# Students in Engineering Design Process and Applied Research

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**Integrating Hands-on Activities with Drones to Engage High School Students in Engineering Design Process and Applied Research**


## Abstract

The overarching goal of Elizabeth City State University's (ECSU's) Drone Exploration Academy is to capitalize on the increasing popularity of unmanned aerial vehicles (UAVs), commonly known as Drones, to spark student interest and provide an experiential learning opportunity (ELO) in science, technology, engineering, and mathematics (STEM). Drones, which have become a popular recreational tool among youth, are ideal platforms with enormous scientific value for engaging students in hands-on, inquiry-based learning to develop science and math skills, thereby focusing on the importance of these skills to succeed in college. The Drone Exploration Academy curriculum included at its core the drone design and build, sensor/payload, programming, and piloting to conduct a field-based scientific investigation. The learning activities were carefully designed to meet the Next Generation Science Standards and the North Carolina Standard Course of Study for Science and Mathematics. The Drone Exploration Academy served eighty-three (83) high school students, with 59.04% Male and 40.96% Female participants. The participants received approximately forty (40) hours of hands-on STEM learning. Approximately, 60% of student participants were from underrepresented groups in STEM. Project evaluation data was gathered through Student Feedback Surveys, Dimensions of Success (DoS) Observation tool, and pre/post topic self-efficacy questionnaire.

## Introduction

By 2030, over 60% of all jobs will require postsecondary education [1]. While adopting the Common Core State Standards should lead to more college-ready students over time, students will still need programmatic support from secondary and postsecondary educational institutions to better prepare them for a successful transition to postsecondary education and career [2]. In addition, science, technology, engineering, and mathematics (STEM) jobs, especially engineering and technology, in the United States are expected to grow nearly twice as fast as other fields by 2024 [3]. An increasing number of jobs at all levels require knowledge of mathematics and science. Hence, STEM education is crucial to the ultimate success of our young people. Several reports have linked K-12 science and math education to continued economic growth in the United States. Unfortunately, there is a shortage of both interested and adequately prepared K-12 students, especially among minority youth and young women [1]. Students' K-12 experiences often do not prepare them adequately for postsecondary education and the world of work. Special attention should be paid to increasing the rigor, relevance, and engagement in the middle and high school curriculum.

Further, there are significant gaps in achievement between student population groups. The reasons are many, including lack of authentic learning activities, inadequate K-12 teacher preparation, especially in math and science content, poor alignment of K-12 and college curricula, and insufficient collaboration between K-12 and higher education institutions to smooth student transitions from high school to college [4][5]. These challenges coupled with issues such as the expectations gap and guidance gap become a major deterrent to improving achievement and attainment of postsecondary educational goals [6].

Engineering is a natural platform for the integration of STEM content into K-12 classrooms while sparking creativity amongst young minds. Research around effective learning in K-12 classrooms demonstrates that an engineering approach to identifying and solving problems is valuable across all disciplines. Incorporating mathematical and scientific fundamentals via engineering design-based methodology that infuses engineering habits of mind has proven to be a highly effective model for STEM education. A National Academy of Engineers report, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, suggests that the STEM disciplines not be treated as silos and that engineering might serve as a motivating context to integrate the four STEM disciplines [7].

The Next Generation Science Standards (NGSS), released in April 2013, were developed to help improve K-12 STEM education through actively engaging students in science and engineering practices while deepening their understanding of the core ideas and interrelationships in these fields over multiple years of exploration. These new academic standards at the state and national level call for integrating engineering design into the K-12 science curriculum [8]. This is accomplished by raising engineering design to the same level as scientific inquiry. As a result, engineering design experience is gradually becoming a vital component of K-12 education, especially at the high school level. The process of initiating and completing an engineering design project requires students to engage both in analytical reasoning, active creation, and testing of solutions. One must ensure that engineering design projects are engaging for all students, particularly those from demographics that are underserved, underperforming, or underrepresented in the STEM fields.

Research studies have shown that the out-of-school environment—after school and summer—advances science and math knowledge and increases interest in postsecondary education and careers [9],[10]. This summer and/or out-of-school math and science-focused programs combined with the 21st century learning environment are required to close the opportunity gap that prevents underrepresented youth from reaching their full potential in meeting college readiness requirements [11].

