Exploration of Undergraduate Engineering Students' motivations within the Virginia CubeSat Constellation

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

A CubeSat is a stackable small satellite classified as a nanosatellite. They are measured in Units or "U's" which are based on the volume of the spacecraft. One "U" consists of a 10x10x10cm cube that holds the instrumentation, electronics, and payload for the mission. Depending on the requirements of a mission and the volume needed for components, CubeSats can be combined to create 2U's, 3U's, etc. The Virginia CubeSat Constellation (VCC) mission is a collaborative project between four member universities in the Virginia Space Grant Consortium; The University of Virginia (UVA), Virginia Tech (VT), Old Dominion University (ODU), and Hampton University (HU). The aim is to provide undergraduate students with hands-on experience working on an engineering design project with real-world implications.

Utilizing three 1U CubeSats built by UVA, VT, and ODU with data analysis support from HU, the scientific goal of the mission is to obtain measurements of the orbital decay of a constellation of satellites to develop a dataset on atmospheric drag and demonstrate the variability of atmospheric properties. Although the air density is significantly lower than the air near Earth's surface, the air resistance in the upper layers of the atmosphere where the three satellites are operating is still strong enough to produce a noticeable amount of drag. It is this noticeable effect from drag that motivated the conception of the mission. The data from the three CubeSats and the resulting density models from Low Earth Orbit (LEO) will aid in calculating deorbit times, help prevent collisions, and help predict the time and location of reentry for orbital debris.

The VCC mission at UVA takes the form of the capstone design course for Mechanical and Aerospace and is focused on having the students acquire a deeper understanding of engineering through active exploration of their specific sub-team topics and issues that the mission is facing as a whole. This style of student driven CubeSat projects is not unique to UVA or the VCC mission. Numerous other universities such as Stanford, MIT, Purdue, and Georgia Tech to name a few have similar programs that are significantly more established and have designed, built, and launched multiple CubeSats over the past two decades. The pedagogical approach shared between these programs is referred to as Project Based Learning (PBL). As described before, this structure differs from traditional classrooms in that it focuses on tackling a project where instructors facilitate, rather than offer direct instruction. The key to success for this approach is emphasizing active student exploration of the topics that they are involved and personally interested in. Self-Determination Theory (SDT) describes how students perform best when they are intrinsically motivated to do well, meaning they are curious and eager to learn the topic at hand. With a PBL structure and students actively researching topics they are interested in to work towards an engineering goal, I will explore the motivations of the undergraduate engineering students within the Virginia CubeSat Constellation.

Case Context

As a student studying to become an engineer, it is rare for projects to specifically model and emulate real-world engineering problems. The CubeSat was invented in 1999 by Bob Twiggs and Jordi Puig-Suari to fill this role as an educational tool " to provide hands-on experience to students in space activities, allowing them to work on the entire cycle of a space project, from the initial concept until its operation in space" (Villela, Costa, Brandão, Bueno, & Leonardi, 2019). Since these were initially developed as educational tools, it was paramount that development, launch, and operational costs were as low as possible. Although initially viewed by the space industry as simply educational tools that hold little value besides teaching the engineering process, now the inherent value of CubeSats to satisfy niche data collection needs at low cost has been seen with the Air Force, the National Reconnaissance Office, DARPA, and even the National Science Foundation funding CubeSat development. Because of its development as an educational tool as well as its popularization in industry and government, CubeSats offer a unique path for students to involve themselves in serious projects with the potential to launch them into a very lucrative field.

One of the largest advocates for partnerships between industry and CubeSat development in education has been NASA. Through a number of programs such as the NASA Advanced Design Program (ADP), the NASA Student Explorer Demonstration Initiative (STEDI), the NASA Human Exploration and Development of Space – University Partners (HEDS-UP), the National Space Grant College and Fellowship Program, as well as these programs' successor the Revolutionary Aerospace Systems Concepts – Academic Linkage (RASC-AL), NASA has demonstrated a significant interest in space education among students. Within the RASC-AL program, "each year over 250 students and faculty participate in the program, engaging over 2500 members of the public through academic and community outreach" (Cardenas, 2006). Implementation of the RASC-AL program has benefitted from using the lessons learned and the results and experiences of previous programs to build upon its ability to inspire young students. From these programs, NASA concludes that through these real-life engineering and technology challenges, student motivation and interest in STEM is increased. This has led NASA to create programs such as the CubeSat Launch Initiative (CSLI) which directly pertains to CubeSat funding within institutions in order to stimulate CubeSat projects.

