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”Student Paper” Aerospace Ambassadors: The Impact of Undergraduate Engineering Outreach in Inspiring K-12 Students to Pursue Careers in STEM

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I am an undergraduate student at Penn State University pursuing a degree in Aerospace Engineering. Currently, I am collaborating with a team of fellow aerospace engineering students on various projects, while also engaging in outreach initiatives at local schools. Our primary objective is to inspire and motivate K-12 students to explore careers in STEM, fostering their interest in science, technology, engineering, and mathematics through hands-on activities and educational programs.

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I am a second-year undergraduate at Penn State University studying Aerospace Engineering. I am a member of many clubs, namely the Nittany Motorsports FSAE Team as well as the Wind Energy Club, but my main focus is on a Science Technology Engineering and Math (STEM) Outreach project. Which sees a group of students creating projects meant specifically for students to begin interest or further interest into STEM.

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Aerospace Ambassadors: The Impact of Undergraduate Engineering Outreach in Inspiring K-12 Students to Pursue Careers in STEM

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Abstract

Recently, there has been a growing need for individuals to enter careers in Science, Technology, Engineering, and Mathematics (STEM) career fields. To meet future demand for STEM workers, efforts must be made in the present to encourage individuals to enter careers in STEM. Often, the best time to educate individuals about STEM career paths is while they are still young and undecided about their plans. Outreach efforts that are oriented towards individuals at the K-12 level can be effective for encouraging participation in STEM careers.

This paper details the efforts of a group of undergraduate students from [Institution] to encourage K-12 learners to become interested in engineering. Specifically, the efforts outlined were designed to teach individuals about principals of vertical flight engineering. This paper discusses three unique projects which have been used to inspire an interest in engineering among K-12 students. The quantitative results of the educational effectiveness of the projects are outlined as well. The authors of this paper hope to inspire other student groups across the country to participate in similar activities.

The team of students, referred to as the Aerospace Ambassadors, broke into three groups to develop unique educational engagement methods. The first project to be initiated involves using custom built LEGO models to teach students about relevant vertical flight engineering topics such as, power transmission, structures, gearing, and controls.

The second project seeks to teach young students about the concept of autorotation through an engaging, hands-on demonstration using a Chinese Top toy. By incorporating physical demonstrations and simplified physics lessons, students can learn about the fundamentals of aerodynamics.

A third project was initiated to teach students about the NASA Dragonfly project and the unique challenges associated with designing a drone meant to fly outside of earth.

Thus far, the Aerospace Ambassadors team has participated in several outreach events. Students from 1st grade to 12th grade have learned from several members of the team about their projects. Each outreach visit included a presentation that complimented the physical models that the students were shown. On several visits, students also had opportunities for hands-on activities.

The scope and complexity of the presentations varied according to the age group of those listening. These efforts took place in a variety of settings, from controlled classroom spaces during the school year to STEM-oriented summer programs for K-12 students.

This paper outlines the educational effectiveness of the presentations that were delivered. Pre-validated survey instruments were used to measure a change in engineering interest and knowledge before and after the presentations were given. These allowed the project team to measure the educational impact of their presentations. Through these instruments, the team was able to identify a significant positive change in students' perceptions towards STEM careers and science lessons.

The overall goal of this paper is to inspire other undergraduate student groups at institutions across the country to develop engineering projects similar to those outlined. Undergraduate research teams from other universities can recreate the projects outlined or can seek to develop their own projects based on other engineering principles.

Introduction

Currently in the United States, STEM careers are a major driving force behind the economy. According to "STEM and the American Workforce," [1] over two in three American workers are supported by the STEM economy and the STEM sector overall is responsible for 69% of the American GDP. Individuals with STEM jobs account for 39% of the American workforce. STEM careers are vital for the sustainment of the American economy.

STEM careers are growing at an average rate of 10.5% per year which is above the national average according to the Bureau of Labor Statistics [2]. Given the above average rate of growth in STEM fields as well as the importance which STEM careers have within the American economy, efforts must be made to cultivate a diverse and enthusiastic next generation of STEM workers.

A study by MacDonald et al indicates that targeting the students at early ages is crucial to foster an interest in STEM [3]. Exposure to STEM can greatly help increase problem solving abilities according to the same article.

