Identifying and Overcoming Challenges in High School CubeSat Programs

Lucas Ribeiro, Zichang Wang, Khoi Dinh, Nicolas Makovnik, Aarush Sivanesan, Kareem Jaber, Nikhil Kalidasu
Thomas Jefferson High School For Science and Technology
6560 Braddock Road, Alexandria, VA 22312; 703-559-5269
lucaszr20@gmail.com

ABSTRACT

This paper analyzes the various problems high school CubeSat organizations face, as well as their potential solutions. We conducted a case study of various high school CubeSat organizations from around the United States, interviewing them about their mission goals, organizational structure, funding sources, and other relevant information. We found that the three most common significant problems faced by these CubeSat teams were a lack of student training, turnover, and time commitment constraints. By comparison, a lack of funding and access to mentors were not expressed as the most significant problems for any of the groups. Teams shared their solution to training issues, turnover, and time commitment constraints, which included the utilization of kits, satellite simulators, and a more hands-on student training approach. In the future, we hope to expand the scope of this study to procure enough data to conduct a meaningful statistical analysis.

INTRODUCTION

CubeSats are a standard of Nanosatellite developed by Professor Jordi Puig-Suari and Bob Twiggs at the California Polytechnic State University in 1999. Due to the high development costs associated with the development of CubeSats, they were at first mostly led by NASA or other international companies.

However, as small satellites become more accessible, the number of high school satellite groups with the intention of launching their projects is increasing exponentially, from only Thomas Jefferson High School's TJ3SAT in 2006 to over 50 programs in 2021 (Gunter 2022).

Our team recently finished development of the Thomas Jefferson Research and Education Vehicle for Evaluating Radio Broadcasts (TJREVERB). TJREVERB is a 2U CubeSat with the mission of testing the signal strength variability of Iridium Short Burst Data (SBD) service in Low Earth Orbit using a 9602N modem and a VHF Automatic Packet Reporting System (APRS) backup radio. After TJ3Sat, it is the second CubeSat launched by Thomas Jefferson students. As members of a high school satellite club ourselves, we have found little orientation geared to those who hope to begin their own high school satellite programs. While there are resources available to explain the technical bureaucratic developmental process of a CubeSat (NASA 2017), we found that this did not include any organizational information specifically tailored towards high school teams.

When high school CubeSat teams do publish their research results, their papers almost invariably cover the technical aspects of their satellite and mission but give little focus to the organizational aspect of the team. This is true of statistical analyses too. For example, (Swartwout 2013) analyzed the relationships between launcher design, project organization (e.g. University vs Military vs Commercial) and project success, but did not cover administrative trends in successful teams, and were not focused on the High School level.

This paper serves to fill this gap, as a snapshot of the administrative and logistical practices of CubeSat programs throughout the United States. We present different case studies from high school CubeSats across the United States and analyze their respective technical developmental procedures, organizational structure, and resource allocation, while identifying benefits and drawbacks of each approach.

METHODS

The first step in gathering data was identifying and contacting schools and organizations conducting satellite projects at the High School level. To do this, we searched for news articles about launches from high school teams. From there, we researched the teams and reached out to them - either from an email on their website, through the "send message" function on their Facebook, or both. We reached out to a total of 9 teams, 6 of which responded.

For each school's satellite club, we conducted an interview, asking them a series of questions regarding their club's project profile (i.e satellite kit vs from scratch, balloon vs orbit, breakthrough research vs existing experiment, etc.). Then, we asked about the inner workings of each club, with descriptions of their training protocols for new members, subsystem and leadership divisions, strategies for reaching out to mentors, and their outreach, funding, and documentation practices. We also gather numerical data on these programs, such as project duration (or expected duration), club size, and yearly turnover rate, when possible.

Other data points include a school profile, asking whether career and technical education is offered at clubs' schools, and what laboratory resources are available to the clubs. Finally, the data collection concludes with information on how the club leaders gauge their own success and where they identify places where they thought major improvements could have been made in their own processes. All interviews were recorded with permission.

Questions asked for all satellite organizations. Follow-up questions were asked based on the flow of each interview:

How did the group first form?

How did you choose your mission?

What was your mission?

What proportion of the satellite was bought flight-ready versus assembled yourselves?

What were the start and end dates for your project?

Where was the project built? What type of lab equipment did you have access to?

