Building a 100% Online Aerospace Engineering Virtual Summer Camp for High School Students

Michael Hughes and Dr. Felix Ewere
Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27606

Abstract

Due to COVID-19, engineering summer camps offered by North Carolina State University (NCSU) shifted to a virtual format for the summer of 2021 and required a new curriculum to be designed with an emphasis on providing a hands-on experience in a virtual environment. The Department of Mechanical and Aerospace Engineering created a curriculum which included some hands-on activities used in previous, in-person camps, a homebuilt wind tunnel used to demonstrate aerospace fundamentals, and a popular engineering game used as a teaching tool to explain astronautics concepts. Each week-long camp was conducted via Zoom and led by a team consisting of a NCSU graduate student, three undergraduate students, and a faculty advisor. Anonymous student feedback following the completion of the camps showed overwhelmingly positive results with a majority of students showing interest in pursuing an engineering degree with multiple students expressing interest in attending NCSU.

Keywords

Online engineering camp, virtual camp, aerospace engineering, wind tunnel, Kerbal Space Program

Introduction

Distance education and the rise of the virtual classroom have been a topic of interest in recent years and the COVID-19 pandemic has underscored the importance of this field of education. Modern technology, including high-speed internet access, video calling software such as Microsoft Teams and Zoom, and learning platforms such as Moodle and Canvas, allow both students and teachers to experience distance education with increasing levels of participation. The College of Engineering at NCSU has a strong background in distance education. The Engineering Online program at NCSU, which began as the Video-Based Engineering Education (VBEE) program in 1985, offers Master's degrees in a variety of engineering disciplines. Despite the recent growth in distance education as a whole and the success of online graduate programs, such as those at NCSU, online engineering education at the secondary school level presents a variety of challenges.

Current in-person engineering programs at the secondary school level, such as Project Lead the Way (PLTW)[1], have shown great success among students, but include a high degree of hands-on and project-based curriculum. Studies have shown that younger students tend to benefit from one-on-one and peer instruction[2,3] and hands-on, project-based curriculum[4]. During the COVID-19 pandemic, schools who moved to a fully virtual model showed significantly less student involvement[5]. Coupled with the nature of engineering curriculum, which benefits greatly from tactile projects which encourage students to build and prototype, there are significant challenges in developing engineering curriculum for students at this level. Current strategies to improve student involvement, both for in-person and virtual instruction, encompass a wide array of techniques. The Flipped Classroom[6] has been shown to have considerable success at the undergraduate level[7]. Student involvement in the course material, beyond that of a numeric grade, has shown great success in improving the outcome of the course and the retention of information.

Prior to the COVID-19 pandemic, the Department of Mechanical and Aerospace Engineering (MAE) at NCSU conducted engineering summer camps through the Engineering Place, a department within the NCSU College of Engineering dedicated to exposing K-12 students to engineering through problem solving and hands-on learning. These camps, used to foster interest in engineering to students in both primary and secondary school, also showed success in attracting potential students to the College of Engineering at NCSU[8,9]. The MAE department's camp in past years included a week-long, on-site camp where students completed a wide range of engineering projects amongst NCSU's world class facilities. Students worked in groups to build gliders, rockets, and learn about more advanced topics such as aeroelasticity and supersonic flight. Following a year hiatus due to the pandemic, faculty and students in the NCSU MAE department developed an online camp for high school students which incorporated hands-on projects, small student-to-instructor ratios, and novel software applications. Due to restrictions on in-person gathering on NCSU campus and to prioritize the safety of staff and students, the Engineering Place decided to shift its focus to online camps for the summer of 2021. While virtual learning in and of itself present challenges, the hands-on nature of aerospace engineering topics adds an additional layer of complexity. The development of the curriculum used in the camp will be presented first, followed by the operation of the camp over Zoom, and finally the results of a self-assessed post camp survey will be presented in order to highlight the success of the program and encourage further exploration using similar methods.

Learning Objectives

In keeping with the in-person camps from previous years, the primary goal of the week-long, online camp was to introduce students to the field of aerospace engineering and foster interest in engineering programs at NCSU. For the in-person camps, the curriculum developers provided student attendees with several hands-on projects representing aerospace topics for both sensible atmosphere and spaceflight applications, as shown in Table 1. These projects were usually performed in groups or teams, with friendly competition between teams in certain events. In addition to the projects, current undergraduate and graduate students in the MAE department gave short lectures on topics including aeroelasticity, flight stability, supersonic flight, and aircraft and spacecraft propulsion. The combination of projects and short lectures exposed the students to a balanced learning environment that promoted academic learning as well as creativity.