As a result of these private and government efforts to increase CubeSat development, schools have built serious programs around their Aerospace Engineering departments. The success of these programs comes over a long span of time, allowing instructors and faculty to mold the program to one that has the most success and sets up students the best for when they enter the workforce. One notable example is at the University of Illinois Urbana-Champaign (UIUC), which is going on the 18th year of its CubeSat program. Through a 15-year case study of their PBL design course, UIUC has succeeded in improving its program to a point of great proficiency in educating their students through a design project that uniquely mirrors industry practices and adapts CubeSat timelines to a semester-based University structure. Kroeker, Ghosh & Coverstone (2016) emphasize in their conclusions that education is the main focus of their design course, as should be the case for all PBL CubeSat courses. The focus is on "building engineers and not satellites." Through the development of their program, the faculty at UIUC have instilled methods of maintaining intrinsic motivation within their students and instructors to provide the best educational experience possible. Through the adaptation of CubeSat design courses into a PBL style program, instructors are introducing learning styles that inherently enhance student and instructor intrinsic motivations. Although courses can be poorly managed and result in a poor educational experience, PBL style classes by definition hold the building blocks of intrinsic motivation.

The success of CubeSat programs such as at UIUC have definitely had an effect on the development of CubeSat programs nationwide and has served as a model for the programs of all three of the Virginia CubeSat Constellation's universities. What differs however, is that the cooperation between the University of Virginia, Old Dominion University, and Virginia Tech allows for a unique view into the development of three simultaneously built CubeSats, the interactions between the universities, and the motivations of students within three different

CubeSat design courses over the lifetime of the mission. It is this unique set of circumstances that prompts a deeper analysis of student motivational and educational development.

Student Self-Determination within CubeSat design courses

The key component that allows PBL, and more specifically CubeSat programs, to be so successful is the intrinsic motivation they inspire within students. Self-Determination Theory (SDT) is a framework which describes the environmental factors and basic psychological needs which provide the optimal conditions for motivation. SDT argues that supporting individual's experience of autonomy, competence, and relatedness foster the highest quality forms of motivation and engagement for activities. Autonomy describes the capability of being the main driving force affecting one's behaviors, competence is an individual's ability and confidence to perform tasks, and relatedness is the desire to experience connection between individual learning goals. Deci & Ryan (1982) claim that intrinsic motivation is based on the innate need to be competent and self-determining.

This in turn leads people to pursue situations and activities that interest them, provide optimal challenges, and allow them to learn and achieve. Within PBL style classes, students are provided opportunities to explore topics they are interested in with the instructor used as a facilitator for exploration rather than as a traditional lecturer. This assertion shows that at its best, PBL classes set up students in an optimal setting to stimulate their own personal curiosity and intrinsic motivation to do well in the class. These claims are backed up by citing the author's previous paper (Deci & Ryan, 1980), which details numerous studies done to explore the conditions within which intrinsic motivation is likely to be diminished and enhanced. One other important aspect necessary for the success of a PBL class is having the instructor intrinsically motivated to want the project and the students to succeed. The authors state that an instructor must become an active teacher that is "a resource, a guide to students' learning who would facilitate learning rather than control and evaluate it." (Deci & Ryan, p. 33)

This assertion is supported by Lam, Chang & Ma (2009) who, through a study of 126 primary school teachers and their 631 students in Hong Kong, concluded after survey results that teacher intrinsic motivation predicted student intrinsic motivation directly as well as indirectly through the mediation of instructional support. When teachers reported higher intrinsic motivation in the program, their students tended to perceive getting more support from them and reported higher intrinsic motivation in their own learning experience.

Similarly, a recent study done by Liu, Zhao & Zhao (2020) has come to similar conclusions. Their experiment, consisting of surveys sent to 292 engineers who work in various industries within mainland China, utilizes the self-determination theory and the planned behavior theory to describe the effects of engineers' individual continuous learning through the mechanisms of innovative behavior. These mechanisms include career planning, self-efficacy, risk tolerance, and organizational climate. The two mechanisms that best relate to this study of the VCC mission are self-efficacy and the organizational climate. What the authors describe as self-efficacy within this experiment serves as the same descriptor as the competence component within the SDT model that is being utilized for this study. Self-efficacy and Competence describe an individual's belief or confidence in their capacity to make informed decisions on important aspects of their projects. The organizational climate that is described within the paper refers to the environment that the engineer works and develops in. The authors hypothesize that when engineers feel that an organization is conducive to personal exploration and growth beyond the confines of their job description, engineers are more willing and able to demonstrate innovative behaviors. Similarly, as a result of a conducive environment and engineers' willingness to learn on their own, this increases self-efficacy and allows the engineers to perform even better at their duties. The results of Liu, Zhao & Zhao's (2020) analysis serve to validate their hypotheses and provide recommendations for what should be done to foster innovative behavior.