What methods did you use to reach out to and find mentors? Was mentorship mostly by parents, teachers, outside parties/industry, or a mix? How many mentors did you have?

How was the work divided between mentors and students?

How was the project funded?

How did you train people to work on the project?

A problem a few other groups had is that by the time they are experienced enough to do meaningful work on the satellite, students are already close to graduation - was this a problem for your group, and if so, how did you address it?

How many students worked on the project? Was there a smaller core group that did the brunt of the work, if so, how many people were in each group?

How was work split/managed between students?

Would you say the project mostly followed a single group of kids, or did it cycle through a few main groups?

Did most people who join stick with the project?

How did you document work on the satellite?

What are some lessons you learned/ if you did this again, what would you do differently?

Is there anything else you'd like to share?

In addition, we conducted the same analysis on our own CubeSat program, reaching out to our program's alumni when necessary. This information was then combined with the remainder of the interviews.

The people and schools interviewed as part of this paper spanned a variety of project types and environments. For example, Irvine CubeSat and Bishop O'Connell utilized kits, while RamSat, StangSat, SilverSat, Blair3Sat, and REVERB did not. The resources available to each school also varied: 3 projects - RamSat, SilverSat, and StangSat, had a close association to a local space agency or space research site, with multiple students' parents working at these agencies. These varied environments allow us to analyze each school's administrative decisions in the context of the resources available to them. *Figure 1* shows a map of the teams analyzed.

Figure 1 Locations of Satellite Teams Interviewed

Once interviews are conducted, we extract the core information from each interview (Figure 2). We also identify the best quotes and lessons and synthesize them into a discussion.

RESULTS

Tables 1-4 summarize the data collected from each team for each question asked. * Indicates that the team has not yet completed a satellite. For these, project duration is estimated.

Table 1: CubeSat Teams Interviewed: By School, Project Style, and Duration

Team Name	Team School	Project Type(s)	Project Duration
Bishop O Connell CubeSat Program	Bishop O Connell High School – Arlington, VA	ThinSats and 1U CubeSats (Kit)	9 months (Building Only) + 1 year wait to launch
Irvine CubeSat	Multiple in the Irvine, CA area	1U CubeSats (Mentor- Designed Kit)	5-8 months (Idea to Launch)
SilverSat	Multiple in the Silver Spring, MD area	1U CubeSat (Custom designed + off-the-shelf components)	7 years (Idea to Launch)*
RamSat	Robertsville Middle School – Oak Ridge, TN	(Custom designed + off-the-shelf components)	~4 years to build + 1 year of operation in orbit
StangSat	Merritt Island High School	1U CubeSat (from scratch), in P-POD with CalPoly 2U	~9 years, test launch after 3 years
BlairSat	Montgomery Blair High School	Small ultra-low orbit kit satellite (passes through ionosphere)	5 years (Idea to Launch)*
REVERB	Thomas Jefferson High School for Science and Technology	2U CubeSat (Custom designed + off-the-shelf components)	5 years

Table 2: CubeSat Teams Interviewed by Club Size and Work Split

Team Name	Club Size (Total)	Club Size (Core)	Management Organization	Work Split
Bishop O Connell CubeSat Program	500	6	Subsystems (Number of subsystems varied between projects.)	Kit was purchased, Students programmed and assembled with help from mentors
Irvine CubeSat	15-25	15-25 (Work is well spread)	6 Subsystems, each done by a different school	Mentors designed kit, Students programmed and assembled
SilverSat	~20	8	Subsystems, not rigid.	Mentors designed much of the satellite but building and programming was mostly by students.
RamSat	100 total (taking elective class)	8-12 (dedicated at a time)	Most decisions made collectively rather then through subsystems	Mentors did most of the programming, students designed and built with guidance from mentors
StangSat	80 over 9 years	8-12	4 defined subsystems, merged near launch.	Mentors taught lessons, answered questions, students did all the hands-on work
BlairSat	25	8	3 Subsystems, each with leads with executive power.	Students do all work hands-on; mentors are mostly there for guidance
REVERB	20	8-12	5 Subsystems, not rigid.	Students do all work hands-on; mentors are mostly there for guidance