**Program Description**

The engineering-focused Drone Exploration Academy project is a partnership between an institution of higher learning, a federal agency, school districts, private foundations, and other STEM enrichment programs. The Drone Exploration Academy is offered as part of a comprehensive Student Science Enrichment Program (SSEP).

The overarching goal of the SSEP – Drone Exploration Academy project at ECSU is to capitalize on the increasing popularity of unmanned aerial vehicles (UAVs), commonly known as drones, to provide an experiential learning opportunity (ELO) in STEM. The informal learning environment will integrate modern educational technology tools and inquiry-based hands-on learning activities to reinforce science and mathematical concepts required to enter STEM careers, especially high-demand and emerging field of drone technology.

Students learned about potential college and career opportunities and why a background in advanced science and mathematics is crucial to achieving these careers. However, a balance must be met for providing a rigorous informal academic environment for the students while allowing them to enjoy the program's activities so that they will remember the experience positively and perhaps consider STEM-related degrees and careers. We met this challenge by supplementing classroom instruction with exposure to laboratory and field-based experiments, engineering design challenges, guest speakers, and field trips that exposed the students to a wide variety of topics and experiences in engineering and technology.

*<u>Program Delivery Model:</u>* The SSEP – Drone Exploration Academy project is designed to offer high school students an opportunity to learn challenging STEM concepts using drones. The program engaged 6-12th grade students from the 21-county region in activities developed around the ground and aerial drones offered during Friday sessions and an intensive weeklong Summer Academy. The three key components of the SSEP – Drone Academy project are:

1. Authentic STEM Experience – a suite of K-12 hands-on, inquiry-based STEM Curriculum Enhancement Activities (CEAs)
2. Drone Field Experience (DFE) – UAV mission planning, field investigation
3. Engineering Design Competition (EDC) – Designing ground and aerial vehicles to meet specifications

The academy provided students with an informal learning environment to engage in hands-on activities using drones as a platform. Laboratory and field-based activities integrated STEM concepts such as Science: *Bernoulli's Principle, Equilibrium, Aerodynamics, Lift, Drag, Acceleration, Momentum*; Technology and Engineering: *Virtual Reality Simulation, 3D Printing, Engineering Design Process, CAD, Electronics, Programming;* Math: *Pythagorean Theorem, formulas/equations for Lift, Drag, Acceleration, Weight and Balance*.

A total of 83 students participated in the Drone Academy. The outreach and intervention activities in this project targeted high school students, especially from the underrepresented backgrounds within the 21 county school districts, one of the most economically disadvantaged, underserved, and rural communities in the state and nation. The program offering was marketed to all the schools in the 21 county areas to develop ongoing school partnerships. Marketing materials created in the program development stage (Flyers, Emails, and Weblinks) were distributed to each district office and school in the targeted area. Additionally, project team members contacted STEM coordinators, distributed applications to guidance counselors and were available for questions.

The team members took time to explain the purpose of this endeavor, which was to engage high school students, particularly minority, female and disadvantaged youth, in inquiry-based, hands-on experience and encourage them to consider a STEM-related course of study in higher education and career pursuits. Applications were also made available online to download from the project website.

*<u>Project Goals and Objectives:</u>* The goals of Drone Exploration Academy project were as follows: (i) Goal 1 – improve students' competence in science, (ii) Goal 2 – nurturing students' enthusiasm for science, and (iii) Goal 3 – interesting students in research or other science-related careers. To the program goals, the project team: (i) engaged students in experiential learning opportunities and field-based scientific investigation, use of advanced technology, in a mentoring relationship with professionals working in the STEM fields; (Goals 2 & 3), (ii) engaged students in inquiry and project-based hands-on learning to show why science and math are necessary to obtain careers and succeed in science and engineering fields; (Goals 1 & 2), (iii) educated students utilizing a STEM curriculum that meets national and NC standards for science and mathematics; (Goals 1 & 3), (iv) promoted awareness of engineering-related careers and opportunities among K-12 educators, students, and parents and guidance counselors; (Goals 2 & 3), and (v) integrated computer technologies and simulation tools to develop 21$^{st}$ century skills and increase student interest in STEM disciplines (Goals 1 & 2). The three program goals and the summary of corresponding program activities to meet those goals are presented next.

