High School Payload Challenge: Inspiring High School Students to Experience the Professional Design Process

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A unique opportunity was devised for high school students to gain experience with the professional aerospace design process. This consists of a competition modeled after the competition the LIT (Launch Initiative at Tech) Georgia Tech student team is undertaking: NASA USLI (University Student Launch Initiative). The university-level initiative focuses on the entire engineering design process, with a large component revolving around documentation and design review presentations. Since a second payload can be hosted on the LIT vehicle, a competition modeled after USLI was broadcast to interested high school students. This competition focuses primarily on the presentation aspect of the design process, inviting competitors to undertake PDR (Preliminary Design Review) and CDR (Critical Design Review) presentations before building an actual payload. This is unique as the structure of the competition models the actual process used by NASA engineers. The HSPC (High School Payload Challenge) competition successfully served as a replicable model of a novel STEM engagement methodology that provides experience with both flight hardware and the full engineering design process. Additionally, HSPC provided valuable insight to the realistic operation of such a methodology, including experience with evaluating team performance, managing competition logistics, and expanding the opportunity by operating with other on-campus organizations.

I. Nomenclature

CDR	=	Critical Design Review
GSGC	=	Georgia Space Grant Consortium
Georgia Tech	=	Georgia Institute of Technology
HAB	=	High Altitude Balloons
HSPC	=	High School Payload Challenge
LIT	=	Launch Initiative at Tech
NOI	=	Notice of Intent
PDR	=	Preliminary Design Review
RRC	=	Ramblin' Rocket Club
STEM	=	Science, Technology, Engineering and Mathematics
USLI	=	NASA University Student Launch Initiative

II. Introduction

When considering the emerging STEM workforce of tomorrow, it is unquestionably important to foster student interest in the area. This has been a priority focus of recent research in order to determine the best method of engagement before students begin their journey in the professional world [1]. Many different methods of STEM education are well-studied, particularly hands-on experiences [2]. Georgia Tech's competitive rocketry team, Launch Initiative at Tech, is creating an experience that surrounds the softer technical skills such as design proposal and education at a high school level. This project, modeled after the NASA Student Launch Initiative that LIT competes in [3], aims to synthesize a novel and replicable method of engagement: providing an opportunity for students to exercise STEM creativity while exposing them to real-world engineering design experiences.

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STEM opportunities for students often focus on engaging students in hands-on environments [2], especially in extracurricular STEM exposure. Additionally, previous research has shown that many students gain their first STEM exposure through extracurricular opportunities [4]. These engagement methods often consist of activities such as robotics competitions, which primarily focus on a competitive final product rather than a competitive design process. As such, it is important to ensure that potential STEM enthusiasts interested in a career in the field gain both realistic and engaging first experiences through a new type of activity [5].

A significant quantity of prior research targets the classroom environment to expose the iterative engineering design process to students [6]. This is certainly effective, and existing research proves the positive effects of this instructional method [5]. However, there are limitations to this method, especially prevalent when reviewing the attitudes of instructional professionals regarding STEM education. Often cited limitations in STEM education for professionals include curricular and structural issues as well as a general lack of support [7]. Expanding process-focused STEM education beyond the classroom can combat these difficulties. Many preexisting opportunities that combat this, such as NASA's RockOn [8], are held exclusively at a university level. While this is clearly engaging university students in design process thinking, younger students are often not the target of similar opportunities. Existing experiences that target a wider audience than introductory STEM coursework whilst also showcasing a more complete picture of an iterative engineering design process are far more rare. The most similar experience, rather humorously, is the high school division of the NASA Student Launch Initiative that LIT competes in [3]. However, this competition has a different philosophy that limits raw engagement numbers: the high school division is competitive to enter, and teams must qualify to apply for entry. This can hold back novice students interested in STEM from gaining experience in these areas. Research exists that supports the effectiveness of STEM education that focuses on reviewing and iterating creative engineering concepts [9]; therefore, LIT aims to create a novel and replicable outreach opportunity that provides a practical method of application for this philosophy.

The High School Payload Challenge (HSPC) is designed to combat these issues while synthesizing the merits of existing styles of STEM education. Additionally, HSPC is targeted as a replicable model of engagement and outreach. HSPC takes inspiration from USLI, the competition LIT, a sub-team of Georgia Tech Ramblin' Rocket Club, is taking part in. In HSPC, students create experiments designed for flight as the secondary payload of LIT's USLI competition rocket. This is a mutually beneficial arrangement, as LIT members gain outreach and educational experience, while high school students discover the professional engineering design philosophy. The competition offers up four distinct stages, three of which are focused around the design process rather than the final product - only the fourth stage involves building and testing a rocket payload. With LIT's capacity for outreach, it is possible to offer HSPC to high schools in the region, and engage many potential teams. These teams are also able to come from any part of their school activities, including extracurricular, as they simply need an adult advisor to participate. The HSPC philosophy even can be abstracted to work at-scale, as most universities with an aerospace engineering program could offer similar opportunities in their areas, potentially engaging thousands of students nationwide.

