Eclipse Ballooning Project Live Streaming Activity: Overview, Outcomes, and Lessons Learned

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Abstract. In early 2014 representatives of NASA Space Grant recognized that it was important to make the most of the natural enthusiasm for the 2017 total solar eclipse. Within the higher education realm, the Space Grant Program was in a unique position to take on this responsibility. However, there was no nationwide structure in place to carry out a coordinated higher education eclipse effort. Therefore, a leadership team made up of personnel from several Space Grant consortia designed the Eclipse Ballooning Project. The project combined NASA Science Mission Directorate and Space Grant resources with cutting edge tools to create a network of dozens of high altitude balloon and radiosonde atmospheric science teams positioned along the path of totality across the country. These teams focused on three major tasks: 1) capturing and streaming the first ever live video of an eclipse from the edge of space, 2) partnering with NASA Ames Research Center on the space biology experiment, and 3) conducting high-resolution atmospheric radiosonde measurements. The focus of this paper is the overview, outcomes, and lessons learned of the first task. The second and third tasks, as well as in-depth descriptions about the live streaming systems, communication to the public, and project evaluation, are reported on in separate publications.

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1. Background

The National Space Grant College and Fellowship Program ("Space Grant") is one of four primary programs in NASA's Office of Education. Nationally appropriated Space Grant funds are awarded to a central consortium in each state plus the District of Columbia and Puerto Rico. The primary focus for most Space Grant consortia is offering higher education workforce development opportunities.

Since the early 2000s, high altitude ballooning has been a common hands-on workforce development activity for many Space Grant consortia. Academic high altitude ballooning teams typically use helium or hydrogen-filled weather balloons carrying payloads of experiments weighing a total of less than 12 pounds to approximately 100,000 feet in altitude. At these altitudes—above 99.5% of the atmosphere—payloads experience a space-like environment: the temperature is cold (-40°to -85°Fahrenheit), the pressure is low (down to 0.1 lb/in2), and the curvature of the Earth with the blackness of outer space is visible. Due to this space-like environment, high altitude balloons are often said to fly "at the edge of space" or in "near space" though they do not reach the commonly agreed-upon 380,000 feet beginning of space. Typical experiments include but are not limited to atmospheric measurements, cameras, GPS tracking systems, radiation measurements, and space technology proofs of concept. Figure 1 shows a natural latex weather balloon tied to a string of payloads being launched.

Figure 1. North Dakota students launching a high altitude balloon at Camas Wildlife Refuge in Idahp on eclipse day. The jerk of release has distorted the normally near-spherical balloon shape.

The Montana Space Grant Consortium (MSGC) has involved higher education students and instructors in high altitude ballooning activities since 2001, carrying out approximately 100 flights with hundreds of payloads in 17 years. In 2012, the MSGC director, Dr. Angela Des Jardins, helped NASA Education carry out a survey of active Space Grant student flight projects. The survey indicated that there were about 150 active high altitude ballooning programs in the country. For that reason, when Dr. Des Jardins came across an intriguing story in late 2013 about a pilot who went to great lengths to get his plane full of passengers in just the right place at just the right time to be able to observe a short duration total solar eclipse (TSE) from the air, she thought of the potential view of a TSE from a high altitude balloon and the possibility of involving the existing ballooning programs in a constellation of balloon flights for the 2017 TSE.

Video footage of a TSE from a high altitude balloon had been recorded just once before the Eclipse Ballooning Project, during the 2012 eclipse in Australia (Beldia and Cali 2013). This video is amazing. The astonishing part of the video is *not* the view of the Sun but the view of the shadow of the moon sailing across the Earth. Similar to the feeling astronauts have when they look down on Earth from above, seeing the Moon's shadow soaring across the ground is profound.

Based on this and other research, Dr. Des Jardins thought a nationwide collaboration of TSE high altitude balloon flights could be impactful if three aspects could be met: make student participation meaningful, raise the capability level of academic high altitude ballooning, and share the balloon view with a wide public audience. These three aspects pointed at a solution: have student teams send up balloons across the continent and live stream the 2017 total solar eclipse from the edge of space.