In the context of the VCC mission, the organizational climate is Problem Based Learning (PBL) structured CubeSat design courses. By definition PBL courses serve as a direct method to increase self-efficacy and competence among developing student engineers by promoting individual learning. Since the hypotheses stated and methods used are so similar to the argument that is being made in this thesis, similar results will serve to validate the work done by Liu, Zhao & Zhao's (2020) and convince researchers, companies, and universities to perform similar experiments and promote this style of education and institutional support in their respective areas.

Research Question and Methods

The question that guides this research is: What are the motivations of students in capstone design courses within the Virginia CubeSat Constellation mission? There have been studies of intrinsic motivation in PBL style classes, but no specific studies on how the integration of CubeSats in higher education, using PBL style classes, affects the quality of education received by undergraduate engineering students. Although one could use these other studies as justification of CubeSats as an educational tool, performing more specific studies could potentially highlight unique challenges faced by PBL style engineering courses. I have analyzed the topic at hand by conducting surveys of current and previous graduating classes of the capstone design courses involved with the VCC project across the University of Virginia, Old Dominion University, and Virginia Tech.

Using similar survey questions that Lam, Chang & Ma (2009) used to gauge the intrinsic motivation of students, my survey consists of a rated based questionnaire that addresses the three main parts of the Self Determination Theory, autonomy, competence, and relatedness, as well as specific questions to gauge intrinsic and extrinsic motivation. Each question addressing one part of the SDT model with a positive connotation has a corresponding question that is phrased instead with a negative connotation in order to gauge the participants' satisfaction or frustration according to their experiences during the mission. By using this method of asking the same or similar questions from both a positive and negative viewpoint, I negate any bias that might be associated with the wording of any one question and provide a better picture of the true feelings of the participants. I have also conducted interviews with participating students across the three universities and asked follow-up questions to get a more in-depth view on some of the specific feelings of the students. These interviews have helped to not only allow for the participants to elaborate on their feelings outside of the questionnaire, but have also provided invaluable advice on the operation and design structure for future CubeSat missions and future collaborations between the universities.

After collecting this data, I have analyzed it by looking for trends between the different universities as well as between the different years that the subjects participated in the mission. Since this survey was conducted using a rated question system, each step was assigned a numerical value with 1: Strongly Agree, 2: Agree, 3: Neither Agree nor Disagree, 4: Disagree, and 5: Strongly Disagree in order to quantify the average response of all of the participants. As a result, the number associated with the mean corresponds to this numerical scale and shows the feelings of the participants for that particular question. Since there are negatively connotated questions, an issue arises that disagreeing with a negative question indicates a positive feeling towards that specific component of the SDT. This is taken into account through a reformulation of the negative questions' mean values onto the positive scale. These questions were reformulated using the equation: New Positive Score = 6 – Negative Score in order for the negative questions to be properly translated. For example, if the mean response for a negative question is 3.97, this response indicates that the students 'Disagree' with the negative question, or agree with its positive counterpart. The new value for this data point on the positive scale would be 6 – 3.97, which equals 2.03. This new value of 2.03 matches with the 'Agree' rating on the original scale. All of the average means located in Tables 1 – 5 are formulated onto the positive scale. The average mean scores for each of components of the SDT model were then summed to create an aggregate score that was then analyzed and compared to the other components of the framework to identify trends. These scores are located in Table 6. The same process described above was completed for the Intrinsic and Extrinsic motivation scores and is located in Table 7. Due to a differing number of questions between the SDT scores and the Motivation scores, separate scales that determine their place on the original rated scale accompany their tables.

Throughout the course of the mission, different classes have participated in considerably different steps of the design process, therefore students' motivations over different years could drastically vary as a result of the unique situations that each group of students experienced. Similarly, since this project took place between three different universities across Virginia, inherent differences in how the class was taught could account for varying results. This demographic information was asked at the beginning of the questionnaire and has allowed the results to be split and analyzed accordingly.

Results

The survey results are shown in Tables 1 – 5 in the Appendix and are organized by the survey question that was asked and further divided into the overall trends of the mission, trends between universities, and trends between years. In order to properly analyze the overall trends between these variables, the aggregate SDT Component Scores and Motivation Scores, located in Tables 6 and 7 below, were analyzed. When looking at each of these variables, the first and most surprising result is that for the SDT Components, they all follow a general trend of falling between 'Agree' and 'Neutral'. This means that throughout all universities and all years the mean values show that for Autonomy, the participants believe that they did experience a sense of autonomy which allowed them to succeed within this mission; the values for Competence indicate that the participants were confident in their abilities and gained important decision-making skills while part of the mission; and the Relatedness section is the strongest feeling for the participants, with the results clearly showing that team relationships and team dynamics played a significant role within the mission and helped to better tackle the problems at hand. It is worth mentioning that each of the variables varied between Agree and Neutral with Virginia Tech and Old Dominion University trending more towards 'Agree', while the University of Virginia consistently trended more towards 'Neutral'.

