S.P.I.R.I.T. Student Rocket Payload: Characteristics of a Long-duration Undergraduate Research Project

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Abstract

Student Projects Involving Rocket Investigation Techniques (SPIRIT) used experiential learning and vertical integration techniques to guide students of diverse backgrounds through a three-year design and fabrication process for a complex engineering project. Students from Penn State University, SUNY Geneseo and Lincoln University worked together on the project, with additional support from engineers at NASA Wallops Flight Facility. An active publicity campaign and K-12 outreach program also conducted by undergraduate education and publicity students complemented the technical work. A one-credit course supported project work. By most measures, the project was an unqualified success. This paper reviews our success criteria, the organization and pedagogical methods used in SPIRIT and an assessment of this research project approach to undergraduate education.

SPIRIT was designed to be an educational program with a meaningful scientific component. The scientific mission for this payload was to measure temperature and dynamics in the middle atmosphere (65 – 110 km) by four different methods. In addition to the instrumentation, the students designed and built the payload structure and the internal payload systems (including transmitters and data encoders). This work was performed by small groups of students, each focused on an independent aspect of the payload construction.

The response to the program from students, faculty and outside agencies has been overwhelmingly positive. A scholarly study of student motivation among SPIRIT I students has guided the evolution of the program. SPIRIT II is currently under way and will include a study of mesospheric winds and GPS. We also discuss some of the changes we have made as a result of our experience with SPIRIT I.

I. Introduction

On 17 May 2000, a Nike/Orion rocket lifted off from Wallops Island Flight Facility (WFF) in

Virginia carrying a payload built by undergraduates of the Student Projects Involving Rocket Investigation Techniques (SPIRIT) program. Despite an underperformance of the rocket motors, three of the four student-built experiments and all the rocket systems worked flawlessly during the approximately ten minute flight. The payload was recovered and data analysis is ongoing by the student participants.

The story of the SPIRIT undergraduate sounding rocket project has two dimensions. First, we report on the form and organization of this program. A description of SPIRIT, however, would be incomplete without a further discussion of the effectiveness of the project as a teaching method. How does SPIRIT contribute to the formation of quality engineers? How does it affect the lives and careers of the student participants? It is arguably in this second area that the real value of the project resides.

By most any measure this first SPIRIT payload was a success. Pride and gratification was evident on the faces of the students who had worked so hard on the project for three years. The accomplishment is still fresh in their minds many months after the event. For many, the experience defined their undergraduate engineering education and helped them attain a self-confidence and direction to their emerging careers.

II. Description of the Project and Payload

The SPIRIT project was a joint effort of The Pennsylvania State University and SUNY Geneseo, with additional participation from Lincoln University. Funding was provided by Penn State College of Engineering, NSF sponsored Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL), The NASA Pennsylvania Space Grant Consortium, the NASA Student Rocket Program, and Lockheed Martin Corp. In addition, several companies made non-cash contributions, including Bristol Aerospace Limited, Faran Scientific, Inc., and Physical Sciences Laboratory.

Participation in the project and courses totaled over 75 undergraduate students at the two educational institutions over the three years of the project. There were students from all levels of undergraduate curriculum in more than twelve majors Six faculty memberswere involved to varying degrees, including one (the principle author) who committed half his time to the project.