Table 3: CubeSat Teams Interviewed, by Mentor Sources and Training Strategy

Team Name	Mentor Sources	Training Strategy
Bishop O Connell CubeSat Program	Teachers, Industry	Two-to-three-hour training sessions, plus a satellite simulator for practice
Irvine CubeSat	Teachers, Industry	Self-Research from students
SilverSat	Parents, Industry	Mentors teach classes, students learn hands-on during tasks
RamSat	Parents, Oak Ridge National Labs (nearby)	Elective course + Mentor lessons
StangSat	NASA-provided, Industry	Mentors taught theory and researched; students did the work
BlairSat	Teacher (Teacher had satellite experience at NASA), Industry (Defense contractors, NASA)	Textbook reading, Jump into projects, Microsoft Teams conversation history acts as documentation, GitHub commit messages for documentation
REVERB	Industry	Presentations, Self-Research from Students

Table 4: CubeSat Teams by Funding Methods and Laboratory Resources Available

Team Name	Primary Funding Sources	Resources Available
Bishop O Connell CubeSat Program	School provides funding	School Lab
Irvine CubeSat	CSLI, Industry Sponsors, School-Based Nonprofit	School Labs, Co-founder has background in Satellite building
SilverSat	CSLI, Industry Sponsors	Mentor connections (founders are professional engineers at NASA Goddard)
RamSat	CSLI, ORNL, other nearby labs	Oak Ridge National Laboratory for CubeSat development, Founding group
StangSat	CSLI, Program funded by NASA's Launch Services Program	Dedicated NASA lab at Kennedy Space Center
BlairSat	Partially sponsored by library	Public library, School lab, teacher with CubeSat experience
REVERB	CSLI, School Based Nonprofit, Industry Sponsors	School Lab

Interview Summaries

SilverSat

SilverSat is an independent satellite program based in Silver Spring, Maryland. The program has been run as a non-profit since 2016 with a target launch date of Q1 2024, and the group of students working on the project are middle and high school students. Originally, the mentors started it as a scouting initiative, but after substantial interest from different students around the area, they turned it into an entire organization.

SilverSat launched through the NASA CSLI grant program, "CSLI provides CubeSat developers with a low-cost pathway to conduct research in space that advances NASA's strategic goals in the areas of education, science, and technology development. Schools, universities, nonprofit organizations, and NASA centers and programs can gain hands-on experience designing, building, and operating these small research satellites."

This program is organized by five expert mentors with professional backgrounds in engineering at reputable organizations such as NASA Goddard and APL. The mentors oversee the whole project; they work with funding, project planning, and hosting teaching sessions. However, SilverSat is very student driven with a core team of eight dedicated members, along with a total team of about twenty students.

Before the pandemic, SilverSat met at the Rockville, MD Science Center Makerspace, but they have been meeting virtually now for about two years on google meet; they have recently started meeting in person again. "The students were the ones really pushing to be meeting in person again. Part of it was that we can do things where they're meeting person and doing, not learning, or staring at me lecturing, rather, they're building, when they're sticking parts into breadboards and watching them light up." SilverSat founder David Copeland explains.

Since the organization is made up of students, there is the perpetual problem of high turnover rates, whether due to students graduating high school and going to university or losing interest in the project. This has been a real problem for Silver Sat, "I'm sure every high school group faces turnover. Either kids are graduating or they are no longer interested." The program has a flexible cycle, with some students joining at the beginning of middle school and staying with the program all throughout the rest of middle and high school, and other students joining during high school. These students would subdivide further into subsystems such as communications, radio, programming, and others. "We get the kids involved. [For example], our radio lead is doing work on the level of a college graduate in an engineering firm."

The funding strategy of SilverSat is very mentor driven, with the mentors being responsible for most of the high-level organizational aspect of the project. The mentors used their professional connections to reach sponsors to fund their project.

RamSat

The inspiration behind RamSat's latest CubeSat was a wildfire that occurred in 2016 in the Gatlinburg area. They hoped to employ near infrared cameras to measure forest recovery not only in Gatlinburg, but also throughout the world. However, their project pivoted away from this subject and shifted more towards studying the effects of solar beta angle (the angle between the sun's rays and the satellite's orbit) and the effects the sun's temperatures can have on the satellite. This especially affects the solar panels which are more effective when cold and can often be exposed to constant sunlight for long durations. They mitigated this issue by utilizing magnetorquers to rotate the satellite.