After sending out surveys and conducting interviews, a total of 30 survey responses were received out of the 157 that were sent. In addition to the surveys, 6 interviews were conducted in order to allow the team members to further elaborate on their specific experiences and give any suggestions or feedback for future missions. These 30 responses were split by 14 from the University of Virginia, 8 from Virginia Tech, and 8 from Old Dominion University. In terms of the year, 24.14% worked in 2017, 31.03% in 2018, and 27.59% in 2019. It is worth mentioning that since the sample sizes of participants during 2015, 2016, and 2020 were incredibly small, those results were excluded from the analysis. These results are in Figure 1 and Figure 2 below.

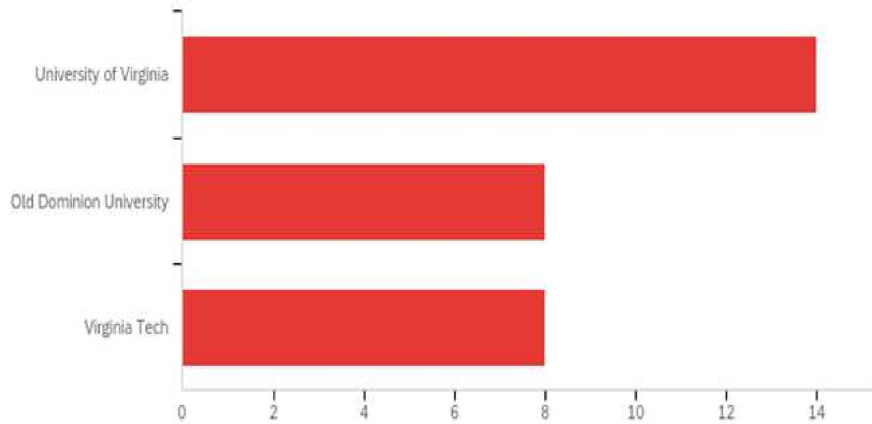

Figure 1: Response Breakdown by University

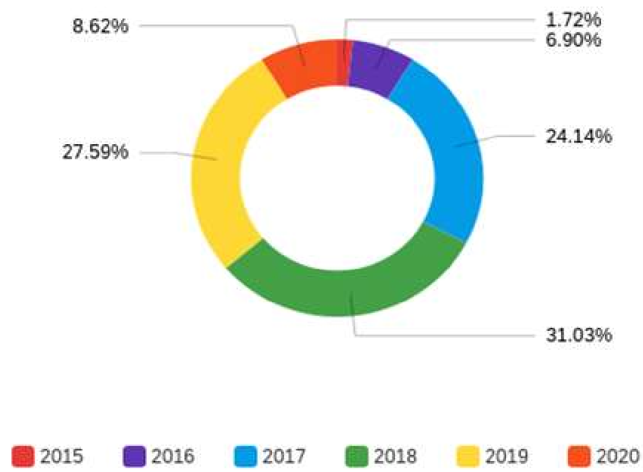

Figure 2: Year Breakdown

One surprising result from the SDT Component scores is the Relatedness score from Virginia Tech. Recall that relatedness refers to creating meaningful relationships and interactions with team members. VT's score for Relatedness was 13.87; a trend between 'Strongly Agree' and 'Agree'. To put this in comparison, this score shows a 6.55 and 5 point difference on the Relatedness scale compared to UVA and ODU's scores respectively. Although the other two universities' Relatedness scores were not as high as VT's, the total Relatedness score between 2017 and 2019 clearly trends more and more towards 'Agree' as the mission progressed. This trend was demonstrated through a 1.28 point difference between 2017 and 2018 and 2.03 a point difference between 2018 and 2019, resulting in a 3.31 point change over this period of the mission. A potential cause of this increase in Relatedness over those three years is an increased amount of communication between the universities. The earlier years of the mission were characterized by a lack of inter-university communication as a result of a perceived sense of competition. It is noted by the students that after each university continually encountered issues that the others were experiencing, it was realized that collaboration would be the only way to succeed as a mission rather than as individual universities.

SDT Component Score	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Autonomy Score	19.68	22.07	18.74	20.25	19.58	19.05	20.06
Competence Score	18.53	25.75	18.23	18.88	19.42	18.83	18.3
Relatedness Score	17.34	20.42	13.87	18.87	18.94	17.66	15.63

Scale	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
	8	16	24	32	40

Table 6: Self Determination Component Scores.