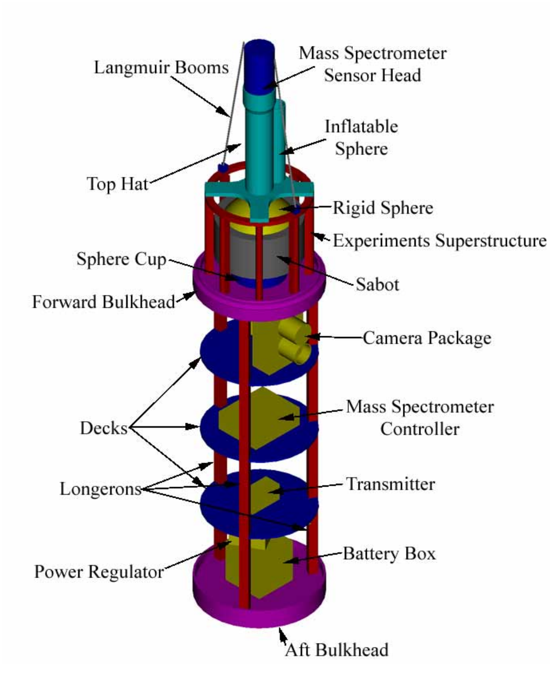

Figure 1: SPIRIT payload configuration

The preponderance of the Penn State participants in the project was Electrical Engineering majors. Participation remained remarkably constant up to a year before the launch, with approximately 35 students at Penn State and an additional 8-12 students (all levels) at SUNY Geneseo under the direction of Dr. David Meisel. In addition, two students from Lincoln University performed atmospheric modeling during a summer internship at Penn State.

The completed payload included four student-built instruments for taking *in situ* data that will support the construction of a temperature profile of the mesosphere at the time of flight. In addition, the students built the payload structure, the payload power systems and harness, the data encoder and the S-band transmitter. One of the experiments was a deployed rigid sphere. This "bowling ball", including the onboard transmitter, data encoder and the patch array antenna were entirely student designed and built.

The four instruments included a pair of Langmuir probes, a miniature mass spectrometer (purchased from Faran Scientific, Inc.), an photodiode array (built by SUNY students), and the rigid sphere. The mass spectrometer quadrapole apparently burned up due to the rocket's lower than expected altitude. The other instruments were not as pressure-sensitive and performed well. Students at Penn State and SUNY continue data analysis efforts as of this writing. Except for some housekeeping sensors, the payload subsystems performed flawlessly. The faculty, students and NASA personnel were all well pleased with the results of the flight.

In parallel to the project work, a one-credit course was conducted for four consecutive semesters. This course provided a common meeting for discussion of topics of global project interest and for student presentations. Topics of specific interest were presented, as were several skill development modules. Several pedagogical features of this course are discussed below.

III. Educational Context of the Project

The Electrical Engineering curriculum at Penn State is a highly regarded, but necessarily compressed progression of lecture and laboratory courses. The students have precious little opportunity to explore areas tangent to their stated concentration. The size of the University and Department (500 undergraduate majors) makes personal interaction with the faculty difficult. A project course, therefore, that offered a high degree of such interaction, as well as lab space available for the undergraduate use was very popular. In fact, a case could be made that the popularity of the project was an expression of student interest in collaborative learning precepts in contrast to the predominant lecture format.

Several factors support the notion that the sounding rocket is an ideal basis for an active learning program. Rockets carry a certain mystique that is hard to rationalize. The attraction to "NASA" and to "rockets" seems to transcend boundaries of gender, race and sophistication. At the same time, the rocket environment requires rigor and a firm focus on reliability – two traits that students often need to develop at this stage of their careers. The extensive pre-flight testing is an unforgiving (but also ruthlessly objective) judge of student work.

The sounding rocket platform is also well suited to research. At Penn State, research in the mesosphere has been conducted with sounding rockets for over thirty years. Each payload is custom designed for the immediate scientific mission, so a high degree of flexibility in payload design is the norm. It was indeed fortuitous that this opportunity arose to broaden the lengthy Penn State legacy in rocket research to include undergraduate students.

Finally, the uniformly high quality of NASA engineers at the Wallops Flight Facility has been an important factor. This group of highly professional, yet uniformly caring engineers and technicians repeatedly extended themselves well beyond what was required to help the SPIRIT students. They proved themselves over and over to be extraordinarily good mentors. They listened well to the students, considered their suggestions on a professional basis and responded sensitively. They developed a professional rapport with the individual students that was inspirational. They have been key to the success of the SPIRIT program.