*<u>Activities:</u>* Curriculum Enhancement Activities (CEAs) that were offered during the program were critical in achieving program goals. These authentic STEM experiences, which consisted of hands-on CEAs were complemented by guest speakers and field trips. All hands-on activities were conducted in a technology-rich learning environment. The three program goals and the associated activity description are presented next.

**<u>Goal 1:</u>** Improving students' competence in science

The CEAs that meet the Next Generation Science Standards and North Carolina Standard Course of Study for Science and Mathematics were at the core of improving students' competence in science. Students in high school grade levels were engaged in engineering design projects as the theme for Summer and Friday Academy. During Friday Academy, students were engaged in various hands-on activities including programming, electronics, robotics, and experiments with robotic sensors. Students were introduced to the engineering design process at the beginning of the session. During Summer Academy, students completed an engineering design project that included virtual design using CAD software and building a small UAV. Students were exposed to different sensors that can be mounted on drones for scientific investigation such as agriculture monitoring, wind turbine inspection, accident scene reconstruction, coastal monitoring, etc. High school students in Friday Academy completed their design project with a mobile robot with a plan to participate in a First Tech Challenge (FTC). These design competitions helped students appreciate science and technology in solving real-world problems. Students participated in multiple sessions aimed at increasing their knowledge of and competence in several areas of science specifically focused on engineering, computer science, environmental science, aviation, and technology. Other activities included sensor-based science experiments, hands-on demonstrations, and a review of science and mathematical concepts relevant to the topic. Where appropriate students conducted simulation before doing an actual experiment with the hardware.

**Goal 2:** Nurturing students' enthusiasm for science

The activities described above under Goal 1 also aimed to nurture the SSEP – Drone Exploration Academy students' enthusiasm for science; all the sessions provided interactive components through virtual simulation that sought to excite the participants about design possibilities and engage students in building skills which were transferable to the real world. Instructors conducted demonstrations to explain difficult concepts. ECSU's drone lab manager and certified drone pilot brought several fixed-wing and rotary drones and demonstrated their aerodynamics principles. He also presented the various civilian applications of drones. Students were informed about more than 300 applications where drones can be used. Students' interaction with the drone professional generated a lot of interest among students to learn more about the science and engineering behind UAV operation. This enthusiasm was further reinforced by students building small quadcopter UAVs and competing to see which design could be more easily controlled better. Students were also exposed to regulations and laws that govern the use of drones for scientific research. Another demonstration included programming drones that can maneuver through small spaces in an indoor setting. Students used a mobile app to control the drone and participated in an obstacle course competition to test their proficiency in controlling the aerial vehicle. Mentors were available to assist project teams when needed. Being part of a project group was instrumental in keeping students' enthusiasm for activity at a higher level.

**Goal 3:** Interesting students in research or other science-related careers

Students were encouraged to engage in self-directed inquiry when refining their project designs to meet the specifications. Students maintained a record of their incremental designs and changes made to improve the output. All activities were recorded in the engineering notebooks. During the program offering, the students got the opportunity to listen and interact with various professionals. Guest speakers included a law enforcement drone pilot, an aeronautical engineer, the CEO of a drone company, and engineers at a local aerostat blimp manufacturer. The program opening included a demonstration with ECSU's inventory of research and commercial-grade drones. In addition, drone operators from Elizabeth City Police Department joined to demonstrate how they use drones for their law enforcement work. The guest speakers discussed their experiences, how they prepared for their careers, and why knowledge of STEM was necessary to address the challenges in science and engineering fields. Participants also had numerous opportunities to meet with undergraduate students and other professionals during field trips, which included ECSU faculty researchers and lab technologists, and discuss with those professionals their careers and the steps required for said career. The field trips afforded students an opportunity to see large airplanes, helicopters and aerostats as well as interact with pilots, technicians, managers, and engineers.

## Program Evaluation and Results

*Drone Academy Participants Demographics*
The student application form was used to collect participant grade level, gender, county, and ethnicity. Table 1 presents the distribution of project participants by grade level.

