reconnaissance) was an engineering design competition that engaged high school students through the use of drones. The student teams were provided with a stock drone and had to use CAD software to design a 3D printable grappling system. These designs were submitted, and 3D printed at Georgia Southern University. This posed several challenges for the teams and for the project director: lack of compatibility, lack of proper communication, lack of completed parts and lack of timeliness. These challenges brought to light an existing problem within the infrastructure of local schools. Many schools did not have access to a 3D printer and many teachers were not trained in 3D printing systems. Hence, the EDC 2022: Eagle-3D was created. This program serves the dual purpose of exposing students to 3D printing systems and empowering local schools and teachers to develop these skills.

The next section presents further details about the Engineering Design Challenge (EDC), specifically EDC 2022: Eagle-3D. Also included are the Competition Results and Discussion, followed by Conclusion and Acknowledgements.

Design Challenge Overview

EDC 2022 was the 8th iteration of the Armstrong campus of Georgia Southern's high school design challenges. The last two challenges (2020 and 2021) were detailed in a prior paper [10]. The goal of EDC 2022: Eagle-3D was to develop the engineering design capacity, 3D printing infrastructure, and technical knowledge of high school teachers and students. The corresponding objectives were similar to the prior work [10]:

1. Engage participants in a hands-on engineering experience that leverages their prior STEM knowledge to develop a deeper understanding of STEM concepts applied to engineering design and 3D printing.

2. Increase the pipeline and diversity of students interested in STEM fields relevant to Georgia Southern University and NASA.

3. Enhance participant's soft skills applied to the presentation of technical content.

4. Leverage participation for the increase in the local community's awareness of NASA related topics and Georgia Southern University STEM education opportunities.

Six high school teams were provided with a 3D printer kit, associated supplies, software resources and training to participate in Eagle-3D. In addition to assembling their 3D printer, the teams had to create a How-To video about the assembly of the printer and perform a reverse-engineering challenge. The reverse-engineering challenge entailed each team selecting a device to dissect, creating CAD models of the device components, and finally creating a 3D printed version of the device. Each team was also mentored by a current Georgia Southern engineering

student. The Eagle-3D challenge culminated with teams presenting their work to create their reverse-engineered device.

EDC 2022 Details

The Ender 3 Pro 3D printer was selected for EDC 2022 based on its relatively low cost and prior use by other Georgia Southern faculty. The Ender 3 Pro kits required hardware assembly and configuration of the software. The How-To video was the first deliverable for EDC teams. The video requirement was intended to contribute to the 3D printing resources community while providing an opportunity for teams to showcase their technical presentation and video editing skills to a global audience. The video presentation documented how to load filament, upgrade the bed springs, manually leveling the print bed, and was required to be uploaded to YouTube for viewing by the public. The How-To video was evaluated based on the rubric shown in Table 1.

Table 1. How-To video presentation scoring rubric

Scoring Category	**Weight**
Content (Filament loading, Print bed spring upgrades, and Bed leveling)	15
Organization	5
Delivery	5
Total	**25**

An in-person team presentation and 3D printer showcase was the second deliverable for EDC 2022. The in-person presentations were evaluated based on the scoring rubric in Table 2. The required presentation details (PD 1-4) were:

1. Overview of how fused deposition modeling (FDM) 3D printers operate
2. How the 3D printer was customized
3. The CAD modeling process of the reverse-engineered device
4. Showcase images of the device parts printed.

Although nine high schools initially expressed interest in participating in EDC 2022, only six schools (23 students) fielded at least one team. Follow up discussions with the non-participating teams revealed that COVID-19 was still a factor for teachers. Each EDC team member was required to complete a pre-test to assess their baseline knowledge and experience with 3D printing. Twelve of the 23 students indicated they had used a 3D printer before. Each team was paired with a current Georgia Southern engineering undergraduate student serving as a project coach. The project coaches were recruited based on their performance in the Georgia Southern Engineering Graphics course. They were not required to have 3D printing experience although most had some general knowledge of the technology from the graphics course.