1.1. Project Initiation

In early 2014 Dr. Des Jardins sought support from the NASA Science Mission Directorate (SMD) education program to carry out the Eclipse Ballooning Project idea. Due to lack of funding availability as well as the immaturity of the ambitious idea, Dr. Des Jardins came away unsuccessful from that initial inquiry. The project idea *was* quite daunting. Among other uncertainties at the time, no one had ever carried out a hands-on student project of this magnitude before and the only live streaming that existed required multi-million dollar communications equipment. Nevertheless, Dr. Des Jardins believed her team, in collaboration with other Space Grant consortia, could figure out a low-cost, low-weight solution suitable for latex weather balloon flights. And they did.

MSGC built up a team charged with research, development, and leadership that included Space Grant personnel from Montana, Colorado, Louisiana, and Minnesota. The leadership team researched and tested hardware and software solutions, created new partnerships with Google Loon and other ballooning companies, and conducted a great deal of practice flights. Then, when a opportunity came along under the new NASA SMD Science Activation program, the team was ready. MSGC won a NASA grant for resources and support and the Eclipse Ballooning Project (EBP) was officially born. More information about partnerships and funding is presented in Section 2.1.

Next came team recruitment and training. Throughout the research and development phase Dr. Des Jardins and the leadership team shared the project idea at Space Grant meetings and other appropriate venues. Therefore, when funding was finally available to implement the project, recruiting official student teams was relatively straight forward. With the SMD award, EBP was able to offer teams all the necessary materials for flying and tracking high altitude balloons, all the materials for the "common payloads," as well as technical and organizational support. Ultimately, 54 official student teams from 32 states signed up to participate. Further participant demographics are reported in Section 2.2.

Training the teams to build, test, and practice operating the fairly complex common payload systems was one of the most important aspects of the project. The project timeline is shown in Section 2.3. Even though the anticipated groundwork was intense, the EBP leadership team decided that kicking off team preparation with in-person workshops at Montana State University would be the most beneficial. At two identical week-long workshops, which took place in May and July 2016, the EBP teams built and tested all the common payload systems. The year between the workshops and the eclipse was dedicated to team practice and preparation. More information about communication and support for the teams during their preparation time period is given in Section 2.4.

Each participating team was expected to fly the common payloads but retained about half of the available balloon lifting capacity for experiments of their choice. The common payloads consisted of the live streaming video system, a satellite tracking system, and a "cut down" system that could cut the payloads away from the balloon should air traffic control deem it necessary. A summary of the Federal Aviation Administration (FAA) coordination is given in Section 2.5. EBP also provided teams with a live still image system. More information about the common payload systems, which were a combination of "off the shelf" and custom designed parts, is covered in Section 2.6. An added benefit provided with the common payload systems—especially the radio components—was that they could continue to be used post-eclipse, for their original purpose as well as for other tasks.

The EBP team is proud of the outcomes, reported in Section 3, of this richly complex project. Some of the many lessons learned along the way are shared in Section 4. Future plans (or lack thereof) are discussed in Section 5.

1.2. Goals

The Eclipse Ballooning Project had four major goals:

1. Conduct meaningful science experiments. The two primary science projects included the Atmospheric Science Project and the Space Biology Project (project development and science led by NASA Ames). In addition, individual teams conducted their own science and engineering experiments.

2. Engage a wide audience. Total eclipses are rare and very impactful events. The EPB was in a unique position to engage the public in an awe-inspiring and educational way, even as the eclipse was happening.

3. Engage the student participants in meaningful, hands-on workforce development activities.

4. Build long-lasting partnerships. With key partnerships, the EBP could raise the bar in the academic high altitude ballooning community.

2. Approach

The EBP leadership team believed strongly in making the most of the 8/21/2017 'Eclipse Across America' event, in the realms of public science outreach, in science, technology, engineering, and math (STEM) education, and in creating meaningful long-lasting partnerships between institutions of higher education, museums, and industry. The leadership team also believed strongly in giving student participants career-making opportunities and experiences. To carry out these core beliefs, EBP endeavored to use cutting edge technology, to take advantage of diverse partnerships and resources, to conduct the clearest communication, and to support the project teams to be best of the leadership team's ability.

2.1. Partnerships and Funding

One of the most important contributions to the success of the EBP was the deep partnerships that were developed. Partnerships included the investment of effort (time), financial resources, and connections. The project, though fairly complex, was relatively inexpensive. It helped that the costs were shared among multiple partners. The three major project partners were: 1) Space Grant Consortia, 2) the NASA SMD, and 3) sponsoring companies.