The participants were also asked direct questions about Intrinsic and Extrinsic motivation and the data from the aggregate scores in Table 7 indicates that the students on the project were both intrinsically and extrinsically motivated to do well with a significantly stronger feeling of intrinsic motivation. All of the variables for Intrinsic Motivation trended between ‘Strongly Agree’ and ‘Agree’, whereas the values for Extrinsic motivation consistently trended towards ‘Neutral’. From this interpretation of the data, it is shown that the students within the Virginia CubeSat Constellation were motivated to participate and do well within the project based on a strong personal desire to learn more about the subject and develop valuable skills to help them within their future careers.

Motivation Score	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Intrinsic Score	7.47	8.36	6.13	6.76	7.35	7.39	7.32
Extrinsic Score	11	13.79	13.38	10.51	10.07	10.6	11.44

Scale	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
	4	8	12	16	20

Table 7: Intrinsic and Extrinsic Motivation Scores.

Results from the personal interviews that were conducted can also be used to shed light on the reasons for some of the SDT Component Scores and future improvements that can be made to further increase them. These interviews produced a large amount of lessons learned that can then be related back to the three SDT components of autonomy, competence, and relatedness.

The most common responses and suggestions are recorded in Table 8 and are organized by which component of the SDT they are best categorized as. There was only one suggestion directly related to Autonomy and that was to have smaller component team sizes. Since each university's teams consisted of design courses, some had classes of thirty students working on the project. This resulted in many students in each of the component groups with a smaller portion of the students actually doing the work that had to be done. Although willing to do work, the other students sometimes did not have relevant tasks to perform. This inability to do relevant work directly affects students' feelings of having an impact on the mission and thus affects their sense of Autonomy.

The most prevalent suggestions came from Competence, with a majority of the suggestions focused on improvements to the structure of the mission as a whole. Addressing student turnover early, documenting everything in a clear and consistent manner, establishing system requirements at the beginning of the mission, setting hard deadlines and sticking to them, and setting clear testing standards and procedures early are all based in the structure of the mission. Since this was the first attempt of a CubeSat program for all of the universities involved, no documentation systems or practiced tests and procedures were in place for the students to follow. This responsibility falls on the faculty and management to establish this ahead of time, as students experiencing spacecraft design or real-life engineering design projects for the first time cannot be asked to create this on their own. Having a solid management structure and consistent systems in place allow the students to feel more confident in the operation of and effect on the mission. The last two suggestions for Competence involved making the project more multidisciplinary and involving more industry professionals in the development and design of the spacecraft. After all, the students learning spacecraft design for the first time will not understand all of the technical intricacies involved in the design process. Bringing in other experts who have experienced the design processes and issues that might arise bring a feeling of confidence to the students. This allows them to understand why certain decisions are the correct ones to make and not second guess the decisions that are made.

The last suggestions were characterized by Relatedness and describe being proactive about communicating well within sub-teams as well as communicating between teams and, once again, wanting to have more collaboration with industry professionals. The VCC mission was unique in the challenges that it faced in regards to communication. Communication within and between sub-teams is one thing, but communicating between three separate university CubeSat teams with three separate designs poses a large challenge. Early communication between the universities was less than optimal, but established relationships between the student leads over the course of the mission allowed for more frequent and candid communication. These relationships built between the universities allowed for the mission to be as successful. The last comment about involving more industry professionals is more related to professional development. By involving industry professionals, the students build relationships with these professionals and their companies, which in turn can lead to job opportunities.

Discussion

The lowest levels of any of the SDT components was Autonomy. Remember that Autonomy describes the students' feeling that the work that is completed is worthwhile to the mission and that they are having a real impact. This is in addition to being allowed to learn and explore topics on their own. Although the students did report that they were given autonomy while learning, the lack of involvement from industry professionals or individuals with this specific subject area knowledge made it difficult to make important decisions early on in the mission. Important decisions were then often made by faculty, which could explain the lower feeling of impact by the students. Although it is true that the students cannot make every decision and the faculty should step in when there are looming deadlines, I believe a lack of understanding about why some of the decisions were made and why they were correct over other decisions, aided in the lack of autonomy. Similarly, as discussed above, the effect of having too large component teams also impinged on the students' ability to complete meaningful work. That being said, these lowest scores still trended between 'Agree' and 'Neutral' and still indicate that the mission succeeded in instilling a sense of autonomy within the students.

A similar explanation can be given for the score of competence being the second highest score for the SDT components. Feedback from the interviews and comments made within the survey indicate that bringing in outside help to assist in making design decisions and solving problems that arose would have gone a long way towards giving the students more confidence in making decisions. Likewise, a direct effort to establish structure with respect to documentation practices and standards for tests at the start of missions in the future will help to improve the confidence and competence levels of students.

