Improving Student Learning Experience via Extracurricular Undergraduate Research in Near-Space Ballooning

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***Abstract*— This paper describes an on-going near-space, high-altitude ballooning program at Gannon, aimed for improving student learning experience via undergraduate research. Through team members' laboratory-based extracurricular activities in a complete cycle of an engineering design, our program is also intended to contribute to the development of the STEM workforce, particularly in electrical and computer engineering. Initially beginning with a high-altitude weather ballooning project with 10 senior undergraduate students in AY 2009-10, this program offered STEM students various opportunities to participate in payload design projects such as High Altitude Radiation Detector (HARD) Payloads #1, #2, and #3, as well as an Undergraduate Student Instrument Project (USIP) 2013 payload. The current student-faculty team is developing several high-altitude ballooning payloads for both the HASP 2017 campaign and the 2017 Eclipse Ballooning Project. We further present assessment results that demonstrate the programmatic success and the effectiveness of our program in improving the student learning experience and also in the development of the STEM workforce through high-altitude ballooning.**

Keywords—high altitude ballooning; student learning experience; undergraduate research

I. Introduction

In a recent survey of FIE participants [1], promoting women and minority recruitment and retention was identified as one of the current frontiers in engineering education. Recent research has also demonstrated that education-related variables that differentiate engineering focused plans from non-engineering plans after graduation may include participation in curricular/extracurricular activities such as senior capstone design, exposure to active/collaborative learning and core engineering skills, and positive interactions with engineering faculty members and other students [2]. In line with this, the Electrical and Computer Engineering department at Gannon University has created and sustained an extracurricular high-altitude ballooning program since 2009. This program aims for improving student learning experience via undergraduate research conducted in a team setting with a diverse group of students including those from underrepresented groups in STEM fields.

For more than a decade, high-altitude ballooning has been somewhat popular at institutions of higher education and conducted in various ways to bring its benefits to research (for example, see [3], [4]) and education (for example, see [5], [6]), as well as for summer camp activities as a tool to stimulate high-school students for college education. High-altitude ballooning for high-school students and/or lower-division non-engineering college students generally takes a form of "launch-and-chase" with relatively simple experimental payloads integrated into a 3rd party ballooning system with a tracking capability (for example, see [7]). In contrast, our approach to the high-altitude ballooning for engineering education differs from others in that students develop an entire ballooning system and/or a complex science payload. We guide and closely work with students to complete a top-down design cycle from gathering requirements to producing a working prototype, and finish the project with a successful balloon launch, tracking, and recovery of the payloads.

As our program is recognized by the Pennsylvania Space Grant Consortium as one of the highly successful student-led engineering and science high-altitude ballooning programs in Pennsylvania, in this paper, we briefly describe its key aspects of the program. The remainder of this paper is organized as follows: Section II provides an overview of the program including its goals/objectives and brief summaries of past and current student design projects. Section III discusses student learning experience and assessment of programmatic success. Finally, concluding remarks are provided in Section IV.

II. Overview of the Program

A. Program Goals and Objectives

The goal of the high-altitude ballooning program is to improve the student learning experience by participating in extracurricular engineering projects and subsequently contribute to achieving the NASA's education outcomes [8]. Its specific objectives slightly vary year by year depending on the nature of the design projects but are generally in line with

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the SMART[1] goals. For instance, three of the SMART goals of the AY 16-17 program are: [Specific] To engage in two NASA-related projects, High-Altitude Student Platform (HASP) 2017 payload and Solar Eclipse Ballooning (SEB) 2017 payloads; [Measurable] To teach and facilitate students to develop skills in a complete design process with the proposed student projects. The success of the proposed project will be measured based on the ECE course evaluation criteria and delivery of working prototypes, quality of appropriate technical documentation, and supplemental surveys of learning experience; [Time frame] To demonstrate project outcomes by the end of spring 2017, i.e., a HASP 2017 payload and SEB 2017 payloads. The other two goals (Attainable and Realistic) are intentionally omitted due to space constraints.