The project started in an elective class, with many students researching different aspects of satellite operation and mentors giving lessons during school. In addition, a small group of 5-12 dedicated members showed up to work on the actual satellite on weekends. The students led the project, while the mentors guided them through it, and helped with the more advanced aspects such as the flight software. They had finished the satellite 3 years later, but, after the pandemic hit, a manufacturing flaw in the CPU forced them to rebuild.

As the satellite neared completion and was launched in June 2021, the team transitioned towards outreach, using that same elective class as a medium through which they could teach others about their satellite. And, although the research they were attempting wasn't necessarily groundbreaking, this satellite left its mark on the STEM community through the students it helped educate, and the future engineers it helped inspire.

The team's community outreach has also proven valuable to their success. They have presented about their satellite to numerous nearby institutions, including the Oak Ridge National Laboratories. This helped them find some of their mentors and helped them get more funding outside of the NASA CSLI grant. But these benefits were not limited to their project; the attention RamSat brought to their high school helped expand the STEM program — which subsequently received multiple grants that allowed the school to diversify its course options and hire experienced instructors.

StangSat

Based in Merritt Island, Florida, StangSat was the second high school CubeSat in space and the first fully functional one. Developed in partnership with the California Polytechnic State University's PolySat program, it served to test WiFi communication within a P-POD deployer. Against regulations at the time, WiFi communication between satellites in the same P-POD would allow one team to forgo incorporating a complicated or expensive radio into their satellite, piggybacking off the others instead. The mission's goals meant that it lasted only through the launch phase, so the mission was completed once ejected from the P-POD.

The project was conceived and sponsored by NASA's Launch Services Program. Mentors predominantly came from NASA, as well. StangSat was led both by its NASA mentors as well as student leaders. Throughout its lifetime, 80 members worked on the project, with a core team of around 12 dedicated members working on it at any given moment. Until launch, subsystems were well-defined, with four main ones—Robotics, which worked on assembly (and had members from up to two other schools at times), Programming, Hardware, and a dedicated Battery subsystem.

As a mentor from the Air Force explains, the StangSat team let new members ease into their program at their own pace, finding it worked well.

"As students graduated, and the new year started, we got new students. And they would watch for a little bit. It depended on the student, but some jumped right in. We had a sophomore who was incredible with programming. And he did the coding. And he took over. Within a month he was in charge. So, involvement depended a lot on the student," project faculty leader Tracey Beatovich explained.

Once in, the team had members learn through experience. As former member Maurisa Hughes explains, having a synergistic relationship between mentors teaching and students doing was integral.

"It was mainly our mentors [who kickstarted the research process], they did some amount of research. And then they shared what they learned with the group, and then we all researched it together: learning by doing."

On top of experienced mentors, the team had access to a dedicated lab at the Kennedy Space Center, as well as onsite vibration and EMI testing facilities. As launch neared, the subsystems were merged, with every active member doing almost any task needed, regardless of their original subsystem. With their successful launch and mission, StangSat stands today as a model for other high schools willing to start their own program. StangSat was launched on June 25, 2019.

Blair3sat

Blair3sat is a student-run CubeSat team at Montgomery Blair High School. Their project focuses on collecting data from the ionosphere using radio frequency (RF) and optics instrumentation. The data will then be used to measure and update the ion density of certain regions in the ionosphere in real time, allowing scientists on the ground to better understand how ions in the ionosphere will interfere with radio communication.

The Blair3sat team is divided into two primary subsystems: one focusing on the RF instrumentation, and the other focusing on the optical instrumentation. The RF instrumentation team works to integrate satellite communication with ionicons on the ground. By comparing the time of sound transfer to a database and performing signal processing, the team is able to receive a measurement of electron density in the ionosphere. The optical instrumentation team works on measuring air glow and the density of photons in a certain region.

Blair3sat has opted to use a Enduro kit-based cubesat for their project, deciding that their time is better spent focusing on the experimental aspects of their project. "We don't really want to reinvent the wheel… We could go out and design our own satellite kit, but industry has already spent hundreds of millions of dollars developing efficient kits, so we'd rather just piggyback off all that innovation and specifically work on the instrumentation parts of our mission which are unique." The Blair3sat team is building their optics instrumentation from the ground up. Although the team is using off-the-shelf RF instrumentation, they are writing all the software to integrate with the ionicons and to perform data processing.