Camp Modules

When planning the shift to a fully online camp, the authors wanted to preserve the balance of the past, in-person camps, while making the best use of technology available in the MAE department and what students had at their disposal. While some of the topic lectures used during the in-person camps required little or no modification for the online camp, most of the hands-on and interactive activities, such as model rocket builds or on-site wind tunnel testing, were not suitable for the distance education setting. One activity, the balsa wood glider build, was able to be carried over, but redesigned with modifications to make it suitable for distance education. In this activity students modified a commercial glider kit using information they learned in a flight stability lecture to achieve maximum distance and perform aerobatic maneuvers. Modifications to the gliders included, but were not limited to, adding winglets, changing the angle of attack of the wing through simple ailerons, changing the elevator angle, and increasing the planform area of the glider's wing. In order for the students to measure the distances of their glider flights, they made use of GPS tracking on their own smartphones through a variety of free apps available on phones running Android or iOS. Students without access to a smartphone were instructed on how to measure their average pace length, which they used to step off the number of paces of their glider flight and gain a reasonable estimate for the distance. Another activity was carried over with no modifications: a bridge-building activity in which the students constructed bridges made from paper straws to hold as much weight as possible. With only two short activities transferring between in-person and virtual camps, the development of two flagship projects for the online camp was undertaken by the authors: a small, homebuilt, subsonic wind tunnel students could use to run their own experiments and using Kerbal Space Program (KSP) to teach aeronautics and spaceflight topics in a creative, physics-based simulator.

Table 1. Aerospace topics covered during the week of camp.

Module	Learning Objectives	Hands-on Activities
Flight	**Introduce** students to aerodynamic concepts of **Lift** and **Drag**	Wind Tunnel Experiments Balsa Glider Flights
	Introduce students to aircraft **flight stability** and **control**	KSP Flight Stability Mission
	Students will be able to **visualize Lift forces** on an aerodynamic **structure**	Wind Tunnel Experiments
	Students will be able to **visualize** an **aero-elastic instability**	
Space	**Introduce** Students to simple **rocket design**	KSP Rocket Design
	Introduce students to the **orbits** and **spacecraft design**	KSP Moon Mission
	Students will **plan** and carry out a simple **space mission**	
Design	Students will be able to **design** a simple **engineering test**	Wind Tunnel Build
	Introduce students to simple mechanics and stresses on Truss members	Bridge Build

The subsonic wind tunnel project anchored the first half of the week of camp which focused primarily on aerodynamics topics. The wind tunnel was designed by students in the MAE department at NCSU and was centered around a test section sized for small foam gliders and paper airplanes. Additionally, minimizing material costs, ease of shipping, and creating an intuitive build for camp attendees were high priorities. Corrugated cardboard was chosen for the primary structure of the wind tunnel due to its low cost and weight and relatively high strength.

Additionally, corrugated cardboard can be easily cut using hand tools or by advanced manufacturing tools such as laser cutters. Using the MAE department's Universal Laser Systems VLS6.75 laser cutter, pieces for the main structure of the wind tunnel were precut and shipped to students prior to the start of camp along with additional supplies needed for the week. The completed tunnel, shown in Figure 1, consisted of a 12 in. long test section with a cross-section measuring 6 in. by 6 in., an inlet providing a 4-to-1 contraction ratio, and an outlet housing a commercially available, Honeywell HT-908, floor fan with a max flow rate of 230 CFM. The test section contained a small window made from transparent packing tape and an interchangeable insert allowing the students to attach a variety of testing apparatuses.