Our program initially began with a high-altitude weather ballooning project with 10 senior undergraduate students in AY 2009-10. Since then, we carried out subsequent projects including a revision of Gannon's Weather Ballooning System and the High Altitude Radiation Detector (HARD) Payload (PL)#1 in AY 2010-11, HARD PL#2 in AY 2011-12, and HARD PL#3 in AY 2012-13, as a payload aboard the HASP flight operated by a team at Louisiana State University (LSU) [5] in collaboration with NASA Wallops Balloon Program Office. These efforts brought additional opportunities to engage our students in a 2013 Undergraduate Student Instrument Project (USIP 2013) separately funded by NASA for an 18-month project period of Aug. 2013 through May 2015 and also in the STEM Research Training for Underrepresented Pennsylvania Students (STaRT-UPS) program by the Pennsylvania Space Grant Consortium (PSGC). The USIP 2013 payload was also flown aboard WorldView's balloon platform in early March 2015 and also once again, after proper interface revision, as part of the HASP 2015 campaign in September 2015 for a higher-altitude and longer-duration flight.

Building on these successes and maintaining its momentum, the Gannon team of undergraduate students has been working on design and implementation of various experimental payloads including a sophisticated science payload for HASP 2017 and a multi-mode balloon-tracking payload for the SEB 2017 that will take place in Aug. 21, 2017 [9]. The current team consists of 11 undergraduate students from engineering and science and they all actively participate in the extracurricular project activities, regularly dedicating ~5 hours per week in the lab. About 55% of the current student members are from the underrepresented groups in STEM fields. To stimulate interests and proactively recruit and place early-stage undergraduate students in the pipeline, scholarships are integrated into the overall management strategy for the program.

B. *Weather Ballooning System*

Our high-altitude weather ballooning system was primarily comprised of three subsystems as shown in Fig. 1: Command (Telemetry) Pod subsystem, Ground Station subsystem, and On-board Processing and Solar Panel subsystem. These three subsystems were for experimental payloads, transportation of data, and balloon-tracking over the entire course of flight. Each subsystem was developed by a team of 3-4 students.

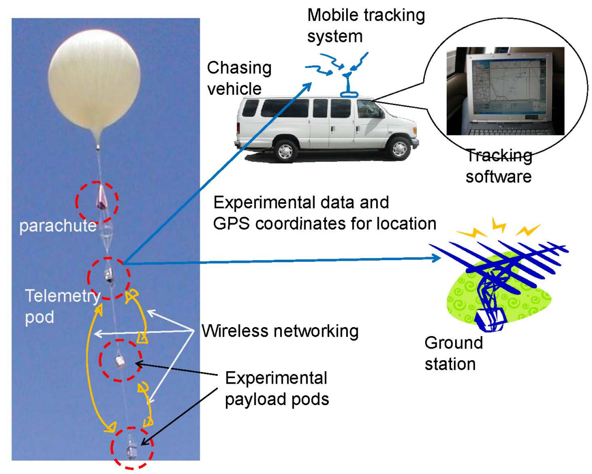

Fig. 1 Gannon's AY 2009-10 high-altitude ballooning system.

The functionality of the Command Pod was to provide onboard control/communication capability during the high-altitude weather ballooning. Six main components were integrated: a) A global positioning system (GPS) b) A short-range wireless network for communication between the command pod and other experimental payloads; c) A 900 MHz radio device as a gateway to transmit GPS and experimental data to the ground station; d) A power supply; e) A data storage device; and f) A data interface module for data formatting and signaling. The Ground Station subsystem was to enable tracking of the balloon system and consisted of three components: a) A directional antenna to receive the signal from the balloon in flight; b) A 900 MHz radio device integrated with the antenna to receive data from the Command Pod; c) A graphical user interface running on a Windows XP-based personal computer to process experimental and GPS data for mapping and chasing of the balloon. Lastly, the On-board Processing and Solar Panel (ODSP) subsystem was to conduct in-flight experiments. In addition to the development of the subsystems, a successful integration, and a successful recovery, of these subsystems further offered an opportunity for students to enhance non-technical skills such as functioning on teams and effective communication. For further details, refer to [10].

