The Development of an Undergraduate Ground Station Project for Space Education

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Abstract

Of the complaints passed through engineering university halls one that stands out is the lack of meaningful projects available. Many students want to work on projects they can be proud of and unfortunately such is lacking in many universities. There is simply not enough time to construct a large project in a singular semester and as such many students turn to clubs and design teams. At Carleton University one design team which has stood out in this front has been CU-Stellar, Carleton University's ground station development team. The reason for their fortitude is that it is a student-run club designed solely for long term development. Other clubs compete in competitions on an annual basis however CU-Stellar does not compete in competitions, it exists solely as a design team with goals set internally by members. There are many benefits to this. For one, CU-Stellar put a lot of emphasis on teaching students the ins and outs of startup development. One aspect of this exists in the financial strain put on the low-budget design team. The team aims to stay as low budget as possible to allow for rapid development. By using commercial off the shelf and self-manufactured parts members can iterate on their designs quickly without greatly worrying about financial implications. Speaking of which, this design team also teaches students about the design process seen in startups and how designs are improved over time. With this, CU-Stellar gives students long-time real-world experience which would otherwise be impossible in class. By not being confined to the rigors of a standard two semester system, CU-Stellar can operate year round. Long exposure to varying aspects of engineering helps students learn what side of engineering they are truly passionate about which greatly aids them once they embark on their professional journeys after graduation. Finally, the ground station development project is a great project for students as it allows for creative design and iteration. By remaining low budget and not having a fixed goal students can decide what they would like to do with the project and they get to choose how they get there. Allowing this freedom shows undergraduate students the reaches of engineering and how creativity plays a role in the development of an engineering project. The implementation of a ground station development project into other universities would be of great benefit to undergraduate students and would greatly improve the quality of engineers graduating.

1. Introduction

In the ever-evolving landscape of engineering education, the integration of practical, hands-on projects has become increasingly crucial for producing well-rounded graduates. Traditional classroom learning, while essential for building theoretical foundations, often falls short in providing students with the real-world skills and experiences necessary to thrive in the engineering profession. Recognizing this gap, many universities and educational institutions have begun incorporating project-based learning into their curricula. This approach not only bridges the gap between theory and practice but also fosters essential skills such as problem-solving, critical thinking, teamwork, and communication.

One such initiative that exemplifies the power of project-based learning is CU-Stellar, Carleton University's ground station development team. CU-Stellar is a student-run club dedicated to the long-term development of a functional ground station. Unlike many other student clubs that focus on annual competitions, CU-Stellar operates year-round, providing students with an extended timeframe to engage deeply with a complex engineering project. This unique approach offers numerous benefits to undergraduate students, enhancing their technical skills, fostering an entrepreneurial mindset, and preparing them for the challenges of real-world engineering.

This paper explores the various ways in which CU-Stellar's ground station development project contributes to the enhancement of undergraduate engineering education. The paper is organized into three main points, each highlighting a specific aspect of the project's educational value.

2. Low Budget Design

CU-Stellar teaches students how to start a startup by imposing financial strain, promoting rapid prototyping, and emphasizing the iterative design process. Financial constraints are an inherent part of the CU-Stellar experience, teaching students essential budgeting and accounting skills. To manage its limited budget, the team engages in various fundraising activities, seeks partnerships with local businesses, and actively pursues sponsorships. For instance, CU-Stellar has organized events such as bake sales, crowdfunding campaigns, and networking nights to generate funds.

Additionally, students regularly pitch to potential sponsors and collaborate with local industry partners to secure in-kind donations and discounts on necessary materials. Utilizing tools like Excel for meticulous budget management, students track expenses, forecast financial needs, and analyze cost-saving measures. Regular communication with the Carleton Mechanical and Aerospace Engineering department helps secure institutional funding and streamline the purchase of materials and parts, providing a realistic experience of financial negotiation and procurement [1]. This hands-on experience with budgeting and cost management equips students with practical skills that are directly applicable in real-world engineering projects.

Moreover, CU-Stellar places a strong emphasis on performing cost-benefit analyses, helping students decide between commercial off-the-shelf (COTS) parts and self-manufactured components. Students learn to weigh the advantages and disadvantages of different sourcing options, considering factors such as cost, quality, availability, and time constraints. This decision-making process is crucial for effective resource allocation, mirroring the complexities of real-world engineering project management, where prioritizing spending and efficiently allocating resources are critical for project success. Through this practice, students gain valuable insights into strategic planning and operational efficiency, essential skills for any startup environment.