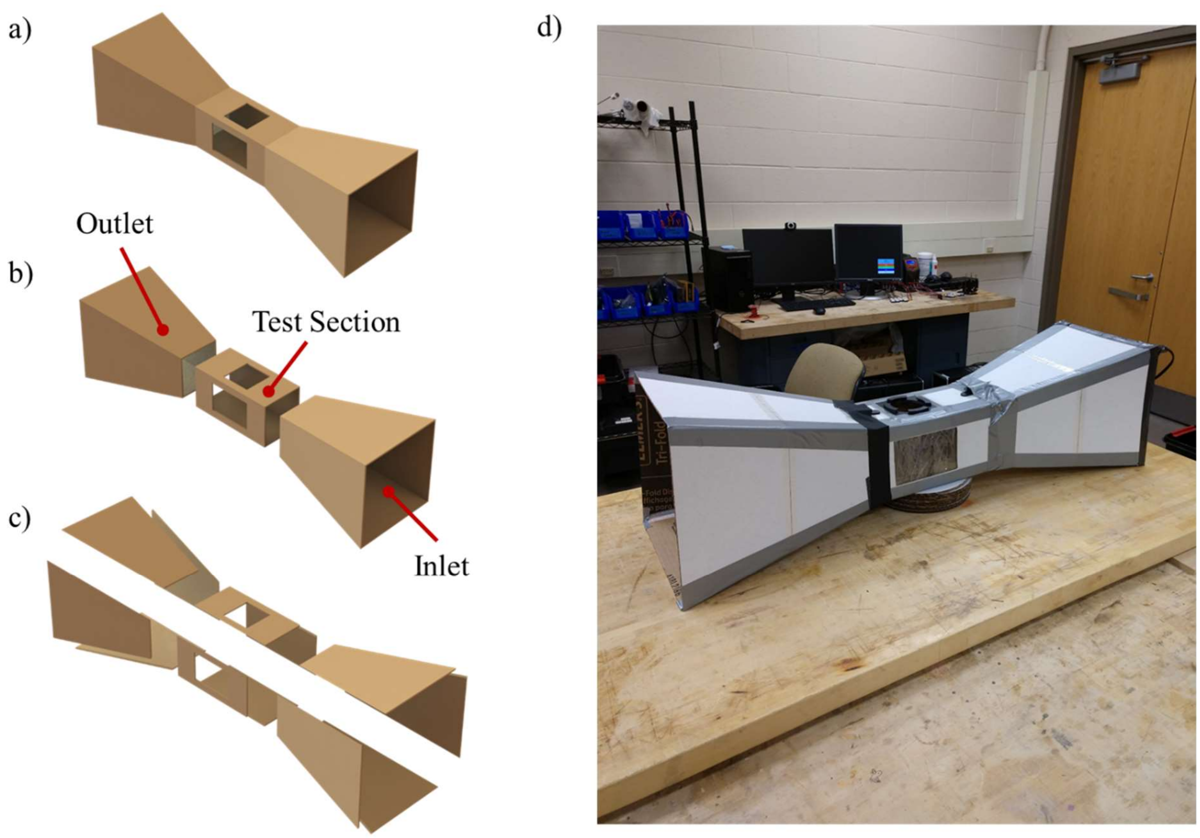


Figure 1. CAD mock-up of wind tunnel design showing a) the main structure, b) exploded view showing major sections, c) exploded view showing individual cardboard pieces, and d) the final prototype model used for demonstrations during camp.

During the course of the camp, students assembled their wind tunnels at home under guidance from the camp instructors. Once complete, three tests were performed in the tunnel. The first test required the students to use a small glider to demonstrate lift being generated in the wind tunnel. The second test required students to design a simple test mount allowing the glider to move with two degrees of freedom (DOF), with bonus points available if they could demonstrate three DOF. The final test consisted of the assembly of a basic aeroelastic system consisting of a rigid mount, aluminum beam, and a rectangular upstream bluff body. Once constructed, the students adjusted the mounting location of the aluminum beam and the orientation of the upstream bluff body to produce a galloping instability in the system, as shown in Figures 2 and 3.

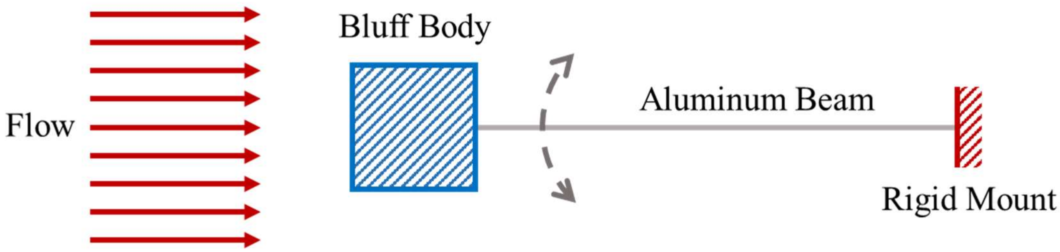


Figure 2. Top-down schematic of the aeroelasticity experimental setup used to demonstrate a galloping instability.