Our research group, “The Aerospace Ambassadors”, consists of nine members. Of the nine members, three are freshmen, four are sophomores, one is a junior and one is a senior. We have completed a variety of aerospace engineering projects thus far and are currently developing each of them further. These projects include teaching about aerodynamics through Chinese Tops, discussing NASA’s Dragonfly program with an emphasis on design constraints, and demonstrating the technical functionality and applications of vertical flight technology through custom LEGO models. Additionally, our team has been developing other projects to demonstrate additional aerospace engineering topics.

The goal of the Chinese Top project is to introduce engineering and physics concepts to children in a way that is engaging and tailored to their level of understanding. Using a Chinese Top and a fan, we can demonstrate lift by holding the blades at varying angles of attack. Applying this concept to real-world engineering problems, this demonstration conveys a myriad of engineering principles, with a focus on safety, problem-solving, and creativity.

Other members of the group have developed a project that is meant to convey the extreme conditions of Titan, Saturn’s largest moon, and the engineering that is involved in NASA’s Dragonfly mission. The Dragonfly mission and the rotorcraft are explained to the students during the beginning of the presentation. Through this presentation, students are introduced to the concept of engineering within design constraints through the Dragonfly mission.

Another project that has been initiated by a member on the research team involves using LEGO models to inspire young students to become engineers. These LEGO models are custom designed to teach about engineering principles such as power transmission, gearing, structures, and mechanical redundancy.

The team is currently developing two additional projects, one that seeks to demonstrate the vertical flight capabilities of the F-35 Lightning II, and another that utilizes a radio-controlled flight computer system to showcase principles of multi-rotor flight dynamics.

Thus far, the research group has participated in many outreach programs with different age groups. The ages of those the Aerospace Ambassadors presented to ranged from six to seventeen years old. Each event the team participated in focused on a different age group; therefore, the presentations and delivery methods were adjusted to fit the education level of the particular audience. Additionally, data about the effectiveness of the presentation methods was collected during one of the events.

Overall, the goal of our team is to inspire the engineering community to initiate similar efforts to those outlined. Our efforts have focused on the aerospace engineering discipline; however, other groups can choose to design projects based on other disciplines. This type of outreach is imperative to inspiring the next generation of engineers.

Literature Review

Outreach presentations play a vital role in shaping students' perceptions of STEM by bridging classroom concepts with real-world applications. They inspire confidence, demonstrate complex disciplines, and highlight diverse career opportunities. Research on precollege STEM programs showcases their ability to improve students' attitudes toward STEM fields through engaging and interactive activities [4]. Similarly, studies on secondary education outreach emphasize how such experiences motivate students and broaden their understanding of STEM pathways [5]. Programs like the Space Public Outreach Team show the value of using relatable role models to make technical topics accessible and inspiring [6]. These efforts collectively highlight the transformative power of outreach in encouraging students to explore and pursue careers in STEM.

Additionally, using LEGO in educational outreach activities is well documented in the literature. For example, LEGO bricks have been used to teach about engineering principles through the usage of LEGO Mindstorms. In one instance, Mindstorms products were used to teach fifth grade students about the concepts of gravity and mechanical advantage. A change in engineering interest was measured using pre and post surveys [7]. In another instance, a robotics camp run by Wichita State University gave students bricks to construct different robotic models such as animals, bridges, and vehicles. Students were then shown the relationship between the models they built and the real-life versions of what they sought to replicate. Through this project, students learned about the real-life versions of what they assembled in a more fun and interactive manner [8]. The team studied the effectiveness of previous outreach efforts and employed what they learned in their own endeavors.

Methodology

The Chinese Top project began in the spring of 2024, inspired by NASA's concept of using autorotation to land on Titan. What started as a class paper evolved into a long-term research mission dedicated to connecting physics concepts and engineering applications in a way that is engaging to young students.

After much research, it was time to determine a project, and we circled back to NASA's Dragonfly mission. Since a curiosity for innovative technologies and space exploration is often natural to young students, coupling a fascinating new spacecraft with simplified hands-on physics principles seemed like a natural progression.

