THE STUDENT SPACE PROGRAMS LABORATORY: FOSTERING STUDENT SPACE SYSTEMS EDUCATION AND RESEARCH WITHIN A UNIVERSITY ENVIRONMENT

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ABSTRACT

In August of 2006, faculty and students at The Pennsylvania State University established the Student Space Programs Laboratory (SSPL) in an effort to consolidate and formalize space systems research and education at the University as well as to improve student opportunities. Further, SSPL strives to encourage collaboration with international institutions as a valuable resource and learning experience for its students. Because of the synergies between projects and the growing number and complexity of the projects, the need for a central management structure and systems engineering framework was evident.

This paper is an update from the discussion presented at the 18th ESA PAC meeting, when the SSPL was still in its infancy. Now in existence for three years, the Lab has faced several challenges, such as managing the Lab's resources across multiple projects; enabling communication and collaboration between student teams; student retention and training; and formalizing effective processes for developing spaceflight hardware in the academic environment, with primarily an undergraduate workforce and a high turnover rate.

Three successful flight projects, a flourishing first-year training program, inclusion on the JANUS mission, and industry recognition, show that the Lab as an organization is sustainable. Further anecdotal evidence from the students and industry has shown that the model of collaborative interdisciplinary efforts improves the student experience compared to coursework alone. The experience the SSPL provides will prepare students to make significant contributions to the area of space science and engineering.

1. INTRODUCTION

The Student Space Programs Laboratory (SSPL) coordinates Penn State student space projects to enable more complex missions and to provide opportunities for its students. The SSPL provides experience in the processes of project development rarely seen in the classroom. The Lab serves to coordinate the sharing of resources between projects and continually recruits students. The SSPL also supports the infrastructure required to attract future student project opportunities with meaningful science and engineering objectives. The Lab organizes an education and public outreach program to inspire young students in the fields of science, engineering, and math. Finally, the SSPL is dedicated to encouraging collaboration with international institutions as a valuable resource and learning experience for its students.

SSPL was created in recognition of synergies between independent projects and because the growing number and complexity of the projects necessitated the need for a central management structure and with emphasis placed on strong systems engineering. The SSPL's original concept was discussed by [1]. Since then, the Lab has refined its strategic plan to incorporate lessons learned and to adapt to changing opportunities in student research. This paper reflects on the effectiveness on the Lab's original strategy and outlines the goals and plans for the years to come.

2. REVIEW OF RESULTS OF PREVIOUS STRATEGY

When SSPL was formed in 2006, the Lab's leadership developed a strategic plan that identified several objectives deemed necessary to enable sustainable operation of the Lab. Since then, some of the objectives have been achieved while experience has prompted the Lab to update its strategic plan to adapt to a dynamic funding environment and student workforce.

The following subsections outline the objectives of the first SSPL strategic plan and discuss the successes and lessons learned since its creation.

2.1. DEVELOP AN EXPERIENCED WORKFORCE

The SSPL has maintained a strong commitment to mentoring and training its students in space systems. This mentorship is critical to the successful continuation of flight projects and the overall success of the Lab. As a student-run lab, the SSPL must deal with high turnover due to students graduating or leaving for personal or academic reasons. If not addressed, student turnover can cause discontinuities in project leadership and subsystem work progress. To mitigate the effects of student turnover, a strong mentorship and training program must exist to ensure smooth transitions in the short term, as well as the long-term success of the projects.

The SSPL provides mentoring through several methods. Informally, all students have the responsibility to help younger or less experienced students. More formally, student leaders of functional groups are required to hold regular weekly office hours in the Lab. This provides

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another opportunity for students to interface with student technical experts in the Lab.

On a more infrequent basis, short courses are offered to all students in the Lab. These courses are usually taught voluntarily by more experienced students to address a perceived need throughout the Lab. It is expected that students new to the Lab often are inexperienced and require training and mentorship. In fact, students are encouraged to learn fundamental theories and practical skills even before their courses touch on the subjects. For example, when the Lab had a deficiency of students with a background in microcontrollers, an SSPL graduate student prepared a set of weekly short courses that covered the basics of microcontrollers to help them along the initial learning curve. Since students are exposed to technical material early through opportunities like this, it not only benefits the Lab but also gives the students an advantage as they move forward in classes because of this prior knowledge and experience.