Table 1: Percentage of participants by grade level

| **Grade Level** | **# of Participants** | **% of Total Participants** |
|---|---|---|
| 9th grade | 21 | 6.02% |
| 10th grade | 31 | 13.25% |
| 11th grade | 17 | 9.64% |
| 12th grade | 14 | 10.84% |
| Total | 83 | 100% |

Table 2: Percentage of participants by gender

| **Gender** | **# of Participants** | **% of Total Participants** |
|---|---|---|
| Female | 34 | 40.96% |
| Male | 49 | 59.04% |
| Total | 83 | 100% |

As shown in Table 2, 40.96% of the participants were female and 59.04% were male as seen in Table 2. The summer drone academy has set a target of at least 40% female participation which as shown in Table 2 was met.
The breakdown of participants by racial ethnicity is presented in Table 3. As shown in Table 3 over 55% of participants came from underserved/underrepresented groups.

Table 3: Percentage of SSEP participants by ethnicity

| Ethnicity | # of Participants | % of Total Participants |
|---|---|---|
| Asian/Pacific Islander | 3 | 3.61% |
| Bi or Multi-racial | 6 | 7.23% |
| Black | 38 | 45.78% |
| Hispanic/Latino | 2 | 2.41% |
| Native American | 2 | 2.41% |
| White | 32 | 38.55% |
| Total | 83 | 100% |

*<u>Evaluation Instruments:</u>*

Data collection instruments that were used for conducting evaluation included the Student Feedback Survey, Dimensions of Success (DoS) observation tool, and pre/post STEM topic questionnaire.

*Student Feedback Survey:* This survey was completed by student participants after completing at least 36hrs of hands-on learning. The survey was used to assess the overall interest in pursuing STEM degrees and careers. ECSU Summer Academy program adopted (and modified) a post only survey originally developed by The Program Evaluation Group for Science enrichment programs.

The data tables and corresponding graphs generated from responses to the Student Feedback Survey are presented next.

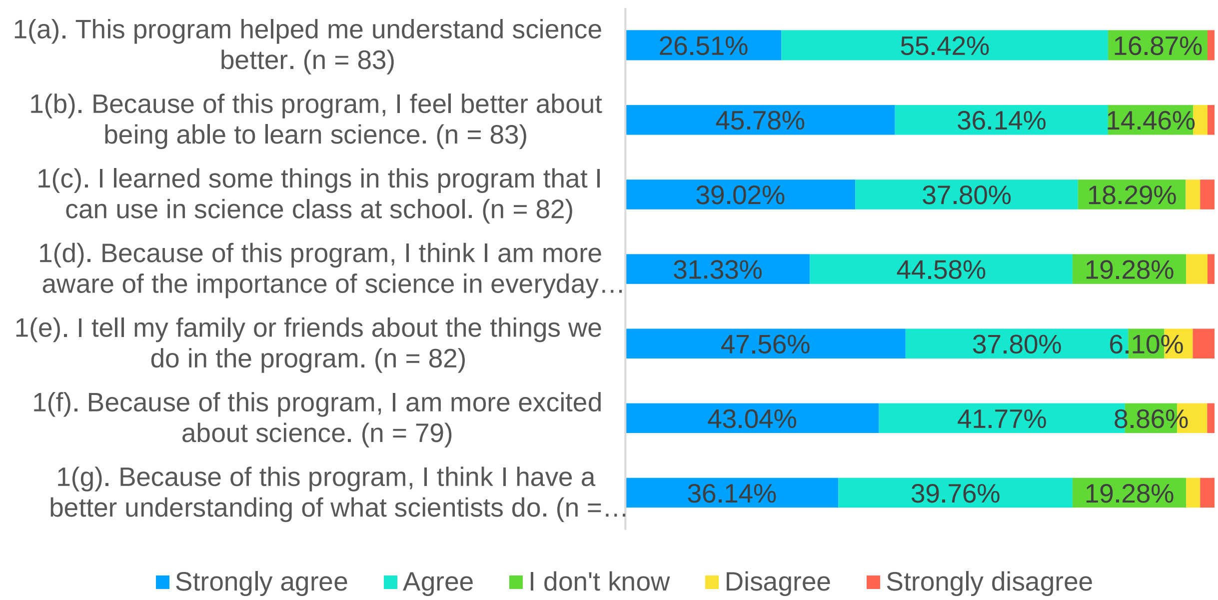
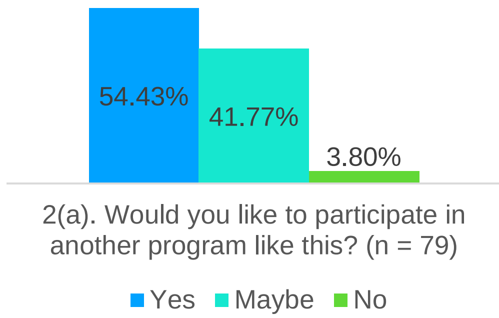