IV. Characteristics of a SPIRIT Project

Our goal is to provide an environment that will encourage students to develop a certain trust in their own judgment and aptitude. If they can come to trust their own interests as a reliable guide, they can discern for themselves the paths that will lead them to a fruitful and satisfying career. Henri Nouwen has said this well:

> "The hospitable teacher has to reveal to the students that they have something to offer. Many students have been for so many years on the receiving side, and have become so deeply impregnated with the idea that there is still a lot more to learn, that they have lost confidence in themselves and can hardly imagine themselves to have something to give …. Therefore, the teacher has first of all to reveal, take away the veil covering many students' intellectual life, and help them see that their own experiences, their own insights and convictions, their own intuitions and formulations are worth serious attention."[1]

This is precisely the task addressed by the SPIRIT program. The fundamental tenets that define a SPIRIT project include:

a) Our Mission is science, but our goal is education.

SPIRIT is fundamentally an educational program. Our scientific mission is important as a motivational tool, but the educational agendas are paramount. This has many ramifications. For instance, it is very difficult to maintain a rigid launch deadline. A "normal" research rocket is by necessity heavily scheduled. There are so many people (not co-located) working in parallel toward a common launch event, that deadlines and milestones are essential for accountability. The launch becomes driven by the schedule and ultimately by the budget cycle. The student rockets should be different. The primary lesson of a rocket launch is that (unlike most student endeavors) there is no second chance. This important professional trait must be emphasized at the same time that we drive home the equally important professional lesson that the students are accountable for the reliability of their work. The way to deliver both of these is to carefully establish the deadlines that are important from a programmatic standpoint and to rigidly enforce those. Other deadlines (such as coursework due dates) should be avoided. For example, in the companion course, each team must establish a programmatic semester goal. Student members are accountable for this goal and its achievement is part of their course grade contract. This helps the students establish priorities and resist distraction. Beyond that, as much as possible, course requirements do not have deadlines. For example, we developed a series of self-paced modules for the course that students can complete on their own schedule during the semester.

b) SPIRIT is a research program designed for undergraduates.
With a standard research program, a panel of experts is assembled to attack a specific problem. Our approach is different. We pose a research topic that is carefully selected to involve the students in current middle atmospheric research. Then we look to this group of "scientists" to respond in fresh ways consistent with their diverse perspectives and experience. This overarching scientific theme is meant to be accessible, yet complex enough to have subtle dimensions that are explored as the student progresses. For SPIRIT I, the theme was "measurement of mesospheric temperature and dynamic behavior".[2] At the beginning, students typically felt they knew what "temperature" was. We challenged that familiarity during the course of the project. What does "temperature" mean in a less dense medium? How is it measured? The overall scope of the project is determined before the students arrive, but the depth of the research effort is dependent on student interest. For SPIRIT I, we suggested five means of implying temperature from measured data. By the time the rocket flew, four had been pursued.

Mesospheric temperature is a routine requirement of *in situ* measurements, but it is difficult to measure directly. Most researchers calculate a temperature using density measurements, the hydrostatic equations and the ideal gas law. The SPIRIT data will be unique in that it will provide a comparative assessment of four measurement techniques. As of this writing, it appears that we have data to compare results from three of them.

c) SPIRIT is a complex, long-duration project
A SPIRIT project lasting three years is well matched to the typical undergraduate career. We can expect a turnover of seniors replaced by incoming freshmen and a central core of students who stay with the program throughout its duration. The highly complex nature of the payload requires both a degree of individual responsibility and interdependence that are new to the students. Many have seen situations that required one of these traits, but in SPIRIT, both are essential or the project will simply never reach flight readiness. This tension continues to challenge the student (and faculty) right up until the final countdown.

Walker (1998)[3] states that most instructors of collaborative learning groups still report problems with student motivation and "free-riding". We have not had such a problem. We did a study[4] of the motivation of the SPIRIT students. Why should they spend many precious hours (out of proportion to the scarce academic reward) on project work? This study led us to conclude that SPIRIT students fall into two broad categories:

i)Students with something to prove: Upper level students repeatedly cite "hands-on experience" as their reason for joining. They seek an opportunity to demonstrate their ability to themselves and to prospective employers. They hope participation in SPIRIT will improve their resume. It is often reported that discussion of the SPIRIT project dominates job interviews. Students in this group further believe that their abilities are not well represented by their GPA. For these students "ownership" of a challenging project is important.