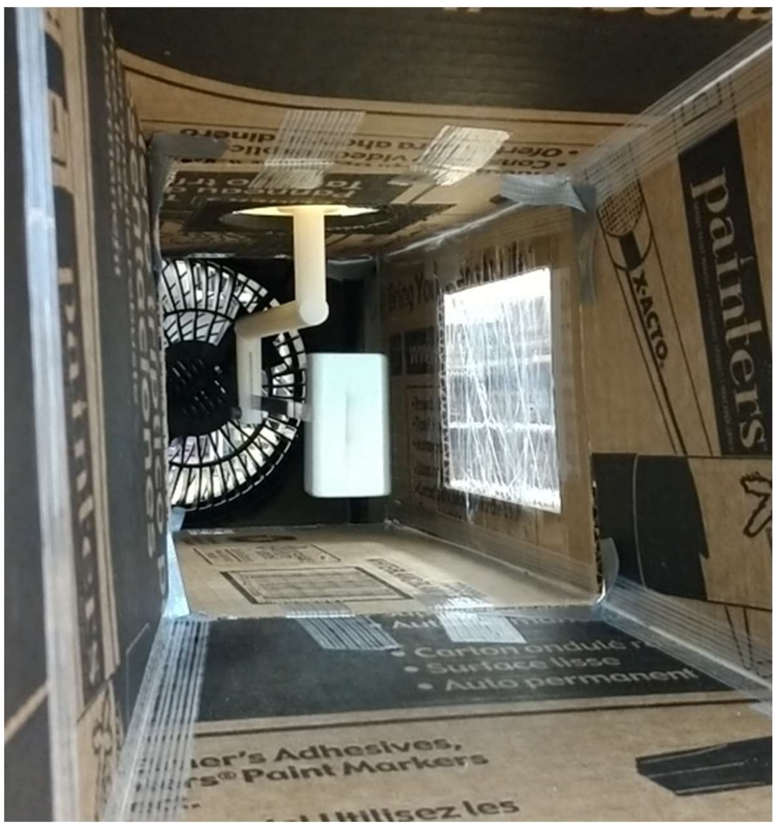


Figure 3. Internal view of the wind tunnel test section with the aeroelasticity experimental setup used to demonstrate a galloping instability.

The second half of the camp focused on space topics and was anchored by "mission assignments" given to students in Kerbal Space Program (KSP), a computer program that is part flight simulator, part video game. As shown in Figure 4, KSP allows users to design their own aircraft and spacecraft from a set of in-game parts which include crew capsule, fuel tanks, motors, and control surfaces. Once designed, users can fly their craft in a physics-based simulator to undertake missions in both atmospheric and spaceflight conditions. Prior to the start of camp, attendees were instructed to install the software on their home computers. During the course of the camp, students designed several vehicles to accomplish a variety of missions. Their first aircraft demonstrated their knowledge of flight stability, with a focus on correctly placing the center of lift and center of gravity on their vehicles. Later missions required students to complete suborbital and orbital flights, followed by an in-orbit docking and lunar exploration mission. Prior to each of the missions, students attended short lectures detailing the information they would need to complete the mission. Additionally, all the camp counselors were well versed in the software prior to the dates of camp and were able to offer assistance when needed. Some camp attendees had previous knowledge of KSP and also assisted their classmates on several occasions. Following the conclusion of the camps, each student retained their copy of KSP allowing them to continue learning about aviation and spaceflight beyond the scope of the camp. Some studies have shown KSP's affinity for educational use[10].

Camp Overview and Schedule

Following scheduling used in previous years, each camp was designed to run for one week, Monday morning through Friday afternoon, with each day consisting of morning and afternoon sessions with an hour-long lunchbreak in between. A faculty advisor in the MAE department oversaw the general camp operations, while three undergraduate students and a graduate student in the MAE department conducted day-to-day camp activities. All camp sessions were conducted over Zoom, and setup through the university's Zoom portal. All four camp counselors conducted the camps together from one lab on NCSU campus. This allowed for quick real-time communication between the counselors, efficient demonstration of camp projects and activities, and "two-deep" leadership accountability of all camp sessions and breakout rooms. Counselors kept their cameras on during the Zoom call unless they stepped away from their computers, while students were encouraged to keep their cameras on so they could show their work and ask questions when they ran into issues during the activities.