Figure 1: Responses to the Student Feedback Survey Q1a-g



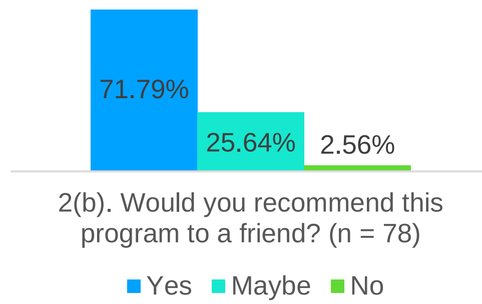




Figure 2: Responses to the Student Feedback Survey Q2a-b

Q3. How would you describe yourself as a science student?

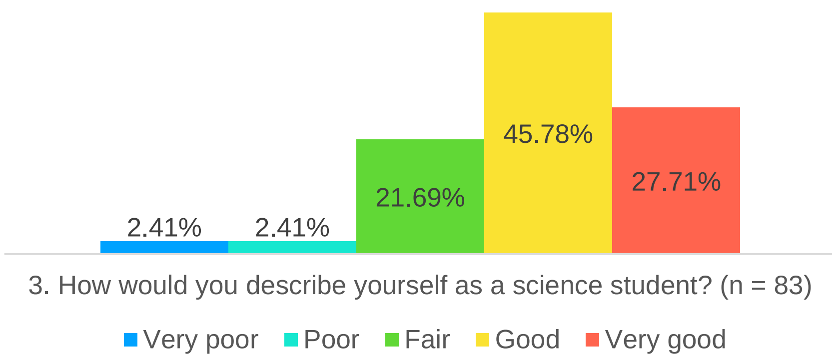



Figure 3: Responses to the Student Feedback Survey Q3

Q4. How would you describe your interest in science before this program?

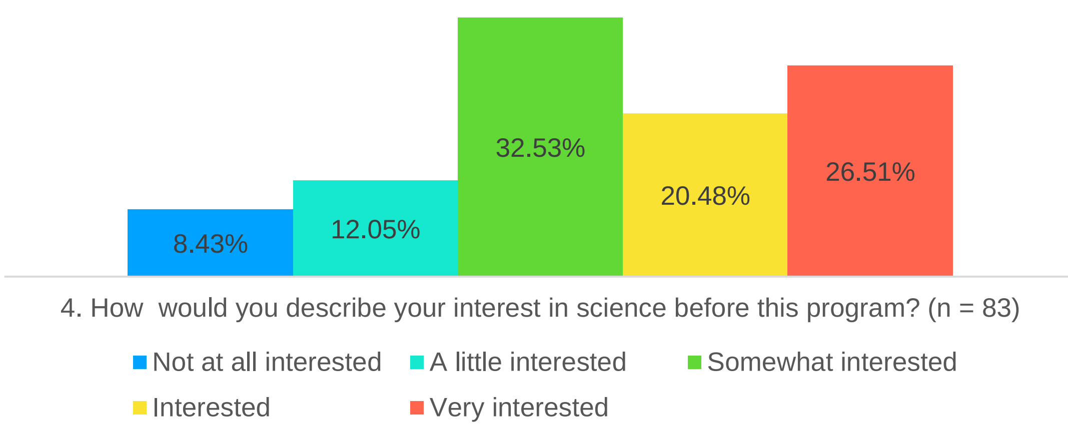



Figure 4: Interest in science before participating in the program

Figure 4 indicates that 46.99% of students were already *"interested or very interested"* in science, 20.48% of students were *"not at all interested or a little interested,"* and 32.53% were *“somewhat interested.”*