ii)Students needing a positive direction: A second group of students found the project very useful as a means of discerning and defining their professional interests. Such a student might be trying to decide what area of EE to pursue. They are studying engineering, but what does a professional engineer do in a typical day? For these students, the group setting, mentoring of older students and the interaction with professionals are of particular importance. These students are valuable to the project as they mature. They provide continuity and often develop into the leaders and mentors of subsequent projects. The study indicated that the boundary between these two groups fell roughly along age lines. In addition to these categories, observation suggests a third group:

iii)Students who learn through direct involvement. For these, the hands-on work is not ancillary to their classroom learning, it *is* how they learn best. These students are close to the first group in that they feel themselves at a disadvantage in the lecture setting. They need close interaction with faculty (difficult at a large university) and room to make mistakes. Given those conditions, they are typically capable of extraordinary accomplishments. Non-traditional students or those who take a long time (longer than a semester) to feel comfortable working in a group come to find SPIRIT a congenial and supportive environment for their work. These students demand of the SPIRIT Program flexibility and sometimes emotional support. In return, they deliver extraordinary work and, often, quiet authority.

The needs of all these groups can be met over time. Because of the long duration of the project, a project team capable of a high level of project complexity has the time to emerge. The students come to have an amazingly realistic appreciation of the talents and shortcomings of fellow team members. In contrast to the core curriculum (a fractured series of individual semester units), SPIRIT offers a steady progression toward a common goal. The atmosphere of cooperation and the very complexity of the project are fundamental factors that give rise to the supportive, inclusive learning environment that is our goal.

d) Outreach is central to the SPIRIT mission

We are committed to developing a work and study environment that is attractive to a widely diverse group of students. Personal growth and respect for others are as important to the goals of the project as rigorous engineering challenge. One might fear a dilution of the scientific/engineering effort due to this outlook, but we do not feel that this has been the case.

Overfull student schedules and the unpredictable pace of student development are the major factors that limit our capabilities, not a lack of determination or focus. In fact, *over*-concentration on project work is more likely to be a problem. In the companion course, we urge the students to keep an eye on the larger issues. Topics such as group dynamics and ethics aid this effort. We have been impressed with how easily these diverse students come to rely on each other. At the same time, we have benefited from the creative vigor that the wide array of student perspectives has brought.

In a similar vein, we take seriously our commitment to spread the excitement of our work. It is in our interest, and the interests of our sponsors, to encourage the early development of science and engineering careers. Undergraduates, it turns out, are ideal ambassadors. Exercising their skills in service to others proves to be a very satisfying endeavor. Indeed, it was ultimately the personal initiative of Publicity team members that resulted in a group of education students volunteering to develop lesson plans and co-lead outreach programs in over a dozen local classrooms. Many engineering students found this to be a very meaningful activity.

In the third semester of the course, SPIRIT hosted a “Rocket Day” for local elementary and middle school students. About 150 students and parents came to launch model rockets the students had built during the SPIRIT outreach programs. The events of the day were capped off with the launch of a 4-meter long scale model of the Nike/Orion rocket (built for the project by a SPIRIT student) that reached an apogee of 1,000 meters.

V. Project Organization

SPIRIT is organized along the lines of models of project-based collaborative learning projects. When the students join SPIRIT, they are assigned to one of five teams. These assignments are made by the instructor on the basis of a personal interview. Due to the nature of the tasks, these teams evolved to represent quite distinct learning environments. Originally structured so as to facilitate student interactions with the NASA engineers, this division of tasks proved to be very practical.

A group of 5-10 students seemed to be most effective. Below five, the size and complexity of the task became overwhelming. At the higher end, the groups tended to fracture into task-related sub-groups. At SUNY Geneseo, the students were also arranged into these five groups in order to increase communication with Penn State and NASA. In several instances, however, SUNY students were members of more than one group.

a) Experiments

The Experiments Team performed the traditional university role in sounding rocket research projects. Students in this group had to be able to work independently. They were often interested in pursuing advanced degrees. Therefore, they benefited from learning research methods as well as increased interaction with professors. The Experiments Team was charged with doing the theoretical justification of the experiments. They also researched the methods and history of the measurement techniques. In addition, they designed and built the instrumentation, making sure the data were defensible. These tasks lent themselves well to independent EE projects, capstone projects and honors theses.