Although there is no direct comparison for analysis of CubeSat courses based on the SDT, Williams & Deci (1996) conducted a similar study of 2^{nd} year medical students' self-determination and came to the conclusion that strong positive relations were found between medical students' self-determination and their autonomous reasons for participating in the course and the perceived autonomy supportiveness of the instructors was found to promote students' becoming more autonomous in learning, feeling more competent, and subsequently behaving in a more autonomy-supportive manner. The conclusions from this study ring true with the VCC mission. Aside from the direct comments made to improve the structure of the mission, the instructors did promote autonomous learning within the students. The students indicated that they were given freedom to explore the topics that interested them within their component teams, which in turn formed a basis for the high levels of competence and relatedness that arose from this autonomy.

Similarly, another study of instructors’ autonomy support and students’ autonomous motivation on learning organic chemistry was conducted by Black & Deci (2000) in order to measure Intrinsic motivations within a similar educational setting. Their study on autonomy over the course resulted in conclusions that students who entered the course with more autonomous motivation had more positive experiences within the course along with higher perceived competence and enjoyment of the subject. The same conclusions from this study can be drawn from the VCC mission. From the interviews that were conducted, despite giving some of the criticisms stated above, the students left the program believing that their time spent with the mission was worthwhile and their continued love for the subject from the beginning to the end of the mission allowed them to succeed. This participation has allowed them the opportunity to obtain space-related jobs in Northrop Grumman, Lockheed Martin, and other companies that they believe they would not have been able to obtain without their experience on the VCC mission. That being said, efforts made to address the criticisms made by the students in this paper will allow for the improvement and continued success of CubeSat missions at all three universities.

This study is not free of limitations. The most evident limitation for this study is the lack of a statistically significant sample size compared to the total population size of students who worked on the VCC mission. Although all of the students were emailed with surveys and requests to do interviews, the emails that were used were old school email addresses, which students could potentially no longer use as most have long since graduated and gone into the workforce. As a result, there were only 30 responses to the survey. Similarly, more responses from each school need to be collected in order to better analyze the trends between the three universities. Another limitation for this study was the time window that it had to be conducted within. The survey responses and interviews took place over a two-week period in order to allow for people to respond and a reminder email to be sent the following week. This left little time to do in-depth interviews with people considering the scheduling difficulties with college classes and the availabilities of the participants. Lastly, the number of questions that were asked, even with positive and negative counterparts, are far from a comprehensive understanding of the Intrinsic motivations of these students.

In order to address these limitations, the biggest aspect of the study that should be changed is the involvement of the other universities. By having the Principle Investigators for each of the schools contact their former students, this could allow for significantly more responses due to the availability of a more comprehensive contact list and the effect that familiarity with the contact could have on a participant’s decision to respond to the survey. Likewise, with more school participation, the task of interviewing the former students could be spread between multiple people and allow for a better understanding of the students’ sentiments within the small data collection window. Potentially funding graduate students to perform these tasks would allow for this to happen. Although this last solution could aid data collection within a small time-frame, a much longer period of time should be taken in order to maximize the response rate of the participants. Finally, if more questions were able to be asked, while still maintaining a high response rate, a more comprehensive analysis of the Intrinsic motivations could be done to better determine the successes and shortcomings of the VCC mission.

The best use of this research is to aid university-led CubeSat programs in serving the students that are participating in missions in order to produce the best results possible. In the context of the VCC mission, this data and analysis can be used to improve the CubeSat programs within the University of Virginia, Virginia Tech, and Old Dominion University. The VCC mission was the first attempt at building CubeSats for all of the schools, so many lessons were learned as a result of this inexperience. As a result, the analysis of student motivations and the suggestions gathered from interviews will allow all three programs to better learn from previous mistakes and produce more successful missions. The capacity for these student-led design projects is limitless in terms of experience gained, knowledge and skills learned, and industry contacts made. As a result, it is in the best interest of the three universities to invest in these projects and provide their students with the best possible path forward into industry and academia.

Conclusion

The results from this research can potentially have serious implications for the Aerospace Industry. NASA in particular knows how important education and outreach are to inspiring students as they seek to explore the topics they are interested in. The results from this research can help to not only demonstrate the importance of educating as a principle, but emphasize the methods that are used to educate in order to maximize students' desire to learn and explore. As a result, this research has the ability to directly improve university-led CubeSat projects across the country and potentially be applied to other design-based courses in other disciplines. Specifically, within the VCC mission, the next steps for other people are to apply the lessons learned from this mission to ongoing or future CubeSat missions within the three universities. The suggestions and experiences obtained from the interviews (see Table 8) would be a great place to start to best serve these future missions. There are a lot of ways to go wrong in a mission of this size and scope, so the need for future missions to heed warnings and take advice is paramount for creating successful missions. Although the technical success of the mission is extremely important, an education-based definition of mission success is necessary. Because of this, the primary take-away from this research should be to focus on the students first. Amid looming deadlines, sponsors expecting results, and the pressures of learning a completely foreign discipline, instructors need to listen to their students and prioritize their education and development as they are the future of the industry.