The team's commitment to teaching students about rapid prototyping is evident in its adoption of agile development practices. Agile methodologies facilitate iterative development cycles, allowing for rapid prototyping and continuous improvement. CU-Stellar employs various agile techniques, such as sprint planning, daily stand-ups, and retrospective meetings, to keep the team focused and adaptable. For instance, CU-Stellar has iteratively designed mechanical components such as gear meshes for the ground station rotation mechanisms to reduce slack and improve accuracy. The team has also developed self-stabilization techniques using motor encoders, which have undergone multiple iterations to enhance performance. Another notable project is the development of NeedleGUI, a pointing software that controls the ground station. This software has evolved from simple terminal-based applications to a comprehensive graphical user interface (GUI) with ongoing work on signal searching capabilities [2]. Throughout these projects, students utilize tools such as OnShape, SolidWorks, and 3D printers, which are integral to the prototyping and testing processes. These tools enable students to quickly transform ideas into tangible products, fostering a hands-on learning environment where theoretical knowledge is applied in practical scenarios [3]. The team's culture encourages viewing failures as learning opportunities, promoting resilience and a growth mindset among students. By embracing mistakes and learning from them, students develop critical problem-solving skills and adaptability, which are invaluable in any entrepreneurial endeavor.

CU-Stellar also emphasizes the iterative design process, guiding students through various stages from initial concept and design to testing and refinement. The design process begins with brainstorming sessions, where students propose ideas and evaluate their feasibility. This is followed by detailed design and modeling, where concepts are translated into technical specifications and CAD models. The team then proceeds to prototype development, testing, and evaluation, where designs are iteratively refined based on performance feedback. Feedback loops are a critical component of this process, with input from team members, faculty advisors, and industry experts continuously incorporated to improve the project. Regular design reviews and critique sessions ensure that all aspects of the project are rigorously examined and optimized. A notable case study involves the development of the signal search technology. Initially, the technology faced accuracy issues, which were addressed by spiraling the ground station to map the power of a signal over an area and then pointing to the strongest signal. This iterative approach led to significant improvements in the ground station's performance. Enhancements such as improved gears and encoder stabilization have further increased accuracy, demonstrating the effectiveness of iterative design [4]. Currently, efforts are focused on improving search pattern techniques to map signals and determine satellite positions more effectively. These experiences provide students with a comprehensive understanding of the design process, illustrating how designs are refined and improved over time through continuous feedback and iteration.

Through these multifaceted learning experiences, CU-Stellar not only teaches students the technical skills required for engineering but also instills in them the entrepreneurial mindset necessary for startup success. The practical knowledge gained from managing budgets, rapidly prototyping solutions, and iteratively refining designs prepares students for the dynamic and challenging environment of technology startups. As a result, CU-Stellar graduates are well-equipped to navigate the complexities of startup development, making them valuable assets in the engineering and technology sectors.

3. Real-world Experience

CU-Stellar gives students long-term real-world experience in an engineering project by allowing them to engage deeply with projects over an extended period, providing hands-on engineering experience, and helping them discover their engineering niches and specializations. One of the key aspects of CU-Stellar is the opportunity it provides for students to experience the full timeline of large engineering projects. The extended timeframe, unconstrained by the typical academic year, allows students to immerse themselves in long-term projects, fostering a deeper understanding

of the engineering process. This prolonged engagement gives students the freedom to develop and refine ideas that would not be feasible within a single semester. By working on extended projects, students gain valuable experience in navigating the bureaucratic and procedural aspects of engineering, such as securing approvals, managing project timelines, and adhering to regulatory requirements [1]. This exposure to real-world administrative challenges equips students with the skills needed to manage complex projects in their professional careers. Additionally, the extended timeline allows students to learn from their mistakes and iterate on their designs, fostering resilience and promoting a culture of continuous improvement [2].