b) Power and Wiring (P&W)

The P&W group designed the power systems and wiring harness for the payload. The level of engineering challenge was accessible to students new to the discipline. This is meticulous work, however, since there are many single point failures in this area. These students must demonstrate a high level of reliability in their work. They must also have a thick skin! They usually catch the first blame when something goes wrong. Generally speaking, the "direct involvement" students described above enjoyed working in this group.

c) Telemetry (TM)

We were indeed fortunate to have two graduate students volunteer to oversee the TM group of SPIRIT I. The complexity of the TM tasks was very high. This group was charged with designing and building an S-band transmitter to perform in the high-vibration/low-pressure environment of space. They also built a 400-kbit PCM encoder. The TM students clearly had something to prove. Nothing else would justify the dedication that these complex projects required.

d) Structures

The number and diversity of tasks faced by the structures group required a high degree of leadership. This group absorbed a wide array of personality types and their constant stream of achievement was an inspiration to the whole project. These students spent many hours in the Learning Factory (an award-winning educational facility at Penn State), on the phone with WFF mechanical engineers, and traveling to Wallops to test and consult about their designs. Their designs had to withstand high vibration and be hermetically sealed despite repeated assembly/disassembly cycles. Several Aerospace Engineering students anchored this effort.

e) Publicity/Outreach

All the non-technical functions of the project tended to end up in this Publicity group. We were again fortunate to have much support in this effort, this time from the Penn State College of Communications. In addition to the outreach described above, SPIRIT benefited from the media interest elicited by these students. Articles appeared in three Penn State journals, common interest newspapers across the state, journals (*ME Advantage*) and space-industry publications (*Space Times* and *Space News*). Due to the excellent leadership and manifold accomplishments, this group was one semester the biggest of all the groups! Due to the excellent work of this group, the importance of the SPIRIT Project was effectively communicated to the student participants as well as to the outside world.

VI. The Companion Course

The one-credit course that parallels the project was conceived as a way for the students to receive academic credit for their project work. Since there were freshmen and seniors; engineers and non-engineers in the course, it was a challenge to present a syllabus that was meaningful at a level that was comprehensible to all. Course material ranged from topics of global interest ("How a rocket works") to professional and skill development (group dynamics, soldering).

The pedagogical approach to the material described a slow evolution from a standard lecture format in the first semester to a round-table working meeting as the launch approached. The standard format was useful at first both because there was a lot of material to be presented and also because it was familiar. As the focus of responsibility shifted from the instructor to the students themselves, so, too did the focal point in the course. Group presentations replaced lectures. The emphasis of course activity became not the delivery of information, but the exchange of information (including status reports) among the groups. Students were required to take the course during their first semester on the project and were encouraged to take it thereafter.

Each student was encouraged to concentrate in the areas of most personal interest. Grading contracts allowed students to define how they wanted their work to be evaluated. In addition, since project work occurred in the context of student groups, peer evaluations were used to register feedback with the instructor of the relative performance of each participant. Graded activities had two concurrent goals: 1)To make each student feel (s)he could be a productive member of the project (by emphasizing group work) and 2)To wean the students from the familiar grade-centered learning to the more cooperative active learning environment.

Even so, there persisted among the students a feeling that the grading activity of the course was a distraction that took valuable time away from project work. We were also not entirely successful in making this "engineering" course accessible to non-engineers. As the course described its evolution from a "traditional" to an "active learning" format, the students needed more help in adjusting their own expectations. In a world that is heavily influenced by GPA angst, the students were entirely willing to *work* cooperatively on the project, but there was an unwillingness to experiment when grades were at stake. Additional work in this area is needed in future projects.

VII. SPIRIT as an "active learning" environment

Though SPIRIT fits very neatly into the paradigm of an active learning environment, there are significant differences. The major difference is the long duration of the project. We work hard at the beginning of the course to define an environment for active learning and to allow the students room to work on a complex task within that defined space. At the same time, there is a slower development going on in which the students learn to trust their own judgment. This second development is fast in some and slower in others. Good group dynamics are very important to this growth. Students gauge their abilities and their progress against those around them. Their definition of themselves reflects their responsibility in the group.