Blair3sat was founded in 2017, starting off as a small club brainstorming ideas. Since then, they have expanded in size and in mentorship, and are currently finalizing the designs and pipelines of their project. Through attending conferences such as SmallSat and SPIE, they have been able to obtain mentors both in the field of CubeSat engineering and design as well as RF and optics tooling. Even with an abundance of mentors, the Blair3sat team is still very student driven; the mentors primarily help the students with the organizational structure of the club and with guiding students through difficult experimental design problems that they encounter.

To address the turnover and training time issue that many high school satellite clubs have, Blair3sat recruits mainly freshman and sophomores, sometimes even recruiting students straight out of middle school. New team members learn both from reading textbooks and papers as well as through completing small projects which require teamwork and collaboration with more knowledgeable members. In this way, new members gain both a solid foundation in the theory behind the project and crucial skills needed to be a productive team member. To document information, the Blair3sat team makes use of Microsoft Teams, where conversations over text can be saved and searched for by future members. The team also makes sure to keep effective documentation of their software through detailed commit messages. They aim to launch in

Irvine CubeSat

Irvine CubeSat had a drastically different satellite development procedure from the rest of the teams. They have successfully launched three satellites and were created as an association of 4 high schools in a single county, rather than by an individual school. Their program is also highly selective - requiring a rigorous admissions process with teacher recommendations for students who hope to work on the satellite. The program was also the fastest high school team to get a satellite from design to launch - doing so in 5 months.

As co-founder Kain Sosa explains, this was made possible through collaborations with the county and local nonprofits.

"We were very, very aggressive. It was October, and I had a conversation where I asked my teammate how much money needed to be raised. I told him 'give me three months to raise the money' — it took me three weeks. I put a deck together, I put a vision together. There was a nonprofit, IPSF (Irvine Public Schools Foundation), which is a vehicle where they raise money for the public-school systems here in Irvine. The school system, IPSF, and everybody associated. We jumped on it, and the satellite launched the following March." Sosa said.

Through Irvine's program, students build on a self-developed kit, rather than ordering and designing components themselves.

"We have launched several satellites into space [prior to founding the program], and then we worked backwards and made it less complex. We reduced the scope, so students focus on the main thing. We created a skeleton of a bill of materials, and basically designed the CubeSat - there was no design from their part. They just assemble it like Lego. That [reduced] the complexity so they just have a box to put things into. They overlay the right kind of layering and they put in radio and the solar panel and different parts – so that made it less complex." Sosa said.

Despite the use of a kit, Sosa believes students still learn a lot from the program.

"[Students] still need to understand the components, [they] were also responsible for the programming. All we did was provide students a vehicle and path to learning. They had to figure it out."

Sosa sees the program as incredibly successful.

"How would I start a new one? I wouldn't change one thing. Not one thing."

Bishop O'Connell

Bishop O'Connell, like Irvine, used a kit, and were able to get their satellite built in a much faster timeframe than the rest of the groups: 9 months for building, with another year before launch. Unlike Irvine's program, Bishop's only involves a single school. O Connell's team also does not build exclusively 1U projects, having done ThinSat and Balloon Projects before.

ThinSats, with a dimension of 11.4 by 11.4 by 1.25cm, are simpler to build than CubeSats, and are available in a kit for easy assembly. Melissa Pore is the staff sponsor for the satellite team at Bishop O' Connell,

"ThinSat was interesting because it was a quick kit, but I wasn't responsible for the telemetry setup -- it was already decided. I didn't have to worry as much." Pore said,

On these satellites, Bishop O'Connell's team places customized chips designed for students, called X chips.

As for Bishop O Connell's club organization, they are organized into subsystems, which changed throughout their projects, but generally involved Avionics, Flight Software, and Payload design. As a training strategy, the team uses a satellite simulator, which provides students a low-stakes option to get used to working on satellites. The satellite simulator also gives students the opportunity to have design experience they wouldn't otherwise get in a kit project.

"[With a kit], you're not really doing the engineering. But hopefully, [through the simulator], you've already modeled that out and prototyped"

To procure mentorship funding for the team, O Connell's team does various presentations at their school's STEM day fair, and encourages parents and teachers to reach out to colleagues in the space industry.