Autorotation can be demonstrated using a Chinese Top and a fan. Chinese Tops originated in the Han Dynasty of China over 2000 years ago [9]. By holding the Chinese Top at varying angles of attack, we can demonstrate the effect it has in producing lift. Using a Chinese Top to simulate rotor blades and a fan to create airflow, we can bridge the connection between physics concepts and engineering applications. We teach that during flight, the pilot can adjust the collective pitch control to ensure the AOA (angle of attack) stays within the range that supports autorotation. If the AOA is too high, drag increases, and the rotor RPM drops; if it is too low, lift decreases, and the descent rate increases. While using the Chinese Top, the students can find and identify the critical angle for autorotation, one that provides the most lift with minimized drag, which often causes the Chinese Top to fly out of their grasp.

Figure 1. Image of Research Member with Chinese Top

Although these are concepts taught mainly in college-level aerospace engineering classes, the hands-on demonstration proved to significantly assist the students' understanding of lift and the importance of autorotation.

The Dragonfly Informational Project began in the fall of 2024 with the intent to educate students about NASA's Dragonfly mission and the qualities of Titan's environment. The project sought to teach about the unique constraints associated with flying a drone on another planet.

The original presentation explained the overview of the mission, a basic understanding of the rotorcraft itself, an explanation of why Dragonfly was going to Titan, and the three major characteristics of Titan's environment (extreme cold, thick atmosphere, decreased gravity).

However, it felt necessary to create visualizations for the students of these characteristics of the environment acting on the rotorcraft at a more technical level. This presentation was given to middle school students from 11-14 years old; therefore, the technicality of the presentation had to be at a basic level with useful information such as software and engineering-related equations. Basic engineering formulas, the lift equation and force due to gravity, were explained through the applications and math problems. According to the lift equation, we are able to demonstrate the utility of the thick atmosphere in providing lift to Dragonfly. Using the Dragonfly mission as context, we were better able to explain the mathematical concepts behind vertical flight. The LEGO outreach aspect of the project began in the fall of 2023. Thus far, LEGO models of coaxial and tiltrotor rotorcraft, the NASA Dragonfly drone, the Wisk Generation 6 aircraft, and the Kaman KARGO UAV have been designed and built by the research team.

Each model was first designed with the Bricklink Studio 2.0 software, which provides access to a virtual database of all LEGO pieces in existence. These pieces can be assembled by a user into a virtual 3D visualization of a model. Once the user designs a model, the software creates an instruction booklet that can be used to assemble the model that was designed. The parts for the model can be ordered online at the Bricklink marketplace.

First, two coaxial helicopter models were built to teach about the concepts of mechanical redundancy. Both models are identical, apart from one having a single LEGO motor and the other having two motors. When the single motor model is powered on, it can be made to stop spinning when its only motor is deactivated. If the dual motor version loses power to one of its motors, it still turns. Showing these models side-by-side can effectively demonstrate the safety benefits behind having multiple motors on a helicopter or any other aircraft. The tiltrotor aircraft also demonstrates the redundancy concept as both of its rotors can be spun even if only one of its two motors is not operational.

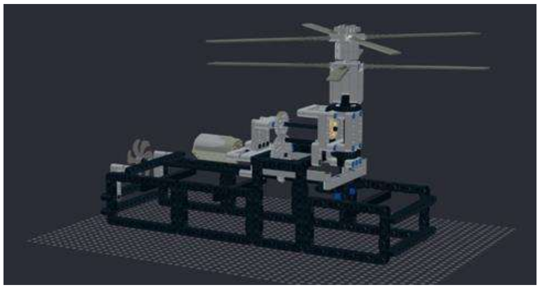

Figure 2. Bricklink Studio Version of Single-Motor Coaxial LEGO Model

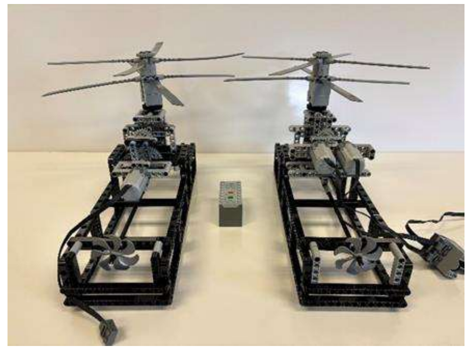

Figure 3. Physical Versions of Single and Dual-Motor Coaxial Lego Models

The other three models have been designed to showcase the exterior of the vehicles they replicate. They have been used to teach about the role that each of the aircraft types play in the modern aerospace world.