Table 2. In-person presentation scoring rubric

Evaluation Area	Weighting %
Content (PD1-4)	30
Complexity	10
Organization	10
Delivery	10
Total	**60**

The team demographics are detailed in Table 3. The teams had racial, gender, and Hispanic diversity levels consistent or exceeding the corresponding levels of ASEE 2021 Bachelor's degrees awarded[11].

Table 3. EDC team demographics.

Race	Percentage of Participants	Percentage of Participants	Ethnicity	Percentage of Participants
Preferred not to say	4.2%	4%	Hispanic or Latino	12.5%
Black	20.8%	21%	Not Hispanic or Latino	87.5%
Bi or multi-racial	8.3%	8%	**Total**	**100.0%**
Asian	16.7%	17%	**Gender**	
White	50.0%	50%	Female	33.3%
Total	**100.0%**	**100%**	Male	66.7%
			Total	**100.0%**

Competition Results and Discussion

All seven teams (one high school fielded two teams) successfully completed all the EDC deliverables. Awards were given for the Best How-To Video Presentation, Best Customization of the Ender 3D Printer, and the Overall Winner (based on a combination of the video presentation, customization, and In-person presentation). Figure 1 shows an example of a team's customization of their 3D printer, where they use their printer to fabricate components to improve the performance or appearance of their 3D printer. Figure 2 and Figure 3 illustrate examples of the reverse-engineered devices modeled by two other EDC 2022 teams.

The pre-test (mentioned earlier) was re-administered as a post-test with additional Likert scale self-reporting survey questions of all participants. Statistical analysis of the pre and post-test score data consisted of a Chi square analysis to compare the number of post-test score

improvements compared to decreases. The statistical significance was set at α=.05. Twenty-three of the 24 participating students completed the pre-test and post-test. The post-test score increase of 96% (n=22) compared to 4% (n=1) with no change in the post-test score was statistically significant ($\chi 2$=11.0, P=.00091). Of the 22 students with a post-test score increase, 87% (n=20) of them showed a ≥2 point improvement. The median test score change was 4.0.

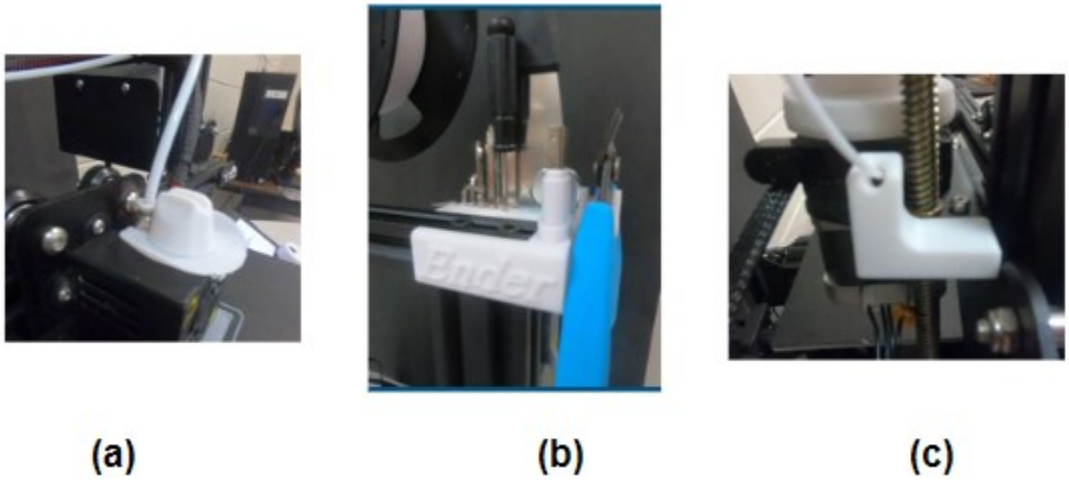

Figure 1. Example of 3D printer customization, (a) Extruder "cap", (b) tool holder, (c) filament guide.