St. Thomas Moore Cathedral School

Note: This project was excluded from our official data collection/analysis, as it is not a high school, and did not receive a dedicated interview

Melissa Pore, the faculty sponsor for Bishop O'Connell's project, also led an elementary/middle school project for those in grade K-8. This project, as expected, had heavy mentor involvement, and utilized a kit. It was also a ThinSat, and not a CubeSat as the rest of the projects featured here. Rather, the purpose of the project was largely to introduce younger individuals to basic concepts in the world of satellite design.

"The kids didn't do the entire project, but all 400 did a full clean suit dress, and a hands-on moment with the entire kit with electrostatic discharge. bracelets. We showed them how to operate the configuration panel and how to use the camera as our tester. For any age, students observed if the satellite took a picture or not."

Thomas Jefferson High School - REVERB

Our own CubeSat program was conceived in 2016 with the intent to study the effectiveness of various methods of radio communication in Low-Earth Orbit. The original mission plan included a tried-and-true APRS radio in addition to experimental Iridium and S-Band radios. We designed our satellite entirely ourselves, without making use of a kit, instead attempting to integrate various off-the-shelf components into a complete system.

Over the many years the satellite was in development, we experienced many of the same issues as other teams. Because of problems with knowledge transfer and lack of experience, as well as insufficient access to mentors, we made several major changes to our mission design. For example, we descoped our S-Band radio and magnetorquer as they proved to be too complex, and we used Iridium our primary radio instead. Another twist came when our original project, evaluating the viability of Iridium radio from orbit, was done by NASA during our development process (Murbach 2020). So, we chose a new mission goal: measuring the performance of Iridium under passive magnet attitude control instead.

We also went through several major organizational shifts over time. Club applications used to be a huge part of our program. Our club was notoriously difficult to be accepted into, and the process for getting in involved interviews, technical questions, and essay responses. However, we learned over time that it was far more valuable to have dedicated and passionate members than talented members with strong resumés. We changed our strategy in recent years away from lengthy club applications and towards a more decentralized and open model. Our current meetings are always open to anybody interested; all a prospective member would have to do to become part of the club is show up, read documentation, ask questions, and start doing work on our satellite.

Our leadership and management structure has followed a similar trend as other clubs. Currently, our program has one topmost director and individual project managers for each CubeSat project we have running. Below that, everyone is an equally valued member. This decentralized model has allowed for members to fluidly engage themselves in whatever aspects of the project they are most interested in, as well as gives the project manager the authority to assign out backlogged tasks that aren't as appealing—such as writing documentation. Members regularly jump between working on assembly, software, and electronics, giving them a broad range of experiences, and increasing opportunities for creative problem solving.

On the problem of knowledge transfer, we as a club had to struggle for many years before developing what we hope to be a solution. Our past documentation pages were cluttered, filled with redundancies, and unappealing to read. As a result, few students took the time to read through old documentation, meaning we ended up repeating a large portion of previous years' work when finalizing REVERB. This year, we attempted to solve this problem by compiling a clear, comprehensive, and readable best practices document that explains what a CubeSat is, what the process is for building and launching one, and what lessons we learned in our experience with REVERB. We do not expect any future generations to copy our mission design or club structure; rather, it is our hope that future generations of students will use this document as a foundation for future missions, as well as add to it with their own experiences, lessons learned, and recommendations. This provides us with a centralized method of knowledge compilation.

Our current program also strongly values outreach. We regularly engage in programs such as TJ Techstravaganza, a school-sponsored activity where clubs each have a booth, and the SmallSat conference to reach more members of our community and share our love of aerospace. With REVERB completed and its launch scheduled for October of 2022, this also gives us an opportunity to connect with potential sponsors so that we can fund our future CubeSat missions. Conferences such as SmallSat also give us the opportunity to find more mentors to address the lack of experience of incoming high school students.

DISCUSSION: COMMON PROBLEMS FACED BY CUBESAT TEAMS AND THEIR SOLUTIONS

During our analysis of the interviews, we found several problems that were common among most if not all the high school teams studied. These included resource and time constraints, lack of technical knowledge by students, and maturity issues. Teams developed different methods to address these problems, with varying levels of success.

