CubeSats and Effective STEM Education

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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

In today's technologically advanced society, current projections reflect that the demand for Science, Technology, Engineering, and Mathematics (STEM) jobs in the United States will continue to increase. However, by 2025, approximately 3.5 million jobs will remain open due to the lack of individuals with STEM skills. Additionally, according to a White House report, only 20% of high school graduates are prepared for the rigorous coursework of STEM majors (Barone, 2021). Increasing the number of qualified individuals with STEM skills can be fundamentally achieved by fostering student interest and retention in STEM disciplines. To do so, and prepare students for challenging STEM coursework past high school, many educational institutions across the United States are seeking alternative means to improve their students' STEM education experience. Several frameworks on how to cultivate an effective learning environment in STEM education have been developed such as the Deliberate Pedagogical Teaching with Technology Theory, the Growth Mindset Theory, and the Situated Cognition Theory. One way these theories have been applied is through the use of the CubeSat platform, which facilitates opportunities for enhanced STEM learning through student-led research. This paper will discuss the CubeSat platform as an effective tool to increase student attraction and retention in STEM fields and ultimately minimize the deficit of qualified individuals with STEM skills in the United States.

Context

CubeSats are low-cost nanosatellites. Nanosatellites are defined as any satellite weighing between 1 and 10 kilograms. The standard CubeSat is "one unit" or "1U" in size, measuring 10 cm x 10 cm x 10 cm and weighing less than 1.33kg. CubeSats are able to be enlarged to 2U, 3U, 6U, and even 12U (Loff, 2018).

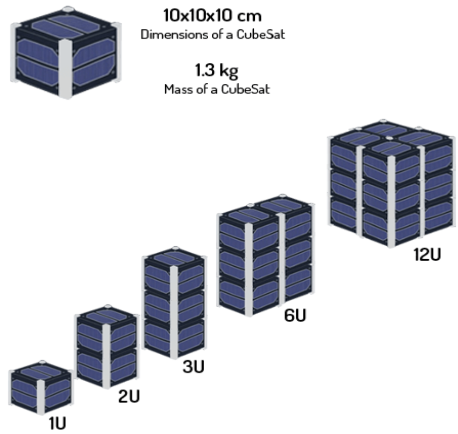

Figure 1: Models of 1U, 2U, 3U, 6U, and 12U CubeSats (Alen Space, 2021)

The nanosatellites were first developed in 1999 by Professor Jordi Puig-Suari of California Polytechnic State University and Professor Bob Twiggs of Stanford University, with the intention to design a cost-effective platform to “allow graduate students to conceive, design, implement, test and operate in space a complete spacecraft in a reasonable amount of time” (Camps, 2019, n.p.). At this time, traditional satellites were large in size, which caused a greater temptation to pack as much hardware into the satellite as possible. This created expensive projects, decreased the initiative to create something smaller and more efficient, and made space science less accessible to students. Therefore, the professors challenged their students with constructing a satellite that was equivalent to the size of a Beanie Baby, transforming the world of satellites to be dominated by the CubeSats we are familiar with today (Harford, 2019). Students ranging from elementary to graduate-level education have the capability of conducting research with CubeSats. U.S. universities have collectively reported that more than a thousand students per year graduate with some experience working with CubeSats (National Academies of Sciences, Engineering, and Medicine, 2016).