C. *High-Altitude Radiation Detector*

Our 15x15x30 [cm] HARD payloads #1~#3 were intended for the HASP flights 2011, 2012, and 2013, respectively, that were conducted in early September of the year. The primary functionality of these payloads was to collect science data pertinent to arrivals of cosmic rays in the so-called "east-west" angular asymmetry. The science objectives of the payloads were conceived by the Physics faculty member, and the execution of the payload design was carried out by electrical and computer engineering (ECE) students under close supervision of both faculty members.

The payload primarily consisted of a Cosmic-ray Detector subsystem, a Comparator subsystem, a Coincidence Detector subsystem, a Microcontroller & CPU subsystem, and a Power

[1] Specific, Measureable, Attainable, Realistic, and Timely

subsystem. Unfortunately, HARD payload #1 didn't make the HASP 2012 flight due to the technical difficulty encountered during the subsystem design, primarily due to the lack of technical experience in designing electronic systems and software for the aforementioned subsystems. HARD payload #2 was a success, passing the unit and integration testing conducted in our lab, as well as a rigorous thermal and vacuum testing at NASA's Columbia Scientific Balloon Facility (CSBF). When a long-exposure measurement was conducted aboard HASP 2013 at balloon-float altitudes of ~100,000 feet for about 10 hours, the payload collected cosmic-ray data but failed to collect meaningful data of a desired quality while all other subsystems of the payload functioned as expected. Built again, from scratch, based on the lessons learned from the previous experience, HARD payload #3 finally made to a complete success with all subsystems functioning as expected, collecting cosmic-ray data of a desired quality. For further details, refer to [11].

D. Cosmic-Ray Calorimeter for USIP 2013

The design experience in HARD payloads led to a bigger, more challenging project intended for, and subsequently funded by, NASA's USIP 2013 program. As the completion of the USIP 2013 project was relatively recent, we are in the process of preparing a manuscript for dissemination of technical details and educational outcomes – for further details, refer to [12].

E. Further Development – Solar Eclipse Ballooning System

Our SEB 2017 system currently under development is intended to offer a complete high-altitude ballooning system for not only our own payload but also a small number of additional payloads for those who need a high-altitude ballooning carrier. Our SEB 2017 system will be launched in Kentucky as part of the effort, by a nationwide network of college teams, to capture the entirety of the eclipse across the United States. In addition to a tracking and data streaming payload to be provided by Space Grant Consortia's primary engineering team, Gannon's payload will consist of three modes of spot trackers to ensure recovery of the ballooning system in Kentucky's tough terrains. The methods of tracking in the SEB 2017 payload will include a 900 MHz RF-based subsystem, an Automatic Packet Reporting System (APRS)-based subsystem operating at ~150 MHz and a cellphone-based tracking subsystem operating at ~2 GHz. Each method will utilize a GPS receiver and a micro-controller unit (MCU). The MCU will acquire payload's position coordinates from the GPS receiver and convert the raw positon data into readable text strings. These strings will then be transmitted in the aforementioned three modes of wireless transmission to the ground vehicles equipped with at least one on-board subsystem's counterpart and real-time positioning software developed by our students.

III. Program Assessment

A. Program Outcomes

The assessment of our high-altitude ballooning program has been performed at two levels – program and students – with respect to program outcomes and student learning outcomes. The program outcomes are specified in reference to the program goal of *contributing to NASA's education outcomes*. Among the three NASA education outcomes specified in [8], the following two outcomes are assessed: [Outcome 1] Contribute to the development of the STEM workforce in disciplines needed to achieve NASA's strategic goals (Employ and Educate, [8]) through a portfolio of investments; [Outcome 2] Attract and retain students in STEM disciplines through a progression of educational opportunities for students, teachers, and faculty (Educate and Engage, [8]).