Formal training begins with an SSPL-sponsored first-year seminar (FYS) course called *This is Rocket Science*. Offered to first-year students in the fall semester, the course exposes students to the full lifecycle of a space systems project by having students participate in the national CanSat competition [2]. The competition's project is scaled appropriately such that it can be completed over the course of a year by a group of relatively inexperienced students. In addition to the many technical lessons learned by the students, experiencing the full lifecycle emphasizes that project milestones must be met on schedule in order for the project to succeed.

In addition to basic technical material, the course introduces systems engineering topics and the tools necessary for project development. Topics include: the V model of systems engineering, risk analysis, requirements, concept generation, design selection matrixes, and trade studies. These topics are introduced through interactive lectures and then applied to the development of the CanSat payload during the following semester. The course also brings in local experts in related space science fields. Some past topics have included space physics, upper atmospheric research, radar, sounding rockets, and an astronaut's personal account of his experiences in space. The class concludes with a short (approximately one week) and entertaining hands-on final project, separate from the CanSat competition, such as launching an egg and trying to have it land without breaking. Similar to the egg drop competition, the Lab is developing engaging, easy, and fun activities such a model rocket competition in which the students will build and fly their own rockets.

2.2. DIVERSIFY FLIGHT PROJECTS

The initial SSPL concept focused on maintaining a diverse portfolio of active projects for several reasons. First, this would provide the Lab with financial support to continue the development of its facilities and capabilities for the benefit of the participating students. Second, a diverse project portfolio provides better opportunities for student learning. Ultimately, the goal is to have concurrent projects in every phase from concept development through operation on various space flight projects.

Offering projects in different phases of development provides students the opportunity to explore and participate in each aspect of the mission lifecycle, particularly as they develop through the Lab. For instance, some students (i.e., those more experienced) may prefer the high-level design work required for proposal development, while others may be better suited for low-level design work (i.e., those who are less experienced). Similarly, multiple platforms (e.g., balloons, rockets, satellites) each provide unique capabilities and environments that provide a variety of experiences for students and different opportunities for science and engineering investigations.

Practical limitations, however, have prompted the Lab, at least initially, to focus on a limited number of projects. The two primary limiting factors have been (1) the limited funding to support the graduate and advanced undergraduate students necessary for the leadership of a successful project and (2) the limited number of these students sufficiently trained by past projects who, regardless of the funding environment, are capable of assuming key leadership positions to support the projects. As the Lab expands its funding resources and improves training and retention, its "carrying capacity" will increase.

2.3. INTEGRATE THE LAB WITH THE PENN STATE CURRICULUM

Penn State now offers a Space Systems Engineering Certificate that certifies the efforts of students working in the area of space systems. The Certificate also allows students who participate in Lab's programs to earn credits towards their degree. This is a formal recognition for the knowledge they have learned in space systems through project-based work. A student completing the Certificate will:

- be better prepared (in terms of breadth and depth of knowledge) to enter the space industry,
- have completed a hands-on project experience representing the application of principles learned,
- have a deeper understanding of the following:
  - systems approach to engineering;
  - several technical subjects related to space systems and physics;

- processes and procedures for development of space hardware;
- be able to work in multifunctional teams.

As part of the Certificate, a *Space Systems Engineering Seminar* has been created and is taken by 10–15 students each year. This seminar is tightly coupled to efforts in the SSPL, but any student is welcome to take the seminar.

In addition to the certificate, SSPL projects have provided topics for several senior capstone design classes in aerospace, electrical, and mechanical engineering. On an individual level, the Lab often sponsors independent student research through independent study credit and thesis topics for undergraduate and graduate students.

2.4. INTERFACE WITH EXISTING UNIVERSITY RESEARCH INTERESTS

The capabilities, organization, and intentions of the Lab have been validated by its invitation to develop and fly the High Energy Monitoring Instrument (HEMI) as part of the JANUS mission, recently proposed to the NASA Small Explorer (SMEX) program. JANUS will provide the star formation history of the early Universe. SSPL would develop HEMI as a student collaboration component [3] for the JANUS satellite that will meaningfully add to the science return of the mission [4, 5]. SSPL student scientists and engineers have been working alongside members of the JANUS team from around the world since the early mission concept phase and, if JANUS is selected, will continue their efforts through the development, testing, integration, operations, and analysis phases. This student collaboration instrument has been a major success in the Lab's attempts to partner with existing research efforts to provide better opportunities for its students.