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Appendix

Table 1: Autonomy for Overall survey, UVA, VT, ODU, 2017, 2018, and 2019 Mean Response Breakdown.

	#	Field	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Autonomy	1	The decisions I made had lasting impacts on the mission	2.67	2.36	2.63	2.88	2.43	2.28	2.94
	2	The work I completed was worthwhile to the success of the mission	2.47	2.86	2.5	2.63	2.29	2.22	2.56
	3	I had a real say in the decisions that were made for the mission	2.67	2.57	2.88	2.63	2.57	2.5	2.69
	4	My teachers were supportive of me learning on my own time	2.07	2.07	2.25	1.88	2.36	2.22	1.88
	5	I felt forced to do the work within my team	2.03	2.5	1.62	2.12	2.07	1.94	2.12
	6	The work I completed was what the team needed rather than what I wanted to do	3.2	3.93	3.12	3.37	3.29	3.39	3.25
	7	I felt like I did not have a voice in making decisions	2.37	2.57	2.12	2.62	2.43	2.22	2.31
	8	My teachers did not allow me to explore the topics I was interested in learning	2.2	3.21	1.62	2.12	2.14	2.28	2.31
	Autonomy Score		19.68	22.07	18.74	20.25	19.58	19.05	20.06

Table 2: Competence for Overall survey, UVA, VT, ODU, 2017, 2018, and 2019 Mean Response Breakdown.

	#	Field	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Competence	9	I felt comfortable making decisions for the mission	2.53	3.79	2.75	2.38	2.43	2.56	2.69
	10	My confidence in making decisions increased throughout the course of the class	2.62	2.43	2.5	3	2.92	2.67	2.44
	11	I learned a significant amount about spacecraft design	2.23	2.71	2	2.63	2.57	2.33	1.94
	12	My participation in the VCC mission has helped my confidence making decisions in my job today	2.67	3.57	2.75	2.5	2.86	2.72	2.56
	13	I felt insecure about my ability to make decisions	2.37	3.71	2.62	2	2.07	2.33	2.87
	14	My confidence in making decisions decreased throughout the course of the class	1.97	3.54	2.12	2	2	2	2.06
	15	I did not learn much about spacecraft design	2.27	1.86	2.12	2.62	2.71	2.33	1.87
	16	My participation in the mission hindered my confidence going into the workforce	1.87	4.14	1.37	1.75	1.86	1.89	1.87
	Competence Score		18.53	25.75	18.23	18.88	19.42	18.83	18.3

Table 3: Relatedness for Overall survey, UVA, VT, ODU, 2017, 2018, and 2019 Mean Response Breakdown.

	#	Field	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Relatedness	17	I created worthwhile relationships with team members	2.17	2.14	1.5	2.25	2.43	2.33	1.88
	18	Team dynamics were an important part to the success of the mission	1.87	2.57	1.38	2	1.93	1.78	1.69
	19	My experience on the mission prepared me to work with others at my current job	2.3	3	2.25	2.38	2.5	2.22	2.19
	20	I enjoyed working with my team on the VCC mission	2	2.21	1.5	2.38	2.14	2.17	1.75
	21	I did not develop worthwhile relationships with my team members	2.17	2.36	1.37	2.25	2.36	2.33	1.87
	22	My team was disorganized and did not contribute well to the success of the mission	2.53	2.43	2.25	2.87	2.86	2.61	2.31
	23	My experience working on the mission did not prepare me for group work at my current job	2.37	2.21	2.25	2.37	2.43	2.11	2.25
	24	I did not enjoy working with my team on the VCC mission	1.93	3.5	1.37	2.37	2.29	2.11	1.69
	Relatedness Score		17.34	20.42	13.87	18.87	18.94	17.66	15.63

Table 4: Intrinsic Motivations for Overall survey, UVA, VT, ODU, 2017, 2018, and 2019 Mean Response Breakdown.