TABLE I. Assessment of Program Outcomes

M*	AY 10-11	AY 11-12	AY 12-13	AY 13-14	AY 14-15	AY 15-16
(a)	4 (4)	6 (3)	6 (4)	9 (4)	10 (5)	11 (8)
(b)	25.0%	33.3%	16.7%	22.2%	40.0%	36.4%
(c)	0%	0%	0%	44.4%	40.0%	27.3%

* M-(a) number of student participants (new members in parenthesis); M-(b) % women involvement; M-(c) % minority student involvement

For the assessment of its effectiveness in achieving these two NASA outcomes, we have adopted the following metrics (M): (a) number of student participants; (b) % women involvement; (c) % minority student involvement and data are collected based on the demographic status of active participants where the *active* participant is defined as a student who commits a minimum of 5 hours/week for project activities when joining the group and actually puts the committed number of hours/week throughout a semester. Table I summarizes its results over the past few academic years (AY).

As the overall undergraduate enrollment at Gannon University is relatively small, the enrollment in the ECE department is also relatively small compared to that at other larger institutions of higher education. Nevertheless, the effectiveness of achieving the program outcomes in terms of the number of participants and women involvement is considered to be high and also the involvement of minority students has been considerably improved over the past three years.

B. Student Learning Outcomes

For the assessment of another program goal of *improving student learning experience*, we have adopted ABET's student outcomes "(a) through (k)" as metrics to determine the effectiveness of the activity and data are collected from surveys. The survey consists of 22 questions developed in line with the 11 "(a) through (k)" student learning outcomes defined by ABET/EAC. For each student outcome, we asked two questions: i) if the project provided opportunities for the student to improve on the learning outcome and ii) if the student actually did improve the learning outcome by participating in the project. Also, a space for additional written comments was provided for each student outcome. For instance, for the student outcome (a): *an ability to apply knowledge of mathematics, science, and engineering*, the survey questions for Q-a(i) and Q-a(ii) are, respectively, Q-a(i):*The extracurricular project activities provided me with an opportunity to improve my ability to apply knowledge of*

TABLE II. PROVIDING OPPORTUNTIES FOR (A) ~ (K)

Q#	SD	MD	N	MA	SA	NA
a-(i)	0.0%	0.0%	0.0%	0.0%	100%	0.0%
b-(i)	0.0%	0.0%	0.0%	11.1%	88.9%	0.0%
c-(i)	0.0%	0.0%	0.0%	33.3%	66.7%	0.0%
d-(i)	0.0%	0.0%	11.1%	11.1%	77.8%	0.0%
e-(i)	0.0%	0.0%	0.0%	22.2%	77.8%	0.0%
f-(i)	0.0%	0.0%	0.0%	0.0%	88.9%	11.1%
g-(i)	0.0%	0.0%	0.0%	11.1%	88.9%	0.0%
h-(i)	0.0%	0.0%	0.0%	11.1%	66.7%	22.2%
i-(i)	0.0%	0.0%	0.0%	11.1%	77.8%	11.1%
j-(i)	0.0%	0.0%	11.1%	22.2%	44.4%	22.2%
k-(i)	0.0%	0.0%	11.1%	33.3%	55.6%	0.0%

SD: Strongly Disagree MD: Moderately Disagree N: Neutral
SA: Strongly Agree MA: Moderately Agree NA: Not Applicable

TABLE IV. AVERAGE RATINGS FOR (A) ~ (K)

Q#	Opportunity Provisioning / Perceived Improvements					
	Oct. 2013 (9 participants)		*May 2015 (8 participants)*		*April 2016 (9 participants)*	
a	5.00	4.78	4.88	4.63	4.78	4.67
b	4.89	4.67	4.38	4.00	4.56	4.44
c	4.67	5.00	4.00	4.13	4.56	4.56
d	4.67	4.56	4.38	4.25	4.33	4.33
e	4.78	4.89	4.63	4.63	4.44	4.44
f	4.44	4.33	3.88	3.50	4.56	4.44
g	4.89	4.78	4.25	4.25	4.22	4.00
h	3.78	3.78	4.50	4.38	3.56	3.56
i	4.33	4.33	4.00	4.38	3.67	3.56
j	3.44	3.44	3.88	4.25	3.33	3.33
k	4.44	4.44	4.50	4.63	4.78	4.78

mathematics, science, and engineering; Q-a(ii): *Participating in the extracurricular project activities, I have improved my ability to apply knowledge of mathematics, science, and engineering*. For more details and specific texts for all survey questions, refer to Table 2 in [11].