The NASA SMD contributed an enabling grant to MSGC ($609,000), additional financial support for the live streaming bandwidth, valuable connections (including invitations to press conferences), and much appreciated staff time. The grant consisted of two parts. The first part was for common payload development and testing as well as project leadership. The second part was for the purchasing of the project common payload parts and all supplies necessary to undertake high altitude ballooning activities. On top of the SMD award, the NASA Balloon Program Office provided 300 latex balloons for practice and eclipse flights.

The Space Grant Consortia, not counting MSGC, contributed a total of at least $1M in support of their teams. Types of Space Grant contributions included, but were not limited to: student support, advisor support, supplies, and access to resources. The MSGC contribution estimate, for in state-supported leadership time beyond the NASA grant and direct student support, is greater than $400,000. For example, MSGC built many of the common payload components and kitted of all the common payload parts (estimated to be over 40,000 pieces). This contribution was completed by in-kind efforts from MSGC students and staff.

Additional supplies and services were contributed by sponsoring companies. Contributions included but were not limited to the following: A) Donations from the company Stream: no charge access to hundreds of technical development team hours, professional web page designers for `http://eclipse.stream.live`, and more. B) World View and Raven Industries donated testing flights. C) Google Loon donated 150 practice balloons and flight support. D) Ubiquiti Networks provided significant discounts on 5.8 GHz radios and modems. E) NAL Research waived the $600 set up fee for Iridium satellite tracking modems for all 54 teams.

While the funding the project received was limited to the period of performance, the partnerships have, and will continue to have, long-lasting impacts on MSGC, the academic high altitude ballooning community, and on the Space Grant community as a whole. The EBP was the first large-scale national Space Grant collaborative project. The Space Grant community, SMD Education leadership, and NASA Education leadership have lauded this project as an example of the kind of high-level partnering achievement they are proud of and want to continue to pursue.

2.2. Participants

The EBP officially had 54 teams from 32 states, representing 75 institutions (EBP Teams Webpage 2017). See Figure 2 for more information about team distribution.

Of the 54 teams, 70% were college/university, 12% were community college, 12% were high school, and 6% were hobbyist ballooning groups. A total of 919 students participated – 33% women, 30% under-represented minorities, 44% high school, 50% undergraduate, and 6% graduate students.

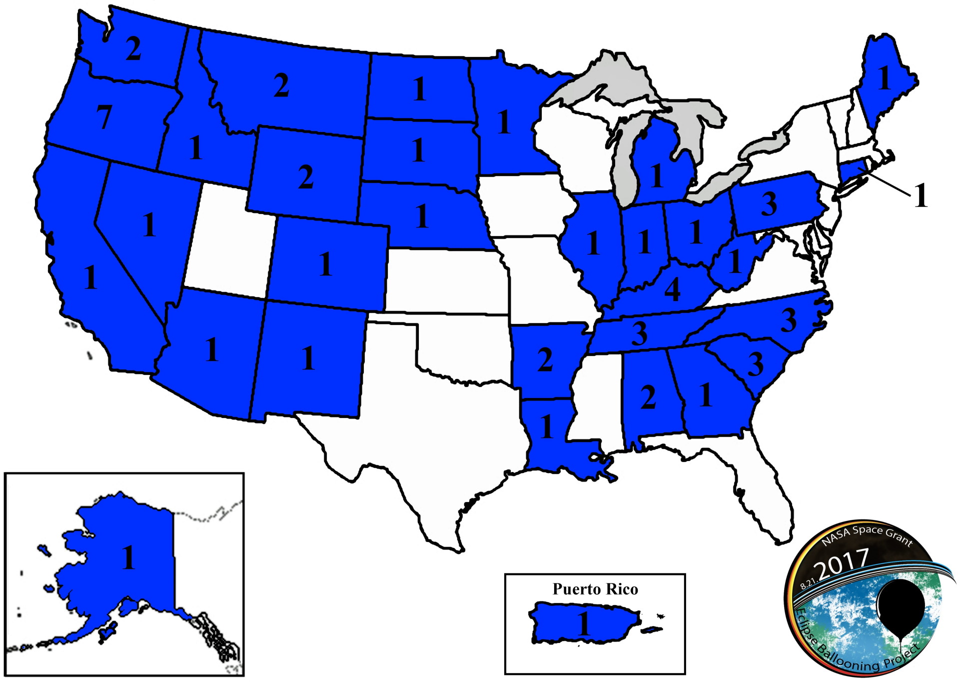

Figure 2. Participating team map

2.3. Timeline

Conceptual planning for the EBP began in late 2013. In some respects this was almost too early – most entities were not planning eclipse events yet, or were not planning in a coordinated fashion. In other ways, however, the EBP leadership team and participating teams could have used more time to accomplish this ambitious project – including letting the necessary technologies mature during the design and development phase. The list below demonstrates the major project timeline benchmarks.