Figure 4. Bricklink Studio Version of Kaman KARGO LEGO Model

Figure 5. Physical Version of Wisk Generation 6 LEGO Model

Engagement Presentations

Our research group has participated in a total of seven outreach events to date. In total, we reached well over 100 K-12 students with our efforts. Our group presented in many classrooms, at a summer camp, and in an auditorium with the presentations in Appendix B. Each of these settings caused the research group to adjust their presentation to meet the environment and audience's level of understanding to maximize engagement. For example, the auditorium event was strictly a presentation, while the classrooms and summer camps included a presentation and a hands-on demonstration. At the summer camp, students were tasked with building a model

LEGO helicopter that effectively demonstrates helicopter gearing principles. In the classroom presentations, students interacted with the LEGO models and Chinese Tops.

Prior to the outreach events, members of the team were interested in increasing young students' engagement with STEM topics. To do so, the members applied their own engineering knowledge when designing their engagement methods. These methods were designed to provide a positive and engaging experience for all listeners. Additionally, the team did not undergo professional training; however, team members received the proper government clearances.

One of the presentations we gave involved the collection of survey data to quantifiably assess the effectiveness of our engagement method. This was done to verify the benefit of having undergraduate engineering students give an outreach presentation to young learners.

Our team gave classroom presentations at a middle school and two separate high schools. During these presentations, our team presented slideshows alongside physical LEGO models and Chinese Top toys. These small-scale events allowed the students to have hands-on interactions with the LEGO models and tops.

During the summer camp visit, our team presented to roughly 40 students under the age of ten. They were given LEGO kits to assemble which taught about helicopter gearing. Following the assembly activity, students were shown the pre-built LEGO models that demonstrated fundamental aerospace engineering principles.

The team also presented in an auditorium to groups of around 70 middle school students. The researchers presented from a stage, making it difficult for the students to directly interact with the LEGO models and Chinese Tops. However, removing the students from the classroom environment eliminated distractions and allowed them to stay focused on the presentation.

Overall, we found that the setting did not matter significantly, as students were engaged during each of the presentation formats. The content of the presentation was the same throughout and most important in determining audience interest. For example, the younger students were most enamored with the LEGO models whereas the older students were more focused on the career opportunities explained in other presentations.

Observations, Evidence and Discussion

After presenting to students ranging from 6 to 17 years old, the team observed that younger students had more interest in the subjects being taught when compared to their older peers.

Younger students generally asked a larger variety of in-depth questions than older students. Additionally, many younger students came up to researchers after the presentation to continue asking questions, seeking to deepen their understanding in the material being taught. (113 to pre, 59 to post)

At the visit where we presented to students in the auditorium, we used pre and post surveys to collect data about the effectiveness of our presentation. 113 students responded to the pre survey, while only 59 responded to the post survey, the drop likely due to not having a designated class period to complete the final survey. Proper IRB approval was obtained to collect such surveys, pre-validated by the paper "Evaluating a complex and sustained STEM engagement program through the lens of science capital: insights from Northeast England" [10].

Based on the survey data, we can conclude that our presentation was effective in generating interest in STEM. Figure 7 shows that students' opinions about STEM related careers improved following the presentation. The percentage of students who said that scientists have exciting jobs jumped from 45.1% to 59.3% between the pre and post surveys, showing a 14.2% increase in positive perceptions of STEM related careers.

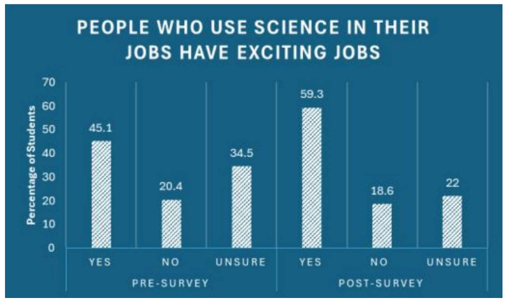

Figure 7. Pre and Post Survey Responses for Survey Question 1

Additionally, Figure 8 proves that our presentation increased students' interest in learning about science. In the pre-survey, only 33% of students indicated that they look forward to science lessons. Following the presentation, 50.8% of students said they look forward to science lessons. This 17.8% increase also proves that our presentation showed students that science lessons are interesting.