The results of the survey conducted in Oct. 2013 are summarized in Table II for providing opportunities and Table III for perceived improvements [11]. The number of students participated in the survey was 9. We used a 0-5 scale with 5: Strongly Agree, 4: Moderately Agree, 3: Neutral (Neither Agree nor Disagree), 2: Moderately Disagree, 1: Strongly Disagree, and 0: Not Applicable. As can be seen from Tables II and III, most students agree that the project has facilitated learning in the "(a) through (k)" categories, and they have improved their ability (or knowledge or understanding, as applicable) in those categories. For some questions, e.g., Q-d(i) & Q-d(ii), Q-f(i) & Q-f(ii), etc., one or two students responded with Neutral and/or Not Applicable, which might have occurred for some of the new team members who just joined in the 13/FA semester.

TABLE III. PERCEIVED IMPROVEMENT IN (A) ~ (K)

Q#	SD	MD	N	MA	SA	NA
a-(ii)	0.0%	0.0%	0.0%	22.2%	77.8%	0.0%
b-(ii)	0.0%	0.0%	0.0%	33.3%	66.7%	0.0%
c-(ii)	0.0%	0.0%	0.0%	0.0%	100%	0.0%
d-(ii)	0.0%	0.0%	11.1%	22.2%	66.7%	0.0%
e-(ii)	0.0%	0.0%	0.0%	11.1%	88.9%	0.0%
f-(ii)	0.0%	0.0%	0.0%	11.1%	77.8%	11.1%
g-(ii)	0.0%	0.0%	0.0%	22.2%	77.8%	0.0%
h-(ii)	0.0%	0.0%	0.0%	11.1%	66.7%	22.2%
i-(ii)	0.0%	0.0%	0.0%	11.1%	77.8%	11.1%
j-(ii)	0.0%	0.0%	11.1%	22.2%	44.4%	22.2%
k-(ii)	0.0%	0.0%	11.1%	33.3%	55.6%	0.0%

SD: Strongly Disagree MD: Moderately Disagree N: Neutral
SA: Strongly Agree MA: Moderately Agree NA: Not Applicable

Table IV further summarizes the average scores obtained from the results of the surveys conducted in May 2015 and April 2016. For student outcomes (a)~(e), (g), and (k), the trend is very similar in the three surveys. But, it is noticeable that the group surveyed in 2015 had relatively low rating for the student outcome (f): *an understanding of professional and ethical responsibility* while there other two groups in 2013 and 2016 rated relatively high. The student outcome (h): *the broad education necessary to understand the impact of engineering solutions in a global economic, environmental, and societal context* was lower in 2013 and 2016 than 2015, perhaps because it was more of an interdisciplinary team including a few non-engineering students. The student outcome (i): *a recognition of the need for, and an ability to engage in life-long learning* was lower in 2016 than the previous two survey years. The student outcome (j): *a knowledge of contemporary issues* was somewhat constantly lower than other items in all three surveys. However, these survey results clearly demonstrate that all student groups in 2013, 2015, and 2016 agreed that our high-altitude ballooning program and its projects provided great opportunities to improve their learning experience and also they did actually improve most of the (a)~(k) abilities that all ABET-accredited engineering programs try for their students to achieve.

IV. CONCLUDING REMARKS

We have presented a brief overview of Gannon's high-altitude ballooning program and its projects over the past 6 years. Recognized as a highly successful high-altitude ballooning program in Pennsylvania, our program has been effective in attracting and retaining students for further development of the STEM workforce and also in improving the student learning experience via various payload design projects for high-altitude ballooning.

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