2.5. IMPROVE DOMESTIC AND INTERNATIONAL PARTNERSHIPS

Since the Lab's formation, it has continued to expand its domestic and international partnerships. Through HEMI's involvement with JANUS, project members have access to a vast array of resources connected to the JANUS project including Penn State's Applied Research Lab, the Southwest Research Institute, and the Los Alamos National Laboratory.

Furthermore, in preparation for the SSPL's new CubeSat effort, the Lab has begun to form relationships with radar facilities in Alaska, Puerto Rico, Norway, and Russia. Collaboration with these facilities will provide students with access to both expert scientists and ground-based facilities that will enhance the CubeSat mission's science return. Other relationships with organizations such as the Aerospace Corporation and the Naval Research Lab provide access to industry professionals and additional resources for the student projects.

2.6. DEVELOP EDUCATIONAL OUTREACH ACTIVITIES AND RELATIONSHIPS

In the past, the educational outreach activities have consisted mainly of current Lab members returning to their primary and secondary schools to discuss the opportunities available to SSPL students in particular, and in the science and engineering fields in general. Since its inception, the Lab has formed an Education and Public Outreach (EPO) group. EPO is currently working toward developing a set of lesson plans for students wishing to return to their previous schools to deliver them. This will make it easier to convey a consistent and successful message to younger students.

The SSPL also is regularly involved in public events such as Exploration Day at Penn State. Exploration Day is an event cosponsored by the Pennsylvania Space Grant Consortium, the Penn State Astronomy and Astrophysics Department, and several other groups. The event is oriented towards K–12 students and also includes local schools to aid in increasing awareness of technology, science, and space. The SSPL volunteers to staff tables with engaging and interactive activities to introduce students to the field of space systems. During the most recent event, the SSPL sponsored a rocket launch that attracted more than 200 people. The event serves to excite younger students in space systems.

3. STRATEGY FOR THE FUTURE

While the original Lab structure has improved student space systems engineering at Penn State, there remain several areas where SSPL is continuing to improve. The largest change is in the organization of the Lab itself. Experience has shown that a strong functional matrix organization is more optimal than an organization only organized by projects. On the project side, SSPL is currently revising how systems engineering is both applied to projects and how it is taught to the students. The hope is that, by creating systems engineering processes and procedures accompanied by formal tools and training materials, all students will be better able to apply the systems engineering mindset to their efforts. Finally, the Lab has forged formal relationships with industry to assist in mentoring students providing formal and informal guidance throughout the project lifecycle.

3.1. ESTABLISH A STRONG FUNCTIONAL ORGANIZATION

Initially, the Lab was organized primarily by projects, with few formal links between the same subsystems on different projects. Recently, the SSPL has adopted a new organizational model using a strong functional matrix organization as illustrated in Fig. 1. For an individual project, the students of a particular subsystem

consult the appropriate SSPL student who is the most knowledgeable in that subsystem. This way, these expert students, known as functional group leaders, can share the collective expertise of the Lab with all of the Lab's projects and also help to more efficiently coordinate SSPL resources.

Anecdotal evidence shows that the new organization has been able to compensate for technical deficiencies within particular projects. Furthermore, it has eased the burden of the project managers from having to micromanage low-level technical development efforts, which are often not in that particular student's area of expertise.

At the laboratory level, with all the students in the Lab having direct access to the most experienced students, the training of new students has become much more effective. Finally, as the needs of projects change, the new organization also facilitates moving personnel resources from one project to another.

3.2. DEVELOP A FORMAL SYSTEMS ENGINEERING PROCESS

While the Lab has valued and encouraged a systems mindset from the very beginning, it has struggled with an efficient method of teaching and implementing the systems engineering process in the Lab's projects. The Lab's experience has echoed that of industry—that a working understanding of the systems engineering process often comes only from the experience of working on projects. The result is that a small number of students who have a good understanding of systems engineering are often overburdened with managing the entire process. For the younger students, being forced into the process without the proper experience and understanding overwhelms and frustrates them as well. Both symptoms can drastically slow a project's progress and discourage the students from continued involvement.