Q5. Has this program changed your feelings about learning science? **(Goal 1)**

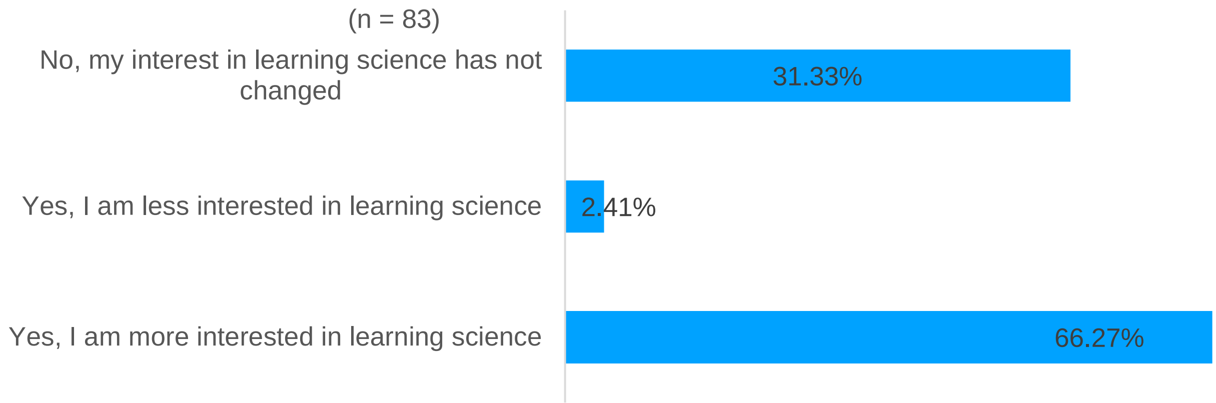



Figure 5: Participants change in interest in learning science

Figure 5 shows that 66.27% of respondents indicated that SSEP program activities increased their interest in learning science. This indicates that a large percentage of students who had indicated (see Figure 4 responses to Q4) *“not at all interested or a little interested,”* or *“somewhat interested”* have now indicated increased interest in learning science.

Q6. Has this program encouraged you to think about taking more science classes in the future? **(Goal 2)**

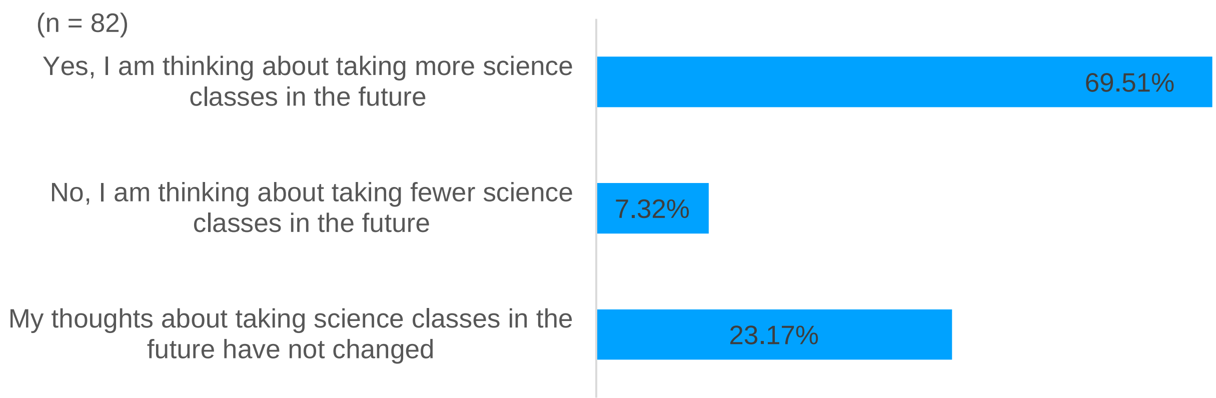



Figure 6: Participants change in interest in taking science classes in the future

Q7. Has this activity encouraged you to think more about getting a job in a science-related career? **(Goal 3)**