For each of the student projects throughout the week of camp, the students were separated into groups of 6, with each group being paired with a camp counselor. Each group was given their own Zoom breakout room where they collaborated on their projects. The groups were also randomized each day, allowing students to meet a larger number of fellow campers. Although the projects were designed to be completed individually, students were encouraged to share ideas and assist their teammates when they ran into an issue or needed to take a different approach. This encouraged collaboration between team members and exposed students to methods of thinking which differed from their own. To foster a sense of friendly competition, groups could also earn points by having all members complete the project quickly or performing outstanding achievements, such as having the longest flight distance during the balsa wood glider project. Input from the camp counselors and the lead counselor were also available to students at all times, but students were encouraged to help each other before reaching out to a counselor.

The morning session of the first day of camp was led by the faculty advisor who introduced the camp counselors and gave a short lecture about the MAE department and NCSU as a whole. This was followed by a series of real-time, virtual tours, during which the camp counselors logged into the Zoom call on their smartphones and walked around NCSU's Centennial Campus, focusing on the MAE department lab facilities, classrooms, and Hunt Library. Subsequent sessions throughout the week followed a more consistent structure, usually beginning with a short lecture covering an aerospace topic followed by a hands-on project or interactive activity.

The final day of camp also differed from the general format. In the morning, students were given the option to attend a variety of special topic lectures including general aerospace history and history of the Russian space program or spend time finishing up any projects from the week. Then students were tasked with creating a 5-minute presentation highlighting their favorite activities from the week and things they learned in camp. During the final afternoon session of the week, friends and family were invited to join the session while students gave their presentation about their week at camp. A full schedule of the camp topics and activities can be found in Table 2.

Table 2. Camp schedule overview detailing topics and activities to be performed.

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00 AM	Introductions	Bridge Building Activity	Propulsion Lecture	Rocketry Lecture	Optional Lecture
10:00 AM	Intro to Aerospace	Wind Tunnel Lecture	Glider Build	KSP Rocket Build	Student Presentation Prep
11:00 AM	Zoom Tours	Wind Tunnel Build	Glider Build	KSP Rocket Build	Student Presentation Prep
12:00 PM	Lunch	Lunch	Lunch	Lunch	Lunch
1:00 PM	Flight Stability Lecture	Wind Tunnel Build	Aeroelasticity Lecture	Orbital Mechanics Lecture	Student Presentations
2:00 PM	KSP Flight Stability	Wind Tunnel Build	Aeroelasticity Testing	KSP Moon Mission	Student Presentations
3:00 PM	KSP Flight Stability	Wind Tunnel Experiments	Aeroelasticity Testing	KSP Moon Mission	Closing

Post Camp Survey Results

At the conclusion of each camp, a short survey was sent out to the attendees. The survey focused on their experience as a whole, which activities they did and did not prefer, and whether or not they were likely to attend another virtual or in-person camp at NCSU again. Surveys were sent to the 54 campers which participated in the camps with a 67% response rate collected. Table 3 shows the survey questions of interest. 100% of respondents stated that they "Agreed" or "Strongly Agreed" with the statement, "I enjoyed my camp experience this summer." This is an increase from in-person camps held in 2019, wherein only 96% of campers who responded stated that they had a positive experience at camp. The campers were also asked to the question "What was your favorite camp activity". As shown in Figure 5, the survey showed that Kerbal Space Program was the most popular activity, followed closely by the wind tunnel build, and the glider project coming in third. When asked about their least favorite activities, several students replied that they did not have a least favorite, while others replied that their answer was only chosen because all of the other activities were more interesting. A few students struggled with KSP due to their lack of familiarity with video game controls used during the simulator portions of the game. The least popular activities overall were the bridge-building activity and the end-of-camp presentations given to friends and family.