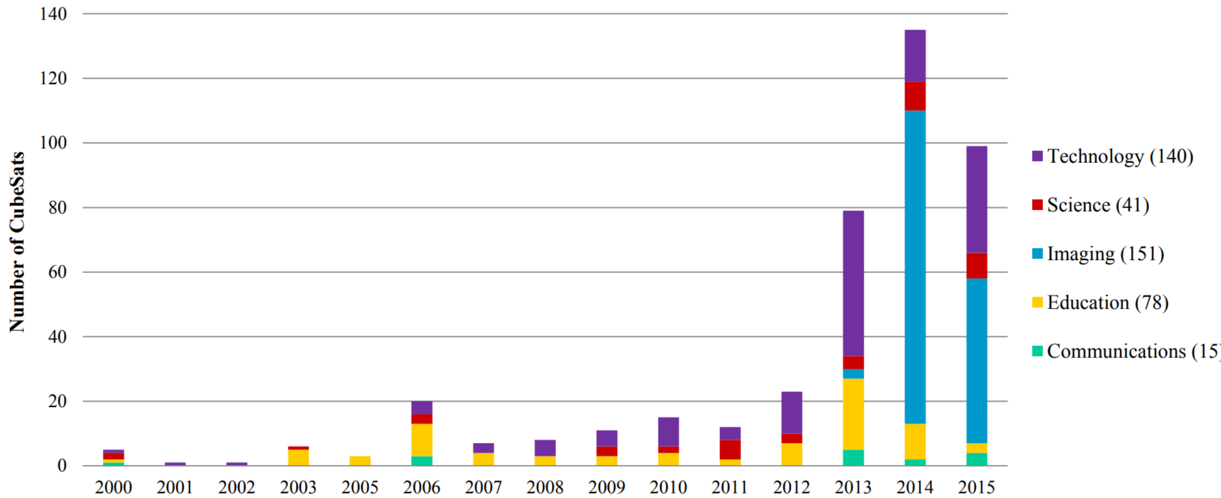

Figure 2: Number of CubeSats launched per year by mission type from 2000-2015 (National Academies of Sciences, Engineering, and Medicine, 2016)

Figure 2 shows that the number of CubeSats launched per year has drastically increased over time, representing the heightened desire to use the nanosatellites for a variety of applications. Today, CubeSats are commonly used for applications in low Earth orbit such as remote sensing and communications. They can be launched into space aboard rockets for other missions, providing an abundance of launch opportunities at a low cost (The European Space Agency, 2021).

NASA's CubeSat Launch Initiative (CLSI) is a program that has provided opportunities for students to launch small satellite payloads on previously planned missions for research addressing "aspects of science, exploration, technology development, education, or operations" (Loff, 2018, n.p.). In this program, students submit proposals for their CubeSat to be launched into space. To date, NASA has launched 124 of its selected 220 CubeSat missions, 37 of which are scheduled for launch within the next year (Costa, 2021).

NASA's Educational Launch of Nanosatellites (ELaNa) initiative is an additional program that intends to increase student attraction and retention in STEM disciplines through spaceflight education in high schools and colleges across the United States. It is managed by the Launch Services Program (LSP) at NASA's Kennedy Space Center. Students are heavily involved in all aspects of the mission from preliminary design to assembling and testing payloads. ELaNa missions consist of payloads selected through the CLSI (Heiney, 2017).

Build, Launch, Utilize, and Educate Using CubeSats (BLUECUBE) Aerospace is an organization created by educators to provide K-12 students the opportunity to gain experience in the design, development, and applications of satellite data through involvement in real-world CubeSat missions. Additionally, it seeks to foster Teacher Professional Development, establish funding opportunities for projects, and hold competitions at various levels (local, regional, state, and national) to enhance engagement in the production and launch of spacecraft. BLUECUBE promotes the use of CubeSats as a superior alternative, or "disruptive technology", for students to acquire relevant skills for the twenty-first-century workforce (Moore, 2013).

These various programs introduce educational spaceflight at diverse levels of education by fostering the development of student-led CubeSat projects. They support increased attraction and retention rates for students in STEM disciplines. Additionally, they serve as evidence of the overall growing popularity of using nanosatellites as an effective tool in STEM education.

CubeSat Setbacks

Although CubeSats have shown to have substantial positive impacts on STEM education, we should also consider the challenges of launching so many nanosatellites into space. According to the United Nations Office for Outer Space Affairs (UNOOSA), over 11,000 objects, consisting of satellites, probes, rockets, and other space objects, have been launched into space (Alen Space, 2021). Although CubeSats are small in size, the debris of all the CubeSats in space may overcrowd the space environment and result in collisions with other space systems.

To this day, even inactive CubeSats remain in orbit, posing a threat to other systems. This overcrowding also leads to interference in data collection, resulting in the creation of unique frequencies which can add even more interference and limit radio communication resources (Novak, 2022). However, students have the capability to design CubeSats that bypass these issues. For instance, students may design the craft such that the satellite burns up after its mission is complete, rather than floating around and creating space debris. There are alternatives for student-led research projects to promote STEM learning such as High Altitude Balloons. However, there does not exist a strong alternative that has an equivalent or greater impact on STEM education than CubeSats and the potential to increase attraction to STEM fields through a cost-effective method of easily launching an object into space. Therefore, CubeSats continue to serve as an effective platform and are projected to be increasingly launched in the future (Camps, 2019).