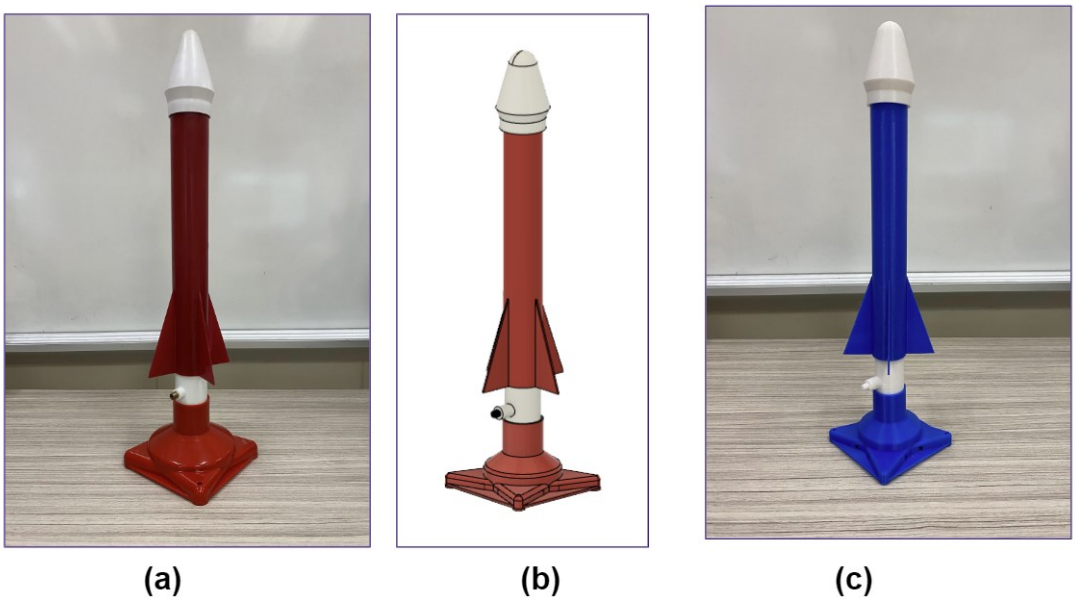

Figure 2. Reverse-engineering example, (a) actual model, (b) CAD model, (c) 3D printed model

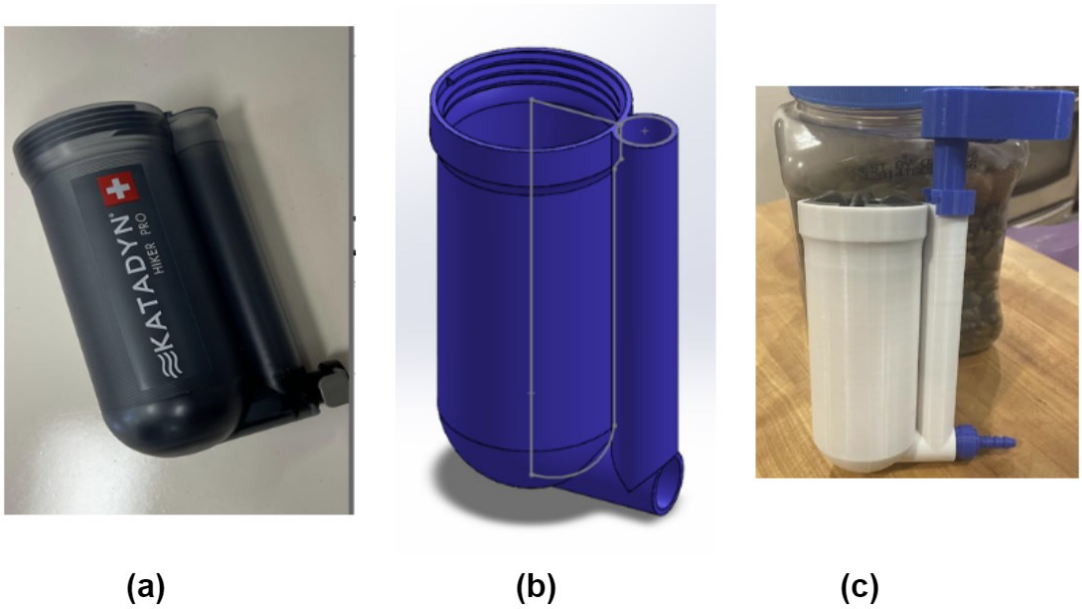

Figure 3. Reverse-engineering example, (a) actual model, (b) CAD model, (c) 3D printed model