Lack of Technical Knowledge

One of the defining characteristics of high school CubeSat teams is the lack of technical knowledge, inherent to the nature of high school teams, as high schoolers do not have the expertise given by studying engineering, computer science, or orbital mechanics at a university level. Especially at a high school level, very few people have the knowledge and experience necessary to take a project from idea to reality. Additionally, the most experienced members graduate each year, so lack of technical expertise is a persisting issue, even for longer projects. In many clubs, by the time students are prepared to do meaningful work on the CubeSat, they only have 1-2 years of High School left, and so the timespan through which they can be productive team members is limited.

This often leads to inefficiency and slows development times as members learn and experiment with new electronics, languages, or concepts before being able to make tangible progress. This also limits CubeSat teams in what kinds of projects they can pursue, as specialized hardware will be difficult to work with for inexperienced students. Ultimately, a lack of experience not only limits the electronics a team can use, but also the projects they can pursue. Therefore, experience is one of the main obstacles for high school CubeSat teams. An obvious solution to this, and one which many teams take advantage of, are mentors who generally have engineering experience in a professional setting. However, finding mentors remains a challenge and acts as a barrier for prospective teams. Likewise, knowledge transfer from more experienced team members to newer ones can help mitigate this issue but is also very difficult to implement effectively. In addition, if the students depend heavily on the mentor for the technical expertise required for the project, the project could start to lose its identity as a "high school built" CubeSat.

Issues with training were addressed in four main ways - through strong mentor connections, intelligent training protocols, by simplifying the scope of projects, and through single-group teams.

Three of the teams we interviewed: SilverSat, RamSat, and StangSat had strong ties to space research facilities. Founding members of these groups often had family working at these facilities, who were deeply invested in their project. For RamSat and StangSat, their satellites were built in these space research facilities, rather than in a school or public makerspace. Because mentors are so well-connected to these teams, they were able to give more involved assistance - perhaps guiding a group of students through a task, beyond just answering questions.

Strong mentor connections were also present where close association to a space research center did not exist, although there was generally less mentor involvement (e.g. answering questions rather than guiding students step-by-step) in these teams. Nevertheless, both types of teams have found success.

To be able to appropriately allow mentors and experienced students to share knowledge with the rest of the group, teams also developed their own training protocols. For some teams, like RamSat, this was in the form of an elective class in school, where students would learn basic satellite design concepts. Most teams followed a variation of the self-research model, for at least part of their training protocols. With this system, students were assigned tasks outside of their skill level, but would use questions from mentors as well as internet resources to attempt to solve the task. Through this process, students learn. Some schools also utilized tools to facilitate the training process for students working on satellites.

Bishop O'Connell, for example, uses a satellite simulator to allow students to train on a lower-stakes project. With these simulators, they would design and interface electronics on a 3D printed model, allowing them to be more prepared for work on the satellite later.

Some teams also turned CubeSats into a less technically and logistically complex project. These - namely Irvine Bishop O'Connell, and St. Thomas Moore, used kits for the bulk of their satellite design. These kits reduce the scope of those school's satellite projects, allowing them to focus on programming and experimentation, rather than the tedious process of ordering individual components and planning how to fit them together. In the case of Bishop O Connell, they also chose to pursue a simpler project: a ThinSat, instead of a conventional CubeSat.

At the same time, the recent rise of kit-based satellites raises the question: is this depriving student of a valuable learning experience? However, the situation is more nuanced than this: kit teams consistently produce satellites far more efficiently than others, with a project timeframe of months rather than years. This means they can involve and educate more students, leading to a greater community impact (Faure 2021). Kain Sosa, co-founder of Irvine CubeSat, addresses this. "I'm not doing everything for the students, I'm just guiding them through a path. 80 or 90 percent of the work is still the students"

Finally, one CubeSat team - RamSat, eliminated the need to re-train students by opting to follow a single group of students, rather than a school. When RamSat was first established, the core group of students who partook in its development were in 7th grade, and the same students continued to work on the satellite as they switched to High School. The satellite launched when they were in 11th grade. However, this isn't possible for most groups. In RamSat's case, they had access to lab space at the Oak Ridge National Laboratory. For groups that rely on their school for labs, a single-group, long-term satellite project is less feasible.

Time Commitment and Resource Constraints

One of the major differences between a commercial CubeSat organization and an educational High School CubeSat program is time and resource availability. Since high school students have many other school and extracurricular commitments, such as sports and academic work, there is not a lot of time available in students' schedules for a high time commitment project such as the development of a CubeSat. Additionally, high school CubeSat teams do not have the resources and labs to work most effectively. Most teams interviewed had to share lab spaces with others, and this can lead to non-optimal meeting times, and low organizational and developmental efficiency.