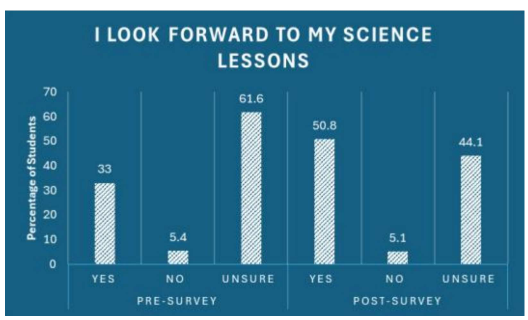

Figure 8. Pre and Post Survey Responses for Survey Question 2

Beyond these two questions, our other questions had less significant change in response between the pre and post surveys. However, the results generally indicated a more enthusiastic response to learning about STEM content.

The numerical data collected has minor discrepancies which could potentially lead to biased results. The reasons for these discrepancies include a potential lack of interest in the presentation, internet connectivity issues, a lack of time et cetera. Additionally, we were unable to ensure all students filled out the surveys in person. This resulted in a greater number of responses to the pre-survey relative to the post survey. However, upon review of the data, we believe the results indicate a level of acceptable accuracy.

Conclusion

In conclusion we can say that our methods of STEM outreach involving LEGO models and interactive workshops were successful in increasing interest in STEM fields. Younger students and those who directly engaged with the LEGO models showed an increased enthusiasm to learn about rotorcraft. This aligns with information which was gathered during our literature review. A significant challenge the research team faced was teaching complex topics to students with limited prior knowledge. The team learned that the children were able to understand more than was originally thought. This prompted the team to be unafraid to share more complicated topics with younger audiences. We believe that outreach efforts such as ours may be able to help students retain an interest in STEM fields as they progress to higher grades and beyond the K-12 system.

Future Research

Our primary focus moving forward is to inspire students to explore STEM fields, particularly engineering and aerospace, by engaging them in interactive and hands-on activities. By showcasing the excitement and creativity involved in engineering, we aim to spark curiosity and motivate students to consider STEM as a potential career path.

In the future, we will continue to develop other projects such as the F-35 Lightning II and multi-rotor radio-controlled flight collect data from outreach events and synthesize it to determine the effectiveness of our presentations. These insights will be shared with universities and educators worldwide to encourage the adoption of similar initiatives in their communities. By demonstrating measurable success, we hope to inspire other individuals to engage in outreach activities.

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Appendix A

The results of the pre and post surveys given to the students

Pre-Validated Pre-Survey and Post-Survey Responses						
	Pre-Survey			Post-Survey		
Question Asked	Yes (%)	No (%)	Unsure (%)	Yes (%)	No (%)	Unsure (%)
I like to learn about science outside of school	47.8	21.2	31	66.7	9.9	23.4
It is useful to know about science in my daily life	66.7	9.9	23.4	81.4	5.1	13.6
One or more of my parents/guardians think science is interesting	40.2	15.2	44.6	N/A	N/A	N/A
One or more of my parents/guardians have told me that science is useful for my future	43.2	31.5	25.2	N/A	N/A	N/A
One or more of my parents/guardians would be happy if I became a scientist in the future	33.0	9.8	57.1	N/A	N/A	N/A
One or more of my parents/guardians expect me to go to a university	63.4	15.2	21.4	N/A	N/A	N/A
I am good at science	46.4	23.2	30.4	52.5	11.8	35.6
If I study hard, I will do well in science	79.6	3.5	16.8	82.8	5.2	12.1
I look forward to my science lessons	45.1	20.4	34.5	59.3	18.6	22.0
We learn interesting things in science lessons	84.1	4.4	11.5	79.7	6.8	13.6
My teachers have told me that science is useful for my future	75.9	2.7	21.4	77.6	8.6	13.8
A science qualification can help you get many different types of jobs	72.6	1.8	25.7	83.1	13.6	3.4
People who use science in their jobs have exciting jobs	33.0	5.4	61.6	50.8	5.1	44.1

Appendix B

The folder filled with several presentations used during the various outreach events.

Aerospace Ambassadors