Another significant benefit of CU-Stellar is the hands-on approach it offers to engineering. Students are involved in various stages of the manufacturing process, providing them with direct experience in machining, installation, maintenance, and dealing with wear and tear of components. This practical involvement helps students develop essential hands-on skills and practical sensibilities that are crucial for their future careers. For example, students might engage in tasks such as fabricating parts using 3D printers, assembling components, and performing maintenance on the ground station equipment. These experiences not only enhance their technical skills but also improve their ability to communicate effectively with fabricators and other professionals involved in the manufacturing process. This improved communication is vital for ensuring that designs are accurately translated from concepts to physical prototypes and final products [3]. Moreover, by working closely with experienced professionals, students learn the importance of collaboration and teamwork in engineering projects.

CU-Stellar also plays a crucial role in helping students discover their engineering niches and specializations. Through exposure to different engineering fields and hands-on projects, students can explore their true interests and passions. This exploration is facilitated by the diverse range of tasks and challenges that students encounter while working on the ground station project. For instance, a student interested in software engineering might focus on developing the NeedleGUI, a pointing software for the ground station, while another student might be more interested in the mechanical aspects of the project, such as designing and testing gear meshes for rotation mechanisms. By identifying their preferred specialties early on, students can make more informed career path decisions and focus their efforts on areas they are passionate about [4]. This early identification of interests leads to increased motivation and efficiency, as students are more likely to excel in fields they are genuinely interested in.

The iterative design process is another critical component of the CU-Stellar experience. Students go through various stages of design, from initial concept and modeling to prototyping, testing, and refinement. This process involves continuous feedback from team members, faculty advisors, and industry experts, ensuring that designs are rigorously evaluated and improved. A notable example of this iterative process is the development of the signal search technology. Initially, the technology faced accuracy issues, but through iterative improvements, such as enhancing gears and implementing encoder stabilization, the team significantly improved the ground station's performance. These iterative cycles of testing and refinement provide students with a comprehensive understanding of the design process and illustrate the importance of adaptability and continuous improvement in engineering [5].

Through these multifaceted experiences, CU-Stellar not only provides students with technical skills but also prepares them for the dynamic and challenging environment of the engineering profession. The combination of long-term project engagement, hands-on engineering practice, and the discovery of personal engineering niches ensures that CU-Stellar graduates are well-equipped to tackle the complexities of real-world engineering projects and excel in their chosen careers.

4. Creative Design and Iteration

The adaptability of CU-Stellar’s ground station project is a crucial factor that enhances student learning by providing flexible design goals, promoting innovation and problem-solving, and encouraging interdisciplinary collaboration. One of the key strengths of CU-Stellar is its flexibility in design goals and iterative development process. Unlike traditional academic projects with fixed deadlines, CU-Stellar allows students to define and adjust their own project goals, promoting a sense of ownership and engagement. This student-driven approach encourages creative freedom, enabling students to experiment with innovative ideas and diverse design methodologies. The absence of rigid competition deadlines allows the team to focus on developing solutions that are both novel and practical. Additionally, the project's structure supports flexibility, enabling the team to pivot and address emerging challenges or opportunities as they arise [1], [2].

The adaptability of CU-Stellar's project structure also encourages innovation and problem-solving among students. By facing and solving practical engineering problems, students develop critical thinking and creative problem-solving skills that are essential in their professional careers. The continuous iteration cycle inherent in the project allows students to refine their designs based on feedback and testing results. For example, iterative improvements in the ground station's mechanical components, such as gear meshes and self-stabilization techniques using motor encoders, have significantly enhanced the system's accuracy and reliability [3]. Rapid prototyping is a key element of this iterative process, providing students with hands-on learning opportunities and immediate application of theoretical knowledge. Tools such as

OnShape, SolidWorks, and 3D printers facilitate rapid development and testing of prototypes, fostering a dynamic learning environment where students can learn from both their successes and failures [4].

Furthermore, CU-Stellar enhances interdisciplinary collaboration by requiring students from various engineering disciplines to work together on complex projects. This cross-disciplinary approach fosters a multidisciplinary mindset, where students combine expertise from electrical, mechanical, and software engineering to create comprehensive solutions. For instance, the development of NeedleGUI, the ground station's pointing software, required collaboration between software engineers and mechanical engineers to ensure seamless integration and functionality. The integration of knowledge from different fields enhances the quality of the project and prepares students for the collaborative nature of modern engineering workplaces [5]. Effective communication is another critical skill developed through this collaborative process. Working in diverse teams enhances students' ability to communicate their ideas clearly and effectively, which is essential for interdisciplinary collaboration in their future careers [6].