Theory

Currently, there exists an increased adoption of "hands-on learning experiences" in STEM education that diverges from traditional lecture-based teaching. Research shows that average exam scores are higher for students who are engaged in hands-on learning versus those in lecture-based learning. In active-learning environments, exam scores improved by approximately 6 percent while students in traditional lecture settings were 1.5 times more likely to fail their classes (NASME, 2016).

In her paper regarding research in STEM teacher education, Milner-Bolotin discusses various theories to enhance STEM education practices and identifies shortfalls of STEM education reforms. The *Deliberate Pedagogical Teaching with Technology Theory* describes "how teachers can utilize modern technology to support student collaboration and engagement with specific subjects at a level previously impossible to achieve" (Milner-Bolotin, 2018, n.p.). This theory also argues that to support effective STEM education, it is important for teachers to include comprehensive STEM curricula rather than teaching subjects separately through problem-solving that involves multiple disciplines. Teachers are encouraged to use educational technology to promote collaborative student engagement. Since STEM teachers are often educated only in the expertise of which they are teaching, they rarely experience multidisciplinary STEM education, collaborate with peers who have different STEM backgrounds, and use technology to enhance learning experiences (Milner-Bolotin, 2018).

Milner-Bolotin also discusses the *Growth Mindset Theory*, which "studies what helps people persevere in the face of failure" (Milner-Bolotin, 2018, n.p.). The theory has shown that those who are more inclined to personal growth by acquiring new skills and knowledge are more likely to work to achieve their end goal, despite facing challenges and failures. Moreover, these individuals view challenging experiences as a natural occurrence in the progression toward success (Milner-Bolotin, 2018,).

In their paper detailing an effective framework for STEM education, Kelley and Knowles discuss the Situated Cognition Theory. This theory is "the concept that understanding how knowledge and skills can be applied is as important as learning the knowledge and skills itself" (Kelley and Knowles, 2016, n.p.). The theory highlights that both physical and social elements of a learning experience are critical to the learning process as a whole. It further states that when a student develops a knowledge and skill base around an activity, the context of the activity is essential to the learning process. When grounded by situated context, learning is found to be authentic and relevant, and therefore an accurate representation of practices found in actual STEM practice. The authors also state, "When considering integrating STEM content, engineering design can become the situated context and the platform for STEM learning" (Kelly and Knowles, 2016, n.p.).

Evidence and Application of Theory

Evidence was obtained through formal sources such as scholarly articles and news reports in addition to informal sources such as blog posts and YouTube videos. These sources describe previous applications of CubeSats in STEM education such as specific missions, responses to CubeSat projects, as well as effects of CubeSats in the classroom setting. Each of the aforementioned theories that provided frameworks for effective STEM education was applied to the evidence collected to support that CubeSats are a powerful platform to promote STEM fields and enhance STEM education.

Through the successful application of the aforementioned theories, the CubeSat platform has been shown to be instrumental in fostering effective STEM education by providing a hands-on learning experience. The design and operation of a space mission, which is exhibited through CubeSat projects, give students the opportunity to be exposed to complex problems while working in a multifunctional team. Collaborative and hands-on learning techniques have been shown to have a positive impact on student retention rates in STEM fields (NASEM, 2016). Student-led CubeSat projects support the Deliberate Pedagogical Teaching with Technology Theory as they enable students to collaborate with one another by working on teams to develop the project and are simultaneously exposed to various STEM subjects, allowing them to gain a more comprehensive understanding of the applied concepts and learning experience.

Applying the Situated Cognition Theory to CubeSats supports the ability of the platform to create experiences that can be applied in STEM professions. The engineering design process of developing a CubeSat mission serves as the "situated context" and allows students to gain an authentic understanding of engineering design and skills relevant to these future careers in STEM. Additionally, students work on teams and are required to collaborate with other team members to successfully complete the project, which is highly likely in an engineering job. This composes the social element of the learning experience, a critical component of the learning process. The actual construction of the CubeSat makes up the physical element of the learning experience and allows students to clearly understand the concept they are developing through a physical manifestation of their design. The application of the Situated Cognition Theory in CubeSats shows how the platform establishes a situated context and contributes to the social and physical aspects of the learning experience, creating individuals who are more interested in the STEM field and prepared for STEM-related professions.