III. Competition Design

The ultimate goal of HSPC is the design of an experimental rocket payload for flight on a NAR L2 sounding rocket. Modeled after USLI, HSPC requires the full engineering design process, with a particular focus on documentation and design review presentations. Specifically, the competition invites competitors to undertake a Preliminary Design Review and a Critical Design Review. After that, if selected, teams proceed with manufacturing their payload, which will then be integrated in the LIT rocket and launched. When designing their payload, the students are subjected to the USLI competition constraints [3], and some added rules to prevent their payload from interfering with LIT rocket hardware. A sponsorship of $100 is provided to the selected teams at manufacturing phase.

A. Initial Stages

HSPC is outlined through the use of a guiding document designed to market the competition to potential high school teams. The document includes a statement of purpose explaining the scope of the challenge and describing the general aspects of the USLI competition [3]. Details related to participation eligibility and HSPC's required commitment are additionally included in the document. The document also includes a description of the PDR requirements and evaluation criteria, which will be discussed further in subsection III.B: Design Reviews. In the appendix, some experiment examples are provided to inspire the teams with their creative design. A full overview of the process accompanied by a timeline highlighting all the relevant dates is also provided, together with a detailed explanation of all the design requirements and regulations. The most relevant requirements are listed below:

- The payload weight must not exceed 12 oz.
- The payload must be physically separate from the launch vehicle, and must fit within a cylinder that is 3.7 inches in diameter and 3 inches in height.
- The center of gravity of the payload must not be more than 0.3 in. off the center line of the cylinder and must not shift throughout the flight of the rocket.
- No energetics, pressure vessels, biomass, or liquids are permitted.
- Data must be stored locally and retrieved after flight.
- Radio transmissions are not permitted.
- The payload must not interfere electronically or magnetically with the rocket.
- The payload battery life must not be less than five hours.
- The payload must have an on/off switch that allows it to be turned on prior to integration.
- The payload must survive a maximum acceleration of 40G.
- The payload must allow two 0.25 inch threaded rods, separated by a distance of 2 inches, to pass through the payload bay.

To enroll in the competition, teams are asked to submit a Notice of Intent form containing technical and demographic information. This includes team size, team members and their academic years, as well as a brief proposal of the experiment they wish to design. In their proposal, they are also asked to defend the relevance of their experiment. Once the form submission window is over, each of the proposals is evaluated on its feasibility, and feedback is released to the teams with advice on how to improve their idea, comments about required modifications to comply with regulations, and in some cases, a note to heavily modify their experiment due to serious feasibility issues.

B. Design Reviews

The first competitive stage of HSPC is the Preliminary Design Review. This phase consists of oral presentations of teams' early versions of experiment designs. Each PDR presentation takes place online through Microsoft Teams for logistical reasons. This ensures that schools from the entire target region can take part in the presentations without travel considerations. Each PDR is comprised of 20 minutes for the teams to present, followed by 10 minutes for questions from the panelists. This is the optimal length for the PDR presentations, as it allows for the LIT volunteers to dedicate a reasonable time to the event while maximizing the quantity of presentations that can be effectively held. Moreover, the 20 minutes dedicated to the team presentations function as a guideline for the required technical depth of teams' designs at the PDR stage. The time dedicated to questions is also extremely important as questions are meant to encourage critical and edge case thinking in the teams, while also receiving feedback from university students that are more experienced in the topic. The basic PDR requirements are as follows:

- An introduction containing a brief overview of the team with a list of all team members and the goals or vision behind the proposed payload.
- An outline of the potential safety risks and mitigation strategies, as well as a description of how the design complies with the safety requirements of the competition. Safety measures that will be in place during construction, testing, and flight must be highlighted.
- A detailed explanation of the scientific or technical experiment that the payload will perform, including an overview of data collected, results, and how the experiment will contribute to broader scientific knowledge.
- A description of the physical structure of the payload, including dimensions, weight and material, and a breakdown of the individual components. A description of how the payload will integrate with the rocket system is also required.
- A project plan including a detailed timeline, a budget, a funding plan in case the budget exceeds the allotted sponsorship, an outline of potential challenges and risks, and how the team plans to address them.

