SECTION 508 OF THE REHABILITATION ACT OF 1973 AS AMENDED IN 1998

This is a draft document only. The working document is currently undergoing the review as required in Section 508 of the Rehabilitation Act of 1973 as amended in 1998. Once the review is complete, it will be uploaded to the Lunabotics Website and replace this Lunabotics 2024 Guidebook – DRAFT with the approved Lunabotics 2024 Guidebook.

ERRATA

The Lunabotics 2024 Guidebook – Draft Ver 1.0, dated Sep 01, 2023 has been changed as to section numbering, placement and with the following changes listed below:

1. 3. ELIGIBILITY, DELIVERABLES, APPLICATION, Eligibility 1.3 " The team shall be composed of enrolled undergraduate and graduate students …" is changed to read "Teams shall: be composed of enrolled undergraduate and graduate students and shall include at least two undergraduate students …"
2. 5. RUBRICS, Systems Engineering Paper, Systems Engineering Merit, 6.Technical Performance Measurement - "Design Optimization Criteria**"** is changed to read "Project Technical Objectives".
3. 8. LUNAR SITE PREPARATION & BULK REGOLITH BERM CONSTRUCTION CATEGORY
   8.2 Scoring - The following is added:
   (Note 1: During each competition attempt, the team will earn construction points for each cubic meter of berm constructed above grade. There is no minimum threshold).
   (Note 2: Obstacles may be part of the berm volume, but only from the Excavation Zone. Prefabricated berm structures are not allowed to be part of the berm – regolith simulant form the arena must be used).
   8.3 Construction Points - The following is added:
   (Note 1: only the green actual berm volume inside the red box will count towards the berm volume measurement)

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The Lunabotics 2024 Guidebook - Draft Ver 0.0, dated Aug 11, 2023 has been changed as to section numbering, placement and with the following changes listed below:

1.1 INTRODUCTION - Lunabotics 2024 and Beyond - updated.
1.13 Frequently Asked Questions / Ask For Help - updated.
2. TIMELINE - updated and now a stand-alone section.
3. ELIGIBILITY, DELIVERABLES, APPLICATION - remains unchanged.
4. CHALLENGE AWARDS - updated.
5. RUBRICS - remains unchanged.
6. ROBOTS - updated.
7. ARTEMIS ARENA SPECIFICATIONS - updated.
8. LUNAR SITE PREPARATION & BULK REGOLITH BERM CONSTRUCTION CATEGORY
8.2 SCORING - updated.
8.3 CONSTRUCTION - updated drawings.

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9. AUTONOMY POINTS - remains unchanged.
10.2 CONSTRUCTION ARENA PROTOCOL, CONSTRUCTION INFORMATION - updated.
10.4 NAVIGATION PROTOCOL - updated.
11. ON-SITE COMPETITION AT THE KENNEDY SPACE CENTER - updated.

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ALIGNMENT WITH NATIONAL STANDARDS IN ENGINEERING AND SPACE

Lunabotics provides students an opportunity to apply the NASA Systems Engineering process in designing a prototype robot capable of performing the proposed construction operations on a simulated Lunar regolith surface. Encouraging innovation in student designs increases the potential of identifying clever solutions to the many challenges inherent in future Artemis Lunar missions. Students will develop a deeper understanding and enhance their communication, collaboration, inquiry, problem-solving, and flexibility skills that will benefit them throughout their academic and professional lives.

The skills students develop in Lunabotics apply to other high technology industries that rely on systems engineering principles. These industries will create a workforce posed to lead a new space-based economy and add to the economic strength of our country. Lunabotics aligns with the Accreditation Board for Engineering and Technology (ABET) criteria outlined below:

Criteria 3. Student Outcomes: For baccalaureate degree programs, these student outcomes must include, but are not limited to, the following learned capabilities:

1. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities;
2. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
3. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
4. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
5. an ability to function effectively as a member or leader on a technical team;
6. an ability to identify, analyze, and solve broadly-defined engineering technology problems;
7. an ability to apply written, oral, and graphical communication in both technical and non-technical environments; and an ability to identify and use appropriate technical literature;
8. an understanding of the need for and an ability to engage in self-directed continuing professional development;
9. an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;
10. a knowledge of the impact of engineering technology solutions in a societal and global context; and;
11. a commitment to quality, timeliness, and continuous improvement.

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