Three Likert scale questions were presented to the participants in the post-test to assess their perceptions of EDC 2022's effectiveness. A Chi square analysis was conducted on the number of participants that either "Strongly Agreed" or "Agreed" compared to "Neutral", "Disagree" or "Strongly Disagree". The statistical significance was set at α=.05. The results of these questions and the P-values are shown in Table 4. The majority of participants felt EDC increased their desire to pursue a STEM career and their knowledge of 3D printing at a statistically significant level. This result, in addition to the pre-post test results support the project's goal of increasing the technical knowledge of the students. The results were mixed regarding the number of participants that would consider attending the Armstrong campus of Georgia Southern University as a result of the EDC; it was also not statistically significant. One possible remedy for this result is to include a tour of the campus and engineering facilities prior to or after the competition event.

Table 4. Self-reporting survey results for EDC 2022 students based on a Likert scale.

Question	SA	A	N	D	SD	Total	P-Value
My participation in EDC increased my desire to pursue a Science, Technology, Engineering or Math (STEM) career	58%	21%	21%	0%	0%	100%	0.0043
My participation in EDC increased my knowledge about 3D printing	67%	25%	0%	0%	8%	100%	0.000045
I am more likely to consider attending the Armstrong Georgia Southern campus for college based on my participation in EDC	13%	21%	54%	8%	4%	100%	0.102
Legend: SA: Strongly Agree, A:Agree, N:Neutral, D:Disagree, SD: Strongly Disagree							

The teacher participants were also surveyed at the end of the EDC program. Table 5 summarizes the survey question results. A Chi square analysis was conducted on the number of participants that either "Strongly Agreed" or "Agreed" compared to "Neutral", "Disagree" or "Strongly Disagree". The statistical significance was set at α=.05. The results of these questions and the P-values shown in Table 5 are consistent with the student results presented in Table 4. Additionally, one of the teachers commented that "…The reverse engineering project gave students the opportunity to put into practice the CAD skills they were learning in their Engineering Modeling and Design Course. The EDC was quite practical for the students planning to pursue engineering degrees, as the skills they learned and honed are ones they will need in the collegiate level coursework. I also appreciate the fact that each school gets something to keep and use - the 3D printer this year and the drone in past years. It really helps those of us who have a limited budget to conduct our engineering courses." Another teacher stated "This program greatly increased my knowledge of 3D printing hardware and software. We intend to begin integrating 3D printing into the Computer Programming pathway and extracurricular activities, so this was very helpful." The teacher survey results and comments further support the achievement of the project goals to improve the design capacity and technical knowledge of the student and teacher participants.

Table 5. Self-reporting survey results for EDC 2022 teachers based on a Likert scale.

Question	SA	A	N	D	SD	Total	P-Value
My participation in EDC increased my knowledge about 3D printing	40%	60%	0%	0%	0%	100%	0.025
My students' participation in EDC increased their desire to pursue a Science, Technology, Engineering or Math (STEM) career	40%	60%	0%	0%	0%	100%	0.025
I plan to use the Ender Pro 3D printer for future (non-EDC) activities with students	60%	20%	20%	0%	0%	100%	0.18
Legend: SA: Strongly Agree, A: Agree, N: Neutral, D: Disagree, SD: Strongly Disagree							

Conclusion

EDC 2022: Eagle-3D was successful in achieving its primary objective of developing an engaging engineering experience to increase participant's knowledge of 3D printing and the engineering design process. A statistically significant increase in the participant's pre/post-test scores was observed. This correlated with the self-reporting survey questions regarding participant's increased interest in pursuing a STEM career, design capacity, and their knowledge of 3D printing. The teams were also diverse in terms of their ethnic, racial and gender makeup. Generating participant's specific interest in attending the Armstrong campus of Georgia Southern

remains a limitation of the EDC, but enhancements such as the addition of campus tours could address this in future efforts.

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