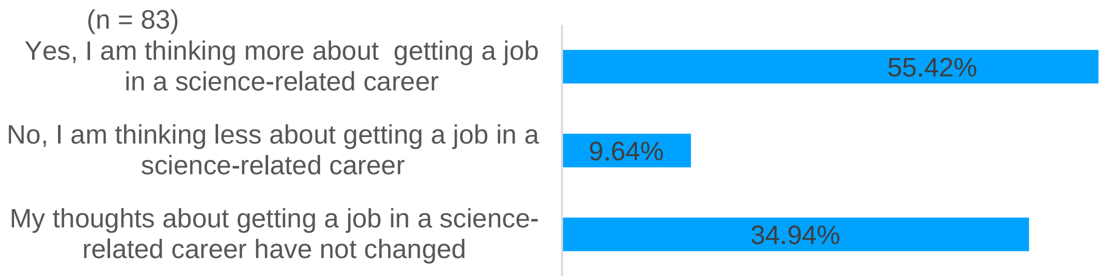



Figure 7: Participants change in interest in pursuing a science-related career

Figure 8 shows what areas within science students were most interested in pursuing.

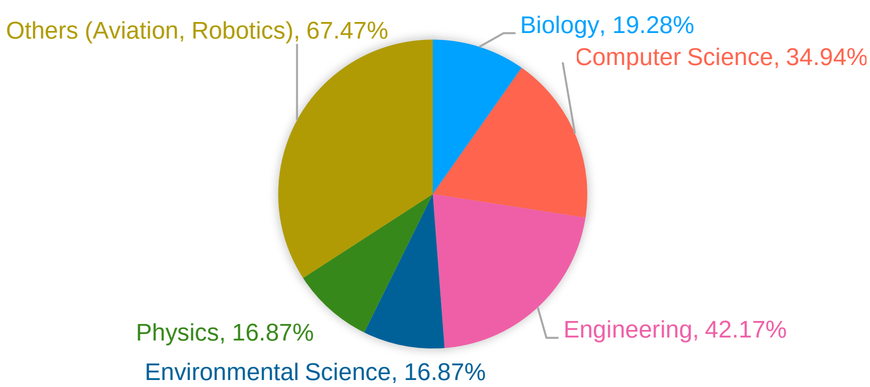



Figure 8: Distribution of interest within the areas of science

Figure 8 indicates that Engineering within the areas of science was chosen by over 42% of respondents. This was followed by Computer Science (34.94%). A large percentage of respondents listed Robotics and Aviation as their areas of science. The results align with the topics that were covered during the program. The focus on engineering design, robotics design, robotics programming, and drone design and building contributed to students' interest in these areas. This was expected as the SSEP – Drone Academy program at ECSU has a substantial focus on drone and robotics activities. While the Friday Academy was dedicated to robotics design and programming, the Summer Academy focused exclusively on aerial drones.

*Pre/Post Topic Assessment Questionnaire:* Students completed a pre and post assessment questionnaire to assess their self-efficacy on a project activity (eg. engineering design challenge).

The High School drone academy participants in the Summer Academy completed a questionnaire about their drone knowledge self-efficacy prior to and after exposure to a hands-on drone experience. To determine whether the experience had a statistically significant effect on their self-efficacy, matched-pairs t-tests were performed on the six items. The results, shown in Table 4, revealed statistically significant increases in self-efficacy after the hands-on experience for each item. Not surprisingly, the students were very confident in their general knowledge about the drone assembly/building process but somewhat less confident in detail knowledge regarding specific components. Given that all of the students reported being more interested in STEM-related areas as a result of this camp and 64% were interested in participating in a similar camp, this lack of confidence reflects a desire to learn more about drones to gain that confidence.

Students responded on a three-point Likert Scale to each of the questions with (1) for "No", (2) for "Somewhat", or (3) for "Yes." It was hypothesized that following the activities at the academy, more students would feel confident in their engineering design abilities. The null hypothesis was the project activity (36-40hrs) would cause no change in the students' self-efficacy. Pre/post questionnaire responses were averaged and an independent two-sample t-test was conducted.