	#	Field	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Intrinsic	25	I felt motivated to do good work because the mission interested me	1.87	2.07	1.5	1.63	1.64	1.72	2
	26	My participation in the mission allowed me to explore topics I am interested in	2.13	2.29	1.75	2	2.29	2.28	1.88
	27	I enjoyed learning spacecraft design as part of a real-life mission	1.6	1.71	1.38	1.63	1.71	1.56	1.5
	28	I enjoyed the challenge that came with the mission	1.87	2.29	1.5	1.5	1.71	1.83	1.94
	Intrinsic Score		7.47	8.36	6.13	6.76	7.35	7.39	7.32

Table 5: Extrinsic Motivations for Overall survey, UVA, VT, ODU, 2017, 2018, and 2019 Mean Response Breakdown.

	#	Field	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Extrinsic	29	I felt motivated to do good work to get a good grade	2.97	3.86	3.75	2.13	2.57	2.83	3.06
	30	I did the work to get good experience on my resume	2.4	4	2.25	2.75	2.07	2.11	2.56
	31	I participated in the class to satisfy degree requirements	2.83	3.43	4.38	3	2.79	2.83	2.94
	32	My participation in the mission was for professional gain	2.8	2.5	3	2.63	2.64	2.83	2.88
	Extrinsic Score		11	13.79	13.38	10.51	10.07	10.6	11.44

Table 6: Self Determination Component Scores.

SDT Component Score	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Autonomy Score	19.68	22.07	18.74	20.25	19.58	19.05	20.06
Competence Score	18.53	25.75	18.23	18.88	19.42	18.83	18.3
Relatedness Score	17.34	20.42	13.87	18.87	18.94	17.66	15.63

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Scale	8	16	24	32	40

Table 7: Intrinsic and Extrinsic Motivation Scores.

Motivation Score	Overall Mean	UVA Mean	VT Mean	ODU Mean	2017 Mean	2018 Mean	2019 Mean
Intrinsic Score	7.47	8.36	6.13	6.76	7.35	7.39	7.32
Extrinsic Score	11	13.79	13.38	10.51	10.07	10.6	11.44

Scale	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
	4	8	12	16	20

Table 8: Interview Results and Common Suggestions

Autonomy	Have smaller team sizes to maximize efficiency and ensure participation
Competence	Student turnover has to be addressed early
	Document everything using a clear and consistent system from the start
	Make the project more multidisciplinary
	Create system requirements at the beginning of the design process
	Collaboration with more industry professionals help to solve problems and instill confidence
	Hard deadlines need to be set and adhered to in an open-ended project such as this
	Set Clear testing standards, testing goals, and procedures early
Relatedness	Be proactive about communication in teams and between teams
	Collaboration with more industry professionals builds valuable professional relationships

Figure 1: Response Breakdown by University

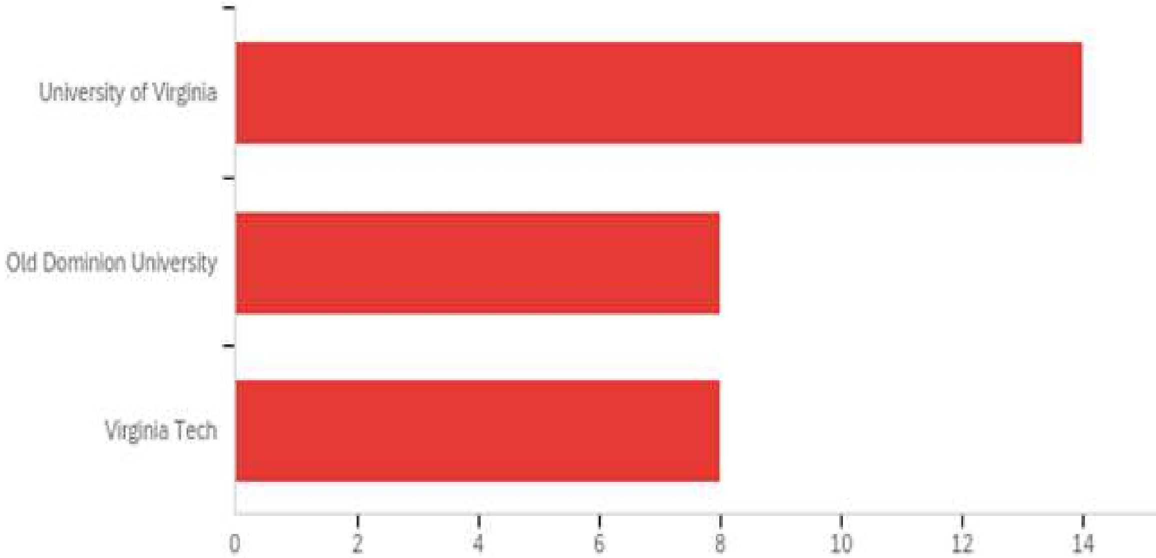

Figure 2: Year Breakdown