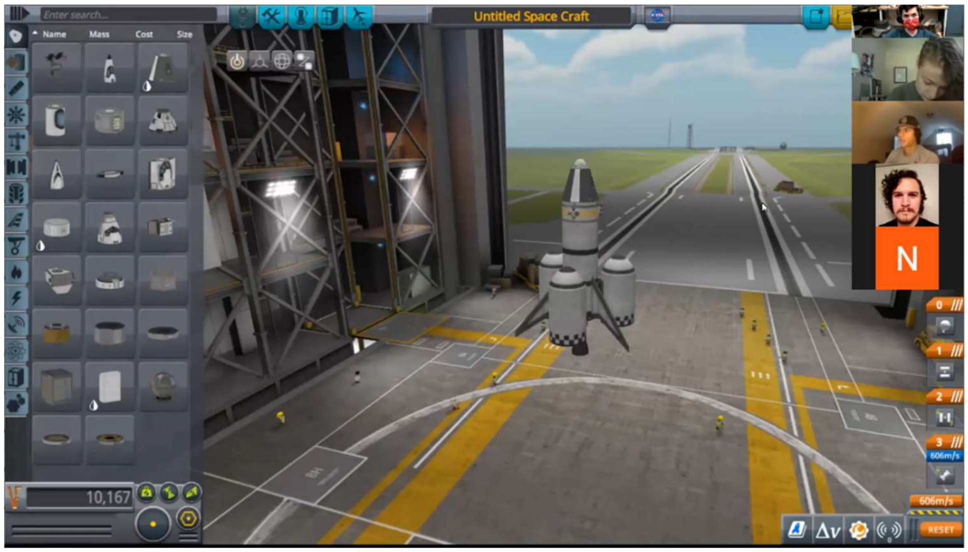


Figure 4. Example of a vehicle model in Kerbal Space Program.

Table 3: Survey Questions of Interest

Question:

[1] I enjoyed my camp experience this summer
[2] I want to come to NC State Engineering Camp next summer.
[3] I would want to attend a virtual camp again.

Responses:

Strongly Agreed, Agreed, Disagree, Strongly Disagree

As shown in Figure 6, all but one respondent said they would be interested in attending camp again at NCSU. When asked whether they would want to attend a virtual camp again, 72% of respondents said they would want to attend a virtual camp again. While this number is to be expected, students were queried about what improvements could be made to the camp in an effort to improve the retention rates for potential virtual camps in the future. One of the responses to the question simply stated, "Make it in person." Other responses included asking for more building activities, more short breaks between sessions, and more one-on-one assistance for difficult topics.

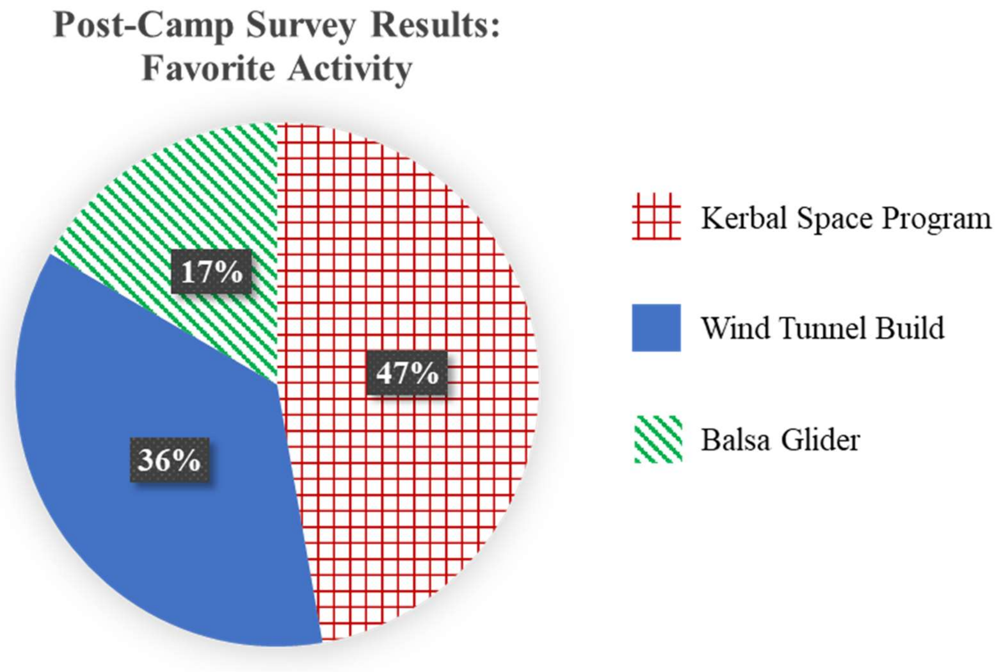
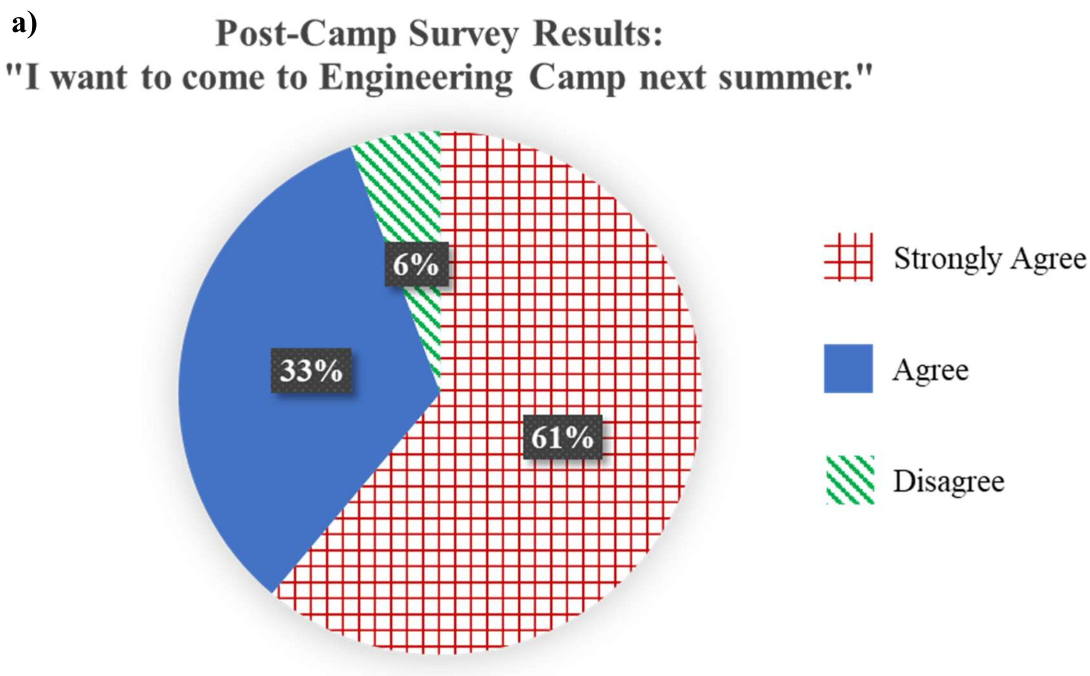