- 2014–2015: common payload design and development
- June 2015: project funding secured
- March 2015–August 2017: coordination and planning with NASA and the FAA
- January 2016: Leadership team workshop and planning session
- May and July 2016: in-person workshops at Montana State University, Bozeman
- July 2016–August 2017: local practice with remote facilitation and support

- June 20, 2017: nationwide dry run at teams' home locations
- August 21, 2017: the big day; teams fly balloons along the path of totality
- September 2017–August 2018: knowledge sharing

2.4. Communication and Support

With nearly 1,000 participants in 54 teams spread across the country, it was paramount to the project success to have good communication at all levels. The EBP approach to communication was to ensure that every team received the customized support they needed to be successful. One of the most important keys to successful support and communication was hiring a fulltime project manager, Shane Mayer-Gawlik. The project manager, with assistance from Dr. Des Jardins and other leadership team members, carried out communications that included three primary areas: technical support, project coordination, and public engagement. Technical support was carried out via an online forum (EBP ProBoards 2017), a software management system (EBP GitHub 2017), occasional e-mail, resources on the EBP website (EBP Website 2018), videos on the EBP YouTube channel (EBP YouTube Channel 2018), and technical telecons. Project coordination was done over e-mail, Eclipse Activity Report (EAR) newsletters, with resources on the EBP website, telecons, individual team calls with the project manager, and in person at Space Grant meetings. Project and team news items were shared with the public via the EBP website, the project Facebook page (EBP Facebook page 2018), NASA-generated outreach, and through hundreds of traditional media articles, and radio and TV appearances.

2.5. Coordination with the FAA and Payload Tracking

To satisfy safety and due diligence as a NASA-sponsored project, MSGC requested and received assistance from the FAA in providing situational awareness to users of the national airspace so all groups were made aware of the activities along the path of the eclipse. EBP and FAA personnel jointly worked on drafting briefing documents for conveying eclipse project operations to FAA Air Traffic Route Control Centers (ARTCCs), to the Department of Defense (DoD) and to other industry groups. MSGC also worked directly with the Notice to Airmen (NOTAM) office to standardize and file launch and landing NOTAMs for each EPB team. Mission Notices provided a point of contact, launch location, balloon identifier and near real-time flight tracking information, flight trajectory, and recovery location for each EBP team. Mission Notices were submitted to the appropriate ARTCC supervisors. In several cases, military airspace was impacted and the appropriate DoD personnel were consulted and included in the notification process.

The collaboration between the EPB and the FAA resulted in two useful lasting products—the EBP Iridium satellite modem tracking database and the EBP tracking website (EPB Tracking 2018). The position information received through the Iridium satellite network and further stored in the EBP tracking database was queried by teams' ground station computers and used to point their ground antennas at their balloon—a difficult and precise business. Both the FAA and the EBP teams used (and are continuing to use) the website for tracking the real time positions and velocities of balloon payload stacks. Flight data is retained in the archive area of the tracking website for future access.

2.6. Common Payload System Technical Summary

The “common payload” system was a student-designed, low-cost platform capable of reporting balloon positions, severing the connection between payloads and the balloon envelope (“cutting down”), streaming live video, and capturing still images and sending them to the ground upon request, all at high altitude in near real-time. The system structure uses Raspberry Pi (“Pi”) computers and commercial radios in combination with MSGC designed and manufactured control and power boards. An overview of the common payload system is given in Table 1. Images of the live video payload and a ground station are shown in Figure 3.

Table 1. Common Payload System Details

Payload	Structure	Downlink	Ground
Position Tracking	Control & power boards	Iridium satellite + XBee to Cutdown	FAA & team website (EBP Tracking 2017)
Live Video	Pi + control & power boards	5.8 GHz Ubiquiti	Dish antenna -> computer
Still Image	Pi + control & power boards	900 MHz RFD	Yagi & patch antennas -> computer
Cutdown	Mechanical razor + control & power boards	XBee to Iridium	Email commands to Iridium

A remarkable achievement of the EBP was the development of a lightweight live video streaming system with adequate range for high altitude ballooning use for relatively low cost (a few thousand dollars per common payload flight/ground system). Prior to the EBP prototype, the only systems capable of streaming live video from a high altitude balloon cost millions of dollars and were much too heavy for small balloons. Further information about the technical details of the system will be available in a separate publication.