Table 4. Pre-Post T-Test Analysis of High School Drone Academy Self-Efficacy Questionnaire

| Question | n | Pre (Mean) | Post (Mean) | p-value |
|---|---|---|---|---|
| I am knowledgeable of the drone design and assembly/building process. | 33 | 1.88 | 2.28 | <.01 |
| I am knowledgeable of the different components of a drone. | 33 | 1.94 | 2.38 | <.0001 |
| I am able to define the role of individual components of a drone. | 33 | 1.44 | 2.09 | <.0001 |
| I am able to explain the working of a drone. | 33 | 1.51 | 2.32 | <.0001 |
| I am able to use software tools and other technologies to configure and program a drone. | 33 | 1.26 | 1.91 | <.01 |

*Dimensions of Success (DoS) Observation Tool:* Program in Education, Afterschool & Resiliency's (PEAR) DoS observation tool focuses on 12 dimensions of quality in STEM out-of-school programs, which are grouped into four broader domains [12]. During each observation, the selected dimensions are rated using a four-level rubric representing increasing quality, where a rating of "1" indicates that evidence is absent, "2" indicates there is inconsistent evidence, "3" indicates there is reasonable evidence, and "4" indicates there is compelling evidence. According to the developers of the DoS, ratings of three or four on a dimension are desirable.

A total of four observations were conducted by a certified DoS observer. The observation days and times were scheduled with individual coordinators to ensure different topics were observed and the entire lesson could be evaluated from the beginning. The camp selection was random to avoid bias and allow the evaluation of different lessons, instructors, and students. Topics included Robotics Programming and Drone Design and Build. Table 5 depicts the average DoS score and the corresponding range for the observations.  Average scores were equal to or greater than three in all categories. Scores were highest (3.5 or higher) in five categories, including Organization, Purposeful Activities, Engagement with STEM, STEM Content Learning, Inquiry, and Youth Voice.

Table 5: Average DoS Scores of Observations on a 4-point scale

| DoS Domain | DoS Category | DoS Scores (n=4) | |
|---|---|---|---|
| | | Average | Range |
| **Learning Environment** | Organization | 3.75 | 3-4 |
| | Materials | 3.5 | 3-4 |
| | Space Utilization | 3.25 | 3-4 |
| **Activity Engagement** | Participation | 3.25 | 2-4 |
| | Purposeful Activities | 3.5 | 3-4 |
| | Engagement with STEM | 3.75 | 3-4 |
| **STEM Knowledge and Practices** | STEM Content Learning | 3.75 | 3-4 |
| | Inquiry | 3.5 | 3-4 |
| | Reflection | 3.0 | 2-4 |
| **Youth Development in STEM** | Relationships | 3.25 | 3-4 |
| | Relevance | 3.5 | 2-4 |
| | Youth Voice | 3.5 | 3-4 |

The classrooms used at ECSU allow for large informal group projects and students were arranged around tables that allowed interaction and easy use of all provided technology. Students were encouraged by facilitators to work between groups and share results. Strengths noted during these observations included Engagement with STEM, Inquiry, and STEM Content Learning.

## Conclusion

In this paper, the implementation and evaluation of an engineering-focused Drone Exploration Academy conducted at ECSU campus were discussed. The goals of this academy were to improve students' competence in science and engineering, increase students' enthusiasm for science and engineering, and encourage and motivate them to pursue science and engineering-related degree/careers. A total of eighty-three (83) students participated through Friday Academy and Summer Academy. Drones are an excellent educational platform for high school students to become familiar with and learn more about ground and aerial robotics, autonomous control, mission planning, sensor/payload integration, piloting and the future of this burgeoning industry and how it will impact society. The STEM topics included engineering design projects, sensors and data logging, basic electronic circuits, mobile robotics, drone design and programming, and Arduino microcontrollers. The project activities were geared towards increasing the number of students interested to enter college and pursue STEM degrees and careers. The project team used multiple instruments to assess the impact of the program. Evaluation data indicated that 36-40 hours of a hands-on engineering design project and other STEM activities resulted in significant gains in interest in learning science and engineering topics. The informal setting and activities were conducive for effective learning, increasing student engagement, evident from DoS observations scores. Guest speakers and field trips completed the hands-on learning activities offered in an informal learning environment. The Drone Exploration Academy at ECSU will contribute to strengthening the STEM pipeline and seek opportunities to create pathways leading students to post-secondary degrees, and ultimately to life-long, sustainable careers.

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