Figure 5. Favorite camp activities based on post-camp survey.

a)



b)

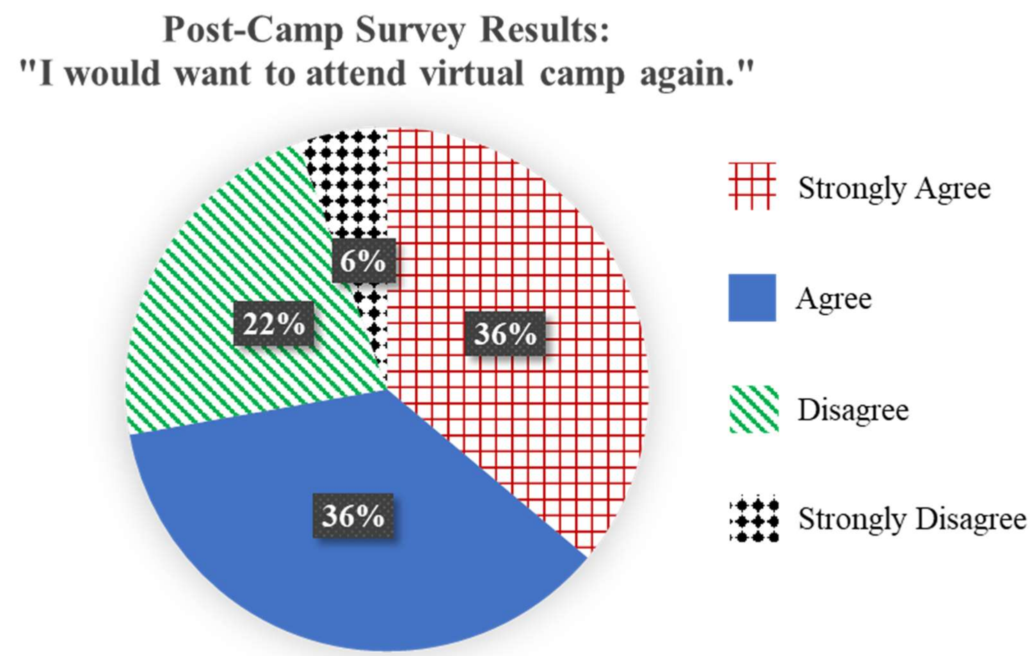


Figure 6. Survey response showing interest in a) attending another engineering camp in the future and b) attending another virtual camp on any topic.