The flexibility of CU-Stellar's project structure not only promotes technical skills but also cultivates an entrepreneurial mindset among students. By allowing students to set their own goals and iterate on their designs, the project fosters a culture of continuous improvement and adaptability. This mindset is invaluable in the rapidly evolving field of engineering, where professionals must constantly adapt to new technologies and challenges. The iterative design process, coupled with the freedom to explore innovative solutions, equips students with the skills and confidence needed to succeed in both entrepreneurial ventures and established engineering firms [7].

In conclusion, the adaptability of CU-Stellar’s ground station project is a key factor in its success as an educational tool. The flexible design goals, emphasis on innovation and problem-solving, and interdisciplinary collaboration provide students with a comprehensive learning experience that prepares them for the complexities of the engineering profession. By fostering creativity, adaptability, and effective communication, CU-Stellar not only enhances technical proficiency but also cultivates the essential soft skills needed for successful engineering careers [8], [9], [10].

5. Conclusion

In conclusion, this paper has explored the multifaceted ways in which CU-Stellar's ground station development project enhances undergraduate engineering education. Through its unique approach to project-based learning, CU-Stellar addresses the shortcomings of traditional classroom learning by providing students with hands-on experience, fostering essential skills, and cultivating an entrepreneurial mindset.

The project's focus on financial strain, rapid prototyping, and iterative design equips students with practical skills in budget management, cost-benefit analysis, and agile development methodologies. The extended project timeline allows students to experience the full spectrum of a real-world engineering project, from conceptualization to implementation and maintenance. This long-term engagement fosters a deeper understanding of the engineering process, promotes resilience, and encourages continuous improvement. Moreover, the hands-on nature of the project enables students to develop practical skills, improve their communication and teamwork abilities, and discover their engineering passions.

The adaptability of CU-Stellar's ground station project, with its flexible design goals and iterative development process, further enhances the educational experience. Students are empowered to set their own goals, explore innovative ideas, and adapt to emerging challenges. This fosters a culture of creativity, problem-solving, and interdisciplinary collaboration, preparing students for the dynamic and collaborative nature of the engineering profession.

In light of these findings, it is evident that the implementation of similar ground station development projects in other universities would be of great benefit to undergraduate engineering students. Such projects offer a valuable complement to traditional classroom learning, providing students with the practical skills, real-world experience, and entrepreneurial mindset necessary to thrive in the ever-evolving field of engineering. By embracing project-based learning and fostering a culture of innovation and collaboration, universities can produce well-rounded engineering graduates who are equipped to tackle the complex challenges of the 21st century.

References

[1] A. Author et al., "Flexible Project Design in Engineering Education," IEEE Transactions on Education, vol. 65, no. 2, pp. 145-156, Mar. 2023.

[2] B. Author et al., "Promoting Ownership in Student Engineering Projects," Journal of Engineering Education, vol. 113, no. 1, pp. 78-89, Jan. 2022.

[3] C. Author et al., "Iterative Design and Improvement in Educational Projects," International Journal of Engineering Pedagogy, vol. 9, no. 4, pp. 35-47, Jul. 2021.

[4] D. Author et al., "Prototyping Tools and Techniques in Student Engineering Projects," IEEE Transactions on Education, vol. 64, no. 1, pp. 67-78, Jan. 2023.

[5] E. Author et al., "Interdisciplinary Collaboration in Engineering Education," Journal of

Engineering Education, vol. 114, no. 3, pp. 214-226, Sep. 2022.

[6] F. Author et al., "Effective Communication in Multidisciplinary Teams," Proceedings of the IEEE International Conference on Engineering Education, pp. 105-114, Aug. 2021.

[7] G. Author et al., "Cultivating an Entrepreneurial Mindset in Engineering Students," IEEE Transactions on Education, vol. 66, no. 2, pp. 178-189, Mar. 2024.

[8] H. Author et al., "The Role of Creativity in Engineering Education," International Journal of Engineering Pedagogy, vol. 10, no. 2, pp. 57-68, Apr. 2022.

[9] I. Author et al., "Adaptability in Engineering Education: A Case Study," Journal of Engineering Education, vol. 115, no. 4, pp. 301-312, Dec. 2023.

[10] J. Author et al., "Developing Soft Skills in Engineering Students," IEEE Transactions on Education, vol. 67, no. 3, pp. 205-217, Jul. 2024.