3. Outcomes

Many outcomes including technical achievements, process management and organization, partnership and communication, and education and outreach can be accounted by the EBP. The major accomplishments of the Eclipse Ballooning Project are:

- First to provide live footage of a total solar eclipse from a space-like perspective (an example eclipse high altitude image is shown in Figure 4)
- First to fly a constellation of balloons across a continent
- First to develop a low-cost system capable of streaming live video to the internet and TV from a high altitude balloon
- First large-scale National Space Grant collaborative project

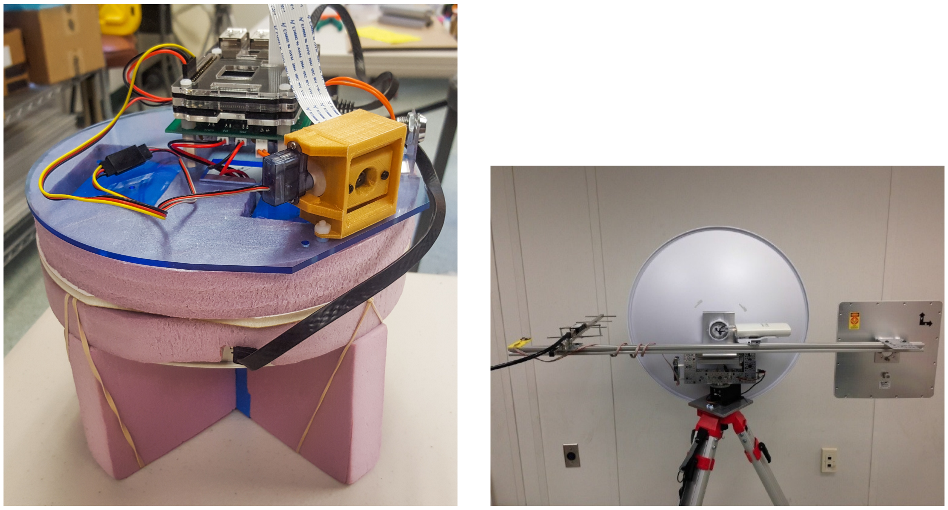

Figure 3. a) Live Video payload and b) ground station antennas.

- Conducted balloon flights for two major scientific studies, one in partnership with a NASA research center and one in collaboration with NOAA
- Featured as part of NASA's eclipse coverage, which reached 600 million people on TV platforms alone
- Project-specific media included hundreds of national and local stories with a pre-eclipse reach of 27 million people
- Engaged 919 students from 32 states in impactful hands-on technical activities
- Among other successful indicators, the professional evaluation showed that 88% of the participants felt they increased their problem-solving skills and 91% felt they increased their teamwork ability
- All official teams had at least one eclipse day success story and nearly every team successfully flew cameras and/or experiments on balloon(s) on eclipse day
- Developed partnerships with every major ballooning entity in the USA including Google Loon and World View
- Developed an award-winning model for future collaborations (inaugural National Space Grant Special Service Award and others)

4. Lessons Learned

The great legacy of the Eclipse Ballooning Project for future large-scale nationwide projects are the major lessons learned:

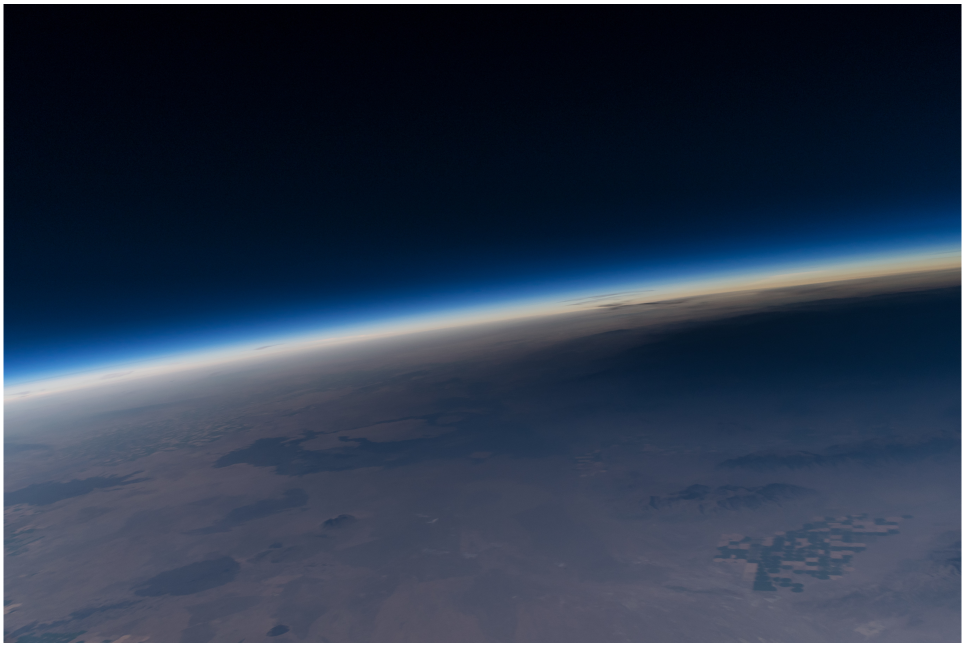

Figure 4. August 17, 2017 total solar eclipse shadow as seen from Montana Space Grant Consortium high altitude balloon at 80,000 feet above Rexburg, Idaho. Image taken with a Nikon D3300 at 18mm, f/6.3, ISO 200 and 1/60s. Note: this camera was not included in the "common payload" system.

- The National Space Grant program is a great model for creating large impacts because it has a healthy fractal nature—a defined base structure with well-connected deeper layers. For example, with the Eclipse Ballooning Project, we had a Principal Investigator connected directly to NASA, a leadership team, clear communication to leaders at 75 institutions who, in turn, engaged dozens of students each, who involved their families and communities.

- A robust communications plan is critical for timely and effective project development. With our large, diverse group it was helpful to share information in many ways: in-person training workshops, a central website, newsletters, email, telecoms, on-line technical forums, social media, etc.

- It's very helpful to take advantage of any excitement already available. There's no way we could have carried out the project for the cost we did without the natural excitement of a total solar eclipse and the momentum generated by NASA efforts.

- Setting challenging goals and using cutting edge technology creates an engaging atmosphere for students. Our project was complex, but this is part of the reason students wanted to participate – they knew they would be gaining valuable workforce skills.

- Building partnerships with related experts is beneficial. We benefited greatly from partnerships with World View, Google Loon, Raven Industries, and many others.

- The project primary point of contact must be highly responsive. Everyone appreciated that our project manager got back to them right away. If it had been otherwise, teams would have fallen through the cracks.

- The structure, capabilities, and expectations of the project designers, leaders, and support staff should be reasonable and clearly communicated during all phases of the project. We asked too much of our student leaders. We should have negotiated for additional funding for design expertise.

- The project evaluator should be on-board at the beginning of the project. We had a fantastic professional evaluator but should have brought them on at the beginning of the project for complete analysis of the goals and outcomes.

- It's important to build confidence with project stakeholders. The connections and resources provided to us by NASA and other stakeholders were essential to success.

- Allow freedom and control wherever possible. We got the best of each team by listening to their feedback and giving them control over half of what their balloon would carry.

- Create a sense of community at all levels – individual teams, leadership, and partners. The culture of the group is very important. For example, it helps to alleviate stress to share successes and anxieties that might arise.

- Anticipate possible complications. There was no pushing back the date of eclipse day so we planned for many potential scenarios. Starting the project early was important.

5. Future Plans

For the Eclipse Ballooning Project, we were in the right place at the right time. There were many established academic high altitude ballooning programs. Live streaming via mobile platforms was just coming into existence. Key technologies—lightweight radio modems and small computers like Raspberry Pi—were just becoming available. The National Space Grant network was looking for a multi-state collaborative project. Though we had to balance using the very latest technology with having time to deliver payloads, the EBP was successful in part because it was new and exciting—it was a first. If we simply repeated the project for the 2024 eclipse, it wouldn't be as exciting or as meaningful to the participants. Therefore, we're in a bit of a holding pattern. If Space Grants want to carry out another nationwide effort, it makes sense to walk the fine line between waiting for the next exciting technology to emerge and having enough time to carry out the project. As of this writing, Space Grants have not settled on a follow-on to the 2017 EBP, but discussions are underway and lessons learned from the EBP will be applied.

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Louisiana, and Minnesota Space Grants). A list of individual team leads is available at: http://eclipse.montana.edu/teams.

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