Typically, "active learning" is envisioned as an alternative to a traditional lecture method of material delivery. Case studies or problem-based activities are seen as a more interactive way to get the subject matter across.[5] SPIRIT is less true to this model. SPIRIT might be termed a "sandbox" model of learning and personal/professional development. We provide the sandbox and the students are free to build whatever castles they can find it in themselves to build. Except at the beginning of the course, we do not control the material that the students acquire. An Aerospace Engineering student might come away from SPIRIT having learned a very different set of skills than the Electrical Engineering student sharing the bench with him.

As a result, though SPIRIT is clearly "active learning", it is not merely an alternative method of content delivery. Rather, it is an alternative learning environment to which certain students will respond with great enthusiasm. Therefore, to gauge our success, we do not look for "increased higher-order thinking" or "social skills beyond those of listening and clarifying"[6]. Rather, we expect that students with a propensity toward those skills will be attracted to this different learning environment. It is hoped that these students will find the freedom to develop at a more natural pace than is allowed by a lecture-formatted course. We are encouraged when we see the realization of leadership and aptitude that students know they possess. Despite its anecdotal nature, this is the measure by which we call SPIRIT I a success.

VIII. Risks

There is no avoiding the fact that a rocket-based student project is inherently a risky undertaking. In addition to the risks of rocket failure, there are risks associated with trying to guide undergraduate students through a complex project. We feel that many of these risks can be lessened with a flexible system, steady oversight, and good student leadership. We hold up SPIRIT I as an example of such a project that met nearly all of its goals.

From a programmatic standpoint, there must be built into the project a series of contingencies and alternative plans of action. If not, those who have worked efficiently end up waiting for those who are struggling. From a motivational standpoint, "ownership" of a project is important, but how to keep the interests of the project as a whole from being held hostage to one conscientious but struggling student? What follows are some precautions that we implemented on SPIRIT I and some that we will have in place for follow-on projects.

a) Make sure that complete responsibility for a task does not fall to a solitary student. This situation was difficult to avoid. Despite our determination on SPIRIT I (and despite having plenty of students), there were two instances when this occurred. The project suffered in both cases. The first instance was caused by student attrition. Instead of letting a sudden departure set the project back, we should have found a way to add manpower to the task. Adding new students to a project takes planning, but, in general, we found that younger students could be added with less danger of personality conflict. In the second instance, a very competent student felt that reliability of an important instrument could only be assured if he had complete responsibility. To the extent that he was right, we conclude that the project had become too complicated for undergraduate work.

b) Maintain many layers of redundancy. This applies to the compliment of instrumentation, to the hardware components and as much as possible to the rocket subsystems. On SPIRIT I, redundancy of measurements was inherent in the payload science. On SPIRIT II, we will plan more carefully for a redundant minimum configuration. For example, at least one instrument will record its data on board the rocket.

c) Recognize that not all students will have the desire to build flight hardware. Even as launch day approaches, there should be meaningful roles for those who have not yet reached full proficiency.

d) Assure that there is at least one faculty member with a significant commitment of time devoted to the project. Constancy of oversight is important.

IX. Conclusions

The first SPIRIT Project provides a successful example of a long-duration undergraduate research project. The sounding rocket vehicle is well suited as a basis for such a project. A flexible program, including a one-credit companion course, provides an alternative learning environment that guides students to take the initiative for their own professional development. The success of SPIRIT I is gauged foremost by evidence that students are motivated by this different learning environment. The not insignificant engineering accomplishments of the SPIRIT I students is evidence of their manifold personal and professional growth. Finally, it should be recognized that a rocket-based project such as SPIRIT is inherently a risky undertaking. Measures for ameliorating this risk can improve the odds, but with a complex project flown on a barely stable vehicle by students of unproven ability will sometimes fail. Despite this risk, the SPIRIT Project has significantly broadened the range of educational options for the technical and non-technical students who have participated in it. The students are justified in their pride of the many-dimensioned success of the SPIRIT I payload.

X. Acknowledgements

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