The ELaNa 41 Mission consisted of three CubeSats designed by students from the University of Alabama, New Mexico State University, and the University of California at Berkeley. The student payloads intended to conduct experiments regarding drag sails, space weather modeling, and quantum gyroscopes. The satellites were launched into space onboard Astra Space Inc.'s Rocket 3.3 vehicle. However, the satellite deployment was unsuccessful after the rocket's upper stage lost control following stage separation (Davis, 2022). Although the CubeSats from the ELaNA 41 Mission were unsuccessful in collecting their intended data, the students were still given the opportunity to be heavily involved in an interdisciplinary engineering design process and were exposed to the reality of failure when working in the engineering field. This mission exemplifies that within their CubeSat projects, students are bound to experience challenges and failures, whether they exist throughout the design process or after launch. This provides students with the ability to apply the Growth Mindset Theory as they continue to persevere through the challenges they face as they work on CubeSat projects, contributing to their personal growth and acquiring new skills and knowledge that are relevant to the STEM field.

CubeSats have not only increased student attraction to STEM disciplines but also increased public awareness of the STEM field. This can be exemplified through news articles, blogs, and social media posts that have highlighted CubeSat launches. Astra's failed launch and the ELaNA 41 CubeSat failures attracted public attention as several news articles were published and the launch was live-streamed and can be found on YouTube. These outlets fostered public discussion as several individuals commented on how the issue might have been avoided while others had negative views on the launch and Astra as a company (Foust, 2022). In the YouTube video broadcasting the launch, many comments include encouragement and support for Astra to keep trying despite the numerous failed launch attempts and condolences to the students and engineers as their hard work was destroyed (NASASpaceflight, 2022). This CubeSat mission attracted public attention and increased awareness of the work being completed with CubeSats, potentially gaining greater interest in STEM disciplines.

According to a report from the National Science Foundation (NSF), CubeSat programs serve as one of the only effective ways for students to be involved with a spacecraft that has a high probability of being launched into space. Over 50% of students who have been involved in a CubeSat project have pursued careers in the aerospace industry. CubeSat projects appeal to a broader range of participants than more traditional science and engineering projects due to the diverse set of skills and interests required to complete a CubeSat project (NASEM, 2016). Public accessibility to CubeSats and their low cost due to the possibility to use commercial electronic parts from various technology suppliers allows practically anyone to conduct their own experiments for research in space. CubeSats have created opportunities for students, teachers, and those interested in spacecraft flight to drive research agendas and strengthen the connection between science and society by exploring new ideas that might not be explored on other more expensive and sophisticated satellites due to high risk (Novak, 2022). The ability to more feasibly launch an object into space is fascinating and increases public interest and knowledge of the STEM field.

Conclusion

Since their first introduction in 1999, CubeSats have been increasingly launched over time. They have been used for a variety of research purposes as well as giving students greater experience in a variety of technical areas as well as familiarity with the engineering design process. Despite potential setbacks regarding the launch of an abundance of CubeSats into space, organizations such as NASA and BLUECUBE Aerospace should continue to fund and coordinate CubeSat projects as the platform has shown to hold high educational value for future scientists and engineers. Various teaching theories such as the Deliberate Pedagogical Teaching with Technology, Theory Growth Mindset Theory, and Situated Cognition Theory provide frameworks for ways to promote effective STEM education. The evidence collected supports the use of the CubeSat platform in STEM education as it directly applies these theories to support student attraction and retention in STEM fields in the classroom setting in addition to increasing overall public awareness of the engineering field.

Further research in this area could consist of interviews with students who completed CubeSat projects regarding their experiences in completing the project, how it affected their view of STEM disciplines, as well as the impacts it had on preparing them for a future career in STEM. This would provide more clear, qualitative data regarding the effectiveness of CubeSats in fostering superior STEM education experiences. Knowledge of teacher experiences with

CubeSat projects would also be useful as they can provide their observations of students working on the projects which can assist in assessing the feasibility of the platform in achieving enhanced STEM learning experiences.

Overall, the use of the CubeSat platform has shown to have high functionality as our world becomes more technologically advanced and there continues to be a need for qualified individuals who can fill the millions of open job opportunities in the STEM field.

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