The lack of laboratory resources was solved through a variety of methods. While most groups were able to find lab space via their school, other groups had to pursue different solutions. Namely, StangSat and RamSat, used a local space research facility to build their satellites (Kennedy Space Center and Oak Ridge National Laboratory respectively). SilverSat is using a local library makerspace for its satellite planning and assembly.

Teams generally solved the time management issue through a dedicated core group of students. For all teams, they had a group of 5-29 students who would prioritize the CubeSat team over other commitments and did the brunt of the work for their team. In addition to this, StangSat had a program where their own students would join a NASA internship over the summer, and, as work for this internship, they would develop their own satellite project. Effectively, 2-3 students were able to work on their satellite for 40 hours/week, with robust mentorship during the summer, and this greatly advanced progress on their satellite.

Funding and Mentorship: Unexpected Results

Some aspects of CubeSat club planning that we expected to be a challenge were found to not be a significant issue in any of the CubeSat clubs. For example, none of the teams interviewed described having struggled with finding mentors, and funding was typically a smaller problem than expected as well. A portion of schools interviewed – SilverSat and BishopOConnell – attributed this to presentation opportunities at SmallSat and similar conferences and symposiums, where mentors and companies would discover High School CubeSat programs, and in turn assist them through funding or mentorship.

DISCUSSION: STUDY PROCEDURES AND NEXT STEPS

Finding contact information for satellite teams and then receiving a response for our interview requests were more difficult than expected. Consequently, this study was limited in scope: with data from only 7 schools, it was difficult to conduct meaningful statistical analysis.

Another issue is that of confounding variables. For example, the teams that utilized a kit were also the ones that had a more hands-on training approach, with immersive tasks through satellite simulators and self-research. This makes it difficult to control exactly where variation in project duration and success stems from. Additionally, because data was collected through interviews directly with members of satellite teams, our research was subject to bias.

However, we feel that this paper does consolidate many valuable and creative solutions to issues that CubeSat teams face, especially as it relates to student training and time constraints. Next steps would include a greater-scope study, with more schools and teams interviewed. Ideally, a future study should look for schools that had almost identical projects in terms of scope in style, but with a single key difference, to better control for confounding variables.

Acknowledgments

Contact Information for the individuals interviewed, by Organization:

RamSat-Hudson Reynolds (Student)- hudsonj.reynolds@gmail.com

Irvine CubeSat - Kain Sosa (Co-Founder) ksosa@bilingualinteractive.com

SilverSat - David Copeland (Founder)- dave@silversat.org

Bishop O'Connell and St. Thomas Moore- Melissa Pore (Founder, Teacher)- mpore@bishopoconnell.org

Blair3Sat - Vijay Shanmugan (Student) - vrswizards2015@gmail.com

StangSat - Tracey Beatovich (Teacher) - secretary.gumc@gmail.com

REVERB - Nikhil Kalidasu (Student) - spaceprogram@tjhsst.edu

References

1. CubeSat 101: Basic Concepts and Processes for First-Time CubeSat Developers. (n.d.). 96.
2. Jackson, S. (2018, December 1). NASA Mission Supports Launch of CubeSats Built by Students NASA. http://www.nasa.gov/feature/nasa-mission-supports-launch-of-cubesats-built-by-middle-and-high-school-students
3. Moore, J. D. (n.d.). Integrating Small Satellites into the United States' K-12 STEM Education Discussion. 11.
4. Spacecraft—Gunter's Space Page. (n.d.). Retrieved June 9, 2022, from https://space.skyrocket.de/directories/sat.htm
5. Swartwout, M. (2014). The First One Hundred Cubesats K-12 STEM Education Discussion. https://jossonline.com/wp-content/uploads/2014/12/0202-The-First-One-Hundred-Cubesats.pdf
6. Murbach, M (2020). Use of Iridium as a Primary Encrypted Command/Control Gateway. https://www.nasa.gov/smallsat-institute/use-of-iridium-as-a-primary-command-control-gateway
7. Faure P (2021). Cal Poly CubeSat Kit – A Technical Introduction to Mk I https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=5108&context=smallsat