The evaluation process for the PDR phase of the competition primarily surrounds two things: the technical presentation capabilities of teams and the originality and quality of teams' experiments. Presentation quality is evaluated at the PDR stage via a thorough requirements check. Just as in real-world engineering work, teams showing a powerful ability to meet all requirements and requests in the competition outline document earn priority for selection. Some weight is given specifically to any safety-related requirements, as these are the most important both from a philosophical and practical point of view - due to the nature of HSPC, USLI safety requirements must also be upheld. This is mostly evaluated with the provided safety risks and mitigation procedures from teams. Professionalism and presentation skills are also an important factor in this area - for teams, it is imperative to clearly, formally, and effectively present their payload. Quality and originality of teams' proposed experiments is also critical to HSPC. This heavily encourages teams to be creative with their experiment ideation and better prepares the students to solve engineering challenges later in their careers. In general, the evaluation criteria are left rather open-ended to allow for scoring adaptability based on the performance of teams as a whole.

At the end of the PDR phase, each team receives feedback through a scoring rubric, and the teams that get a score of at least 90/100 are selected to proceed to CDR. A blank version of the PDR scoring rubric is shown in Table 1

Table 1 Blank PDR Scoring Rubric

Category	Score	Comments
Deliverables Received by Deadline	_/10	
Technical Presentation Capabilities	_/30	
Presentation Design	_/10	
Experiment Originality and Quality	_/20	
Presentation Skills	_/10	
Professionalism	_/5	
Safety Information	_/15	
Total Score:	_/100	

The critical design review is orchestrated as a more complex and thorough version of the PDR. This implies CDR is comprised of a longer presentation and requires teams to showcase a fully complete design concept that includes engineering diagrams and simulation results. Additionally, a full bill of materials is required at the CDR stage to ensure complete design maturity. CDR presentations are also held online through Microsoft Teams, and consists of 30 minutes for each team to present, followed by 15 minutes of questions from the panelists. This is mainly for the same advantages offered by operating PDR presentations under the same format. The CDR presentation is meant to assess the teams' ability to finalize their experiment design and is therefore evaluated more thoroughly than the PDR presentation, as the stage of the competition is more advanced. The time of 30 minutes for presentation allows for a more detailed explanation of the project design, while the 15 minutes for questions give panelists time to ask for clarifications about the project and give constructive feedback on how to improve it. The basic CDR requirements that expand upon the PDR requirements are as follows:

- Thorough analysis of a complete design concept, which requires a well-drawn engineering diagram of the entire design or a complete CAD model.
- Results from simulations, regarding battery life before launch and general structural/safety aspects of the design.
- A launch procedure including any potential points of failure.
- Mitigation procedures for any issues and an overview of safety information.
- A bill of materials including quantities, sourcing links and costs for each component in a spreadsheet form.

Generally, the CDR evaluation process is very similar to the PDR evaluation process, except design completeness and the incorporation of PDR feedback are additionally considered in final team selection. At this stage, presentation quality not only requires thoroughly meeting all requirements and requests in the HSPC outline document, but additionally depends on the ability of the team to defend their experimental design in the questioning portion of the CDR. Teams must truly understand the design decisions and trade-offs they have made throughout the competition to succeed in this area. Additionally, any feedback given to the teams after the PDR stage must be clearly addressed, and should not require questioning by the panelists. Another critical evaluation area is the bill of materials and launch procedure for the team. The bill of materials very quickly highlights design decisions that eliminate experiment costs and complexity, while the launch procedure emphasizes the amount of effort placed in ensuring that the payload provided is well designed and easy to operate. A new highly weighted evaluation category unique to CDR is how finalized the design is. At CDR, the design should be 100% ready for construction to emphasize the proper implementation of planning and foresight throughout HSPC. Overall penalties were also added to the design criteria in case of an issue not foreseen in the evaluation criteria. This was in case of general failure to meet requirements that is greater than the available loss of scoring in the rubric, with some examples including: failing to meet deadlines, modifications after the deadlines, and blatant or critical requirements violations. In all, the CDR evaluation techniques are designed to elicit information on how well the iterative design process is applied over the course of HSPC. Therefore, any changes in the evaluation criteria from PDR to CDR are especially noteworthy.

The CDR feedback is also given to the teams as a scoring rubric, and the two teams that receive the highest score are selected as primary and secondary payload in order of performance. A blank version of the rubric is shown in Table 2. The maximum possible CDR score is 200 points, and the categories vary significantly from their PDR counterparts.