The current solution is to develop a standard systems engineering process for the Lab, using industry standards and requirements as templates. Then, and most importantly, tools will be created that facilitate the process of gathering, controlling, and maintaining systems engineering data. Furthermore, integrating these tools into the everyday group meetings will enable the systems engineering process to be distributed throughout the project team. As the students move up the project ranks, they will be increasingly exposed to the formal systems engineering process.

The systems engineer of each project will be responsible for overseeing the process for that project. As projects continue, the project systems engineers on all projects will work with the SSPL functional group leader for systems engineering to continue to adapt the default plan to fit the needs of the Lab.

The intended result is that the student leadership is less burdened with micromanaging the systems engineering process. At the same time, inexperienced students can participate in the systems engineering process without being overwhelmed. A pseudo-automation of the process, coupled with more formal training and detailed examples is expected to increase the efficiency and thoroughness of student projects at SSPL.

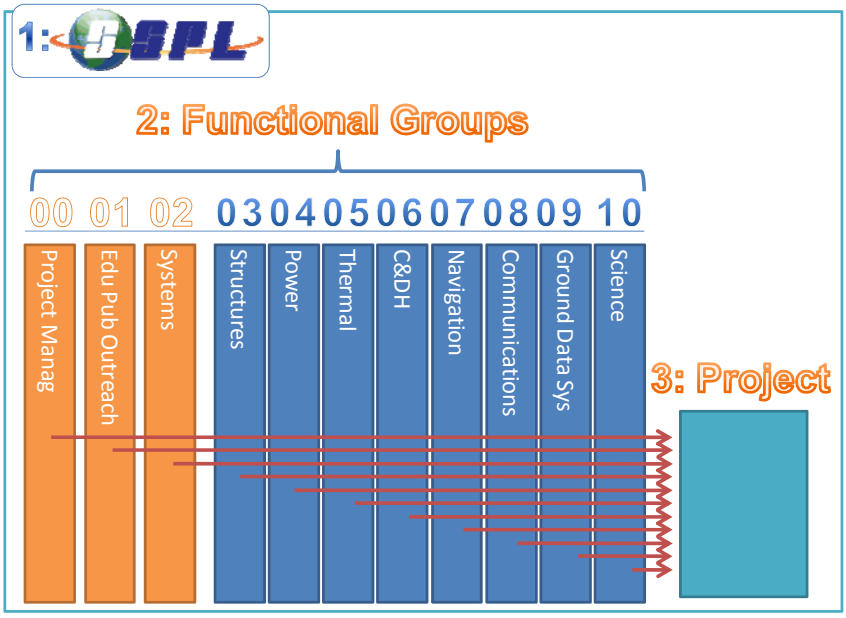

Figure 1 SSPL Matrix Organization

3.3. DEVELOP RELATIONSHIPS WITH INDUSTRY FOR MENTORSHIP

The Lab values the experience and guidance that industry professionals offer to students and, therefore, has begun to form formal relationships with external organizations. For example, a formal agreement was recently signed by SSPL and the Aerospace Corporation in which the Lab receives financial support and mentorship, such as non-advocate reviews for the students' projects, while SSPL students form a strong relationship with Aerospace Corporation useful for future employment opportunities.

4. CONCLUSION

In the three years since SSPL's formation, it has shown that it can adapt to a changing environment and needs. It has been successful in its original strategic objectives, restrained only by practical limits such as financial and personnel resources.

Based on lessons learned and using the aerospace industry as a model, the Lab has successfully adopted a matrix organization model to facilitate knowledge transfer and collaboration between projects. In addition, formally partnering with industry and government labs who serve as mentors has provided students with invaluable motivation and expert advice. This new organization has provided an overwhelming improvement in the efficiency of the Lab's operations. Students across projects are sharing information effectively, and strong student mentors with core competencies have been established to guide the younger students, regardless of project affiliation. Formal tools are being created to facilitate an effective systems engineering process, and to train students in its application. Finally, the annual "CanSat" model rocket payload competition encourages first-year student involvement through offering peer mentorship and training that will provide the skilled workforce for projects to come.

5. REFERENCES

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