Conclusions

The completely online camp developed by the authors show great success as a pilot program. In a time when virtual education is becoming more prevalent, producing high quality curriculum that engages students while providing high-level instruction is paramount. The focus on hands-on activities conducted via Zoom coupled with the creative use of software resulted in a successful engineering camp experience for all attendees. While there are aspects to improve upon, the details given here provide a strong framework which can be used to develop future online engineering camps for students in secondary education.

Acknowledgements

The authors would like to thank the National Science Foundation for its financial support of the students participating in this project under Award No. CMMI-2015983 which is managed by Dr. Robert Landers. The authors also express their gratitude to Dr. Laura Bottomley, Dr. Leah Bug, and Susan D'Amico of The Engineering Place for organizing all of the NCSU Engineering camps and their support during the development of this novel approach to engineering education. Additionally, the authors would like to thank Dr. Matthew Bryant and Dr. Ashok Gopalarathnam for their guidance and support of this endeavor. Finally, this work would not have been completed without the help of Zachary Boulton, Ethan Sites, and Ashwin Sivayogan, who lent their time and knowledge to this endeavor.

References

1 Lee, Yujin, et al. "Comparing mathematics and science achievement of students from schools with PLTW versus schools without PLTW." 2018 IEEE Frontiers in Education Conference (FIE). IEEE, 2018.

2 Crouch, Catherine H., et al. "Peer instruction: Engaging students one-on-one, all at once." Research-based reform of university physics 1.1 (2007): 40-95.

3 Grasha, Anthony F. "The dynamics of one-on-one teaching." College Teaching 50.4 (2002): 139-146.

4 Blumenfeld, Phyllis C., et al. "Motivating project-based learning: Sustaining the doing, supporting the learning." Educational psychologist 26.3-4 (1991): 369-398.

5 Catalano, Amy J., Bruce Torff, and Kevin S. Anderson. "Transitioning to online learning during the COVID-19 pandemic: differences in access and participation among students in disadvantaged school districts." The International Journal of Information and Learning Technology (2021).

6 Bishop, Jacob, and Matthew A. Verleger. "The flipped classroom: A survey of the research." 2013 ASEE Annual Conference & Exposition. 2013.

7 Howard, Anna KT. "Flipped Classroom–Ten Years Later." 2019 ASEE Annual Conference & Exposition. 2019.

8 Bottomley, Laura, et al. "Engineering summer programs: A strategic model." 2015 ASEE Annual Conference & Exposition. 2015.

9 Kendall, Amber LM, Laura Bottomley, and Susan Beth D'Amico. "A Study of the Attitudes and Practices of K-12 Classroom Teachers who Participated in Engineering Summer Camps (Evaluation)." 2018 ASEE Annual Conference & Exposition. 2018.

10 Mallory, Stephen. "To the Mun: Kerbal Space Program as Playful, Educational Experience." International Conference on Human-Computer Interaction. Springer, Cham, 2019.

Michael Hughes is a second-year PhD student in the MAE Department at NCSU. His current research involves experimental research on aeroelasticity and fluid-structure interaction. Prior to his time at NCSU, FirstName obtained at B.S. and M.S. in Mechanical Engineering from Baylor University where he studied aircraft ice accretion and completed two summer internships with the Icing Branch at NASA Glenn Research Center. FirstName worked as an engineering educator at the Perot Museum of Nature and Science and later taught PLTW Aerospace Engineering in Keller, TX before returning to graduate school at NCSU. Outside of school, FirstName enjoys playing disc golf and spending time with his wife, Elizabeth, and dog, Sokka.

Dr. Felix Ewere is a Teaching Assistant Professor in the Department of Mechanical and Aerospace Engineering at NCSU and Instructor of the Aerospace Engineering Capstone Senior Design course. Engineering research interests are in the science and technology at the intersection of aerodynamics, structural mechanics, energy and smart materials. Recent works have focused on exploiting aeroelastic instabilities on piezoelectric structures for engineering applications. Educational research interests include engineering design education, developing better-equipped graduates for the workforce, bridging the core competencies gap, improving diversity and collaboration within disciplines.