Table 2 Blank CDR Scoring Rubric

Category	Score	Comments
BOM Requirement	_/50	
Launch Procedure Requirement	_/20	
Safety Information	_/25	
Design Completeness	_/35	
Presentation Skills	_/15	
Experiment Quality	_/35	
Other Requirements	_/20	
Penalties	- _%	
General Commentary		
Total Score:	_/200	

C. Manufacturing and Launch

Once downselected, the teams receive funding and can begin building their projects. To guarantee the success of competitors' construction phases, teams work closely with the LIT outreach team. Teams are requested to send periodic updates on their manufacturing progress, and LIT serves a mentorship role by sending feedback on the updates and providing suggestions for the more delicate portions of the building process. To facilitate launching the teams' payloads, a dry integration is incorporated into the competition. The integration consists of an in-person session dedicated to testing if the payload correctly integrates with the launch vehicle, allowing the teams to address any potential problems ahead of launch day.

Due to USLI requirements, the launch procedure for teams varies depending on their level of selection. The team selected for the primary launch has two opportunities to launch their payload; however, they may only be present for a single launch. The team is able to attend the LIT full-scale sounding rocket demonstration flight, but unable to attend the actual USLI competition flight. The secondary team is able to attend their single flight on an L2 sounding rocket. Both teams are required to submit a launch procedure at the CDR stage to facilitate this process and to ensure all payload integrations are completed successfully. The launch phase also functions as the end of the competition for the selected teams. After launch, their payloads and data are recovered and returned to them for analysis.

IV. Outcomes

Any information related to the performance or demographics of the teams in the competition is omitted due to IRB limitations. Overall, the competition methodology, structure and design were effective. This is especially true when considering the staged nature of HSPC. Each portion of the competition, from the NOI through CDR, manufacturing, and launch, is designed to smoothly increase in difficulty. However, these transitions also matched the learning accomplished in each stage of the competition, especially considering that prior experience with the engineering design process was not expected from the teams. The transition from the project proposal to PDR allows teams to develop their idea into a design. The following transition from PDR to CDR enables competitors to iterate their design and finalize it before the manufacturing phase requires them to execute their plans. This structure proved effective, and showed no limitations regarding its replicability for future research to be conducted by other similar collegiate student organizations.

A. Team Evaluation

The primary challenge was evaluating the different teams, as there were many variables that were hard to control when evaluating team performance. It became difficult at times to determine which presentations deserved more merit than others when factors such as team size and academic level are relatively varied. Even if limiting HSPC to high school teams and targeting extracurricular groups was originally meant to control for these factors, it became clear during evaluation that more control may have been required. Larger teams tended to have more engagement and division of labor; however, appeared to be worse at communicating across the different aspects of payload designs. Smaller teams were more coordinated but were not able to offer more complex designs. Managing the traits associated with these differences proved to be an issue. Additionally, there proved to be a difference in the quality of work produced by younger teams, which was originally unexpected. One other unforeseen consideration was the availability of resources for student teams to design and manufacture their payloads. Many private or STEM-focused schools have significantly better resources for students to design and build around. While a competition focused on design review rather than construction should theoretically combat this inequality, students with access to these resources have had better and easier opportunities to develop their pre-existing design thinking. However, allowing this to give private/STEM-focused institutions an advantage may be antithetical to HSPC, which is designed to provide as much opportunity as possible. For these reasons, the selection process may need to consider the differences among teams in order to provide fair judgment. Overall, it was often asked what was the appropriate method for team evaluation: to hold equal standards for all teams under HSPC regardless of their size, academic level, and school resources, or to adapt for these factors in evaluation. The primary objective of HSPC was to expose high school students to the full engineering design process using a replicable model. This objective does provide some guidance on the equity vs equality debate within HSPC's review process: HSPC serves as a testing ground of a replicable model; therefore, additional complexities arising from these considerations should be avoided. Ultimately, equality was chosen for a few key reasons:

- It is nearly impossible to accurately measure the effect of the mentioned factors from the standpoint of HSPC.
- If a goal of HSPC was to target those who are disadvantaged, an opportunity that invites and specifically targets schools with fewer STEM opportunities would be more effective.
- Controlling for team size is almost pointless - different schools and groups handle the creation of teams independently. It would be significantly better to control sizing as an initial requirement for participation.
- If engagement across a variety of different levels was initially considered critical, different divisions of HSPC would have been significantly more effective.

A very common theme among this reasoning is that if equitable opportunity was an original goal of HSPC, this should have been an initial consideration. While it is is certainly difficult for HSPC to evaluate these factors independently, restricting for these factors beforehand is a promising method of adjusting to them. In future opportunities structured similarly to HSPC, if these controls are desired, the option to create separate divisions or additional rules for entry should be considered.

B. Logistical Issues

Navigating the various issues and changes within the LIT launch vehicle design process presented a unique challenge for HSPC. While it was imperative to uphold the original timeline of the competition, this was made difficult by the nature of HSPC. This was primarily an issue in the earliest phases of USLI, where major design changes were quite common. This obviously impacts HSPC, as the teams' payloads are required to fly on LIT's sounding rocket. Additionally, engineering and USLI competition issues as previously mentioned could cause doubt in the ability to launch the same number of teams as originally proposed. This at times caused frustrating issues requiring timeline adjustments in HSPC. The natural response to this dilemma is to delay the HSPC competition until the LIT vehicle reached a mature design phase; however, this was not possible for two reasons. Firstly, all outreach activities for LIT were required to take place in a specific time frame in order to be scored. Maximizing this window was of paramount importance to HSPC in order to allow time for the whole competition to take place. Secondly, it was very ideal if HSPC aligned with the academic year, as this allowed teams to stay consistent within their own schedules. These issues were mostly navigated by using generic statements in the competition outline, such as approximating the number of teams that could be accepted at each stage of the competition. In the future, it would most likely be ideal if this was accounted for with conservative estimation and cautious payload requirements. A better solution is most likely possible, and is something future research should explore.

C. HSPC Expansion Opportunities

The PDR stage of HSPC offered many promising team projects; unfortunately, there simply was no feasible way for LIT to accept more payloads. However, LIT was able to expand the opportunity by taking non-qualifying teams for CDR that had high quality experiments and relocating their flight to High Altitude Balloons, another subteam of RRC. This allowed several additional experiments to be flown on weather balloons. These teams selected for HAB also proceeded with their CDR presentations in front of LIT and HAB panelists. This was a significant boon to the HSPC program, vastly increasing the level of engagement the program was able to offer. However, adapting to this unique opportunity caused some issues of its own. The first is a mild selection discrepancy. Those who scored the highest and were not selected for CDR were taken to CDR with HAB instead. However, those who were selected for CDR with HAB could all feasibly be flown on a weather ballon, and those who were not selected for HAB but were selected for LIT CDR were not guaranteed to be flown on LIT's vehicle. As such, it would have been much better if this opportunity was discovered prior to the PDR phase so that vehicle selection for flight could have been determined with all of the best performing teams (most likely at CDR), rather than splitting the competition prematurely. Either way, this was an extraordinary opportunity to engage more teams within HSPC and similar opportunities should not be overlooked in future activities.

V. Conclusion

It is unquestionable that STEM education is of paramount importance to the engineering world [1]. Seeing as research supports the value of STEM extracurricular activities [10] and the importance of teaching the full engineering design process [5], HSPC is a natural evolution of current STEM opportunities in secondary education. Additionally, HSPC's effectiveness can be expanded by creating similar opportunities within comparable collegiate organizations. The competition overall served as an effective method of STEM outreach and education, especially considering its innovative focus on the design review process rather than the final product. Regardless of its unusual nature, HSPC's structure and design review focus successfully serves as a high quality replicable model for prospective outreach activities. Future research should focus on replicating and expanding HSPC-like opportunities to more organizations interested in the development of sounding rockets and other engineering projects of similar scale, potentially with a focus on reaching schools with fewer STEM opportunities as well as younger students.

Acknowledgments

The authors would like to express their deepest appreciation to Dr. Kelly Griendling, for her invaluable advice and guidance into the realization of this paper. The authors would also like to express their deepest appreciation to Dr. Dimitri Mavris, Georgia Tech's AIAA Faculty Advisor for his support in enabling this entire opportunity. The authors would also like to extend their sincere gratitude to Georgia Space Grant Consortium, in particular to Lori Skillings and Parth Garud, for their support with the competition distribution. In addition, the authors would like to extend their deepest gratitude to the competition sponsors, SGA and SAESAC, for their financial support. The authors also wish to extend their sincere thanks to Benjamin Dutschmann, LIT President, and Dr. Wenting Sun, LIT's faculty advisor, for their unwavering support throughout HSPC. Moreover, the authors wish to thank Michael Peña, RRC president, and Will Trimble, HAB president, for their valuable help and assisting with the available HSPC opportunities. Lastly, the authors wish to thank the high school students and their advisors for participating in our competition; without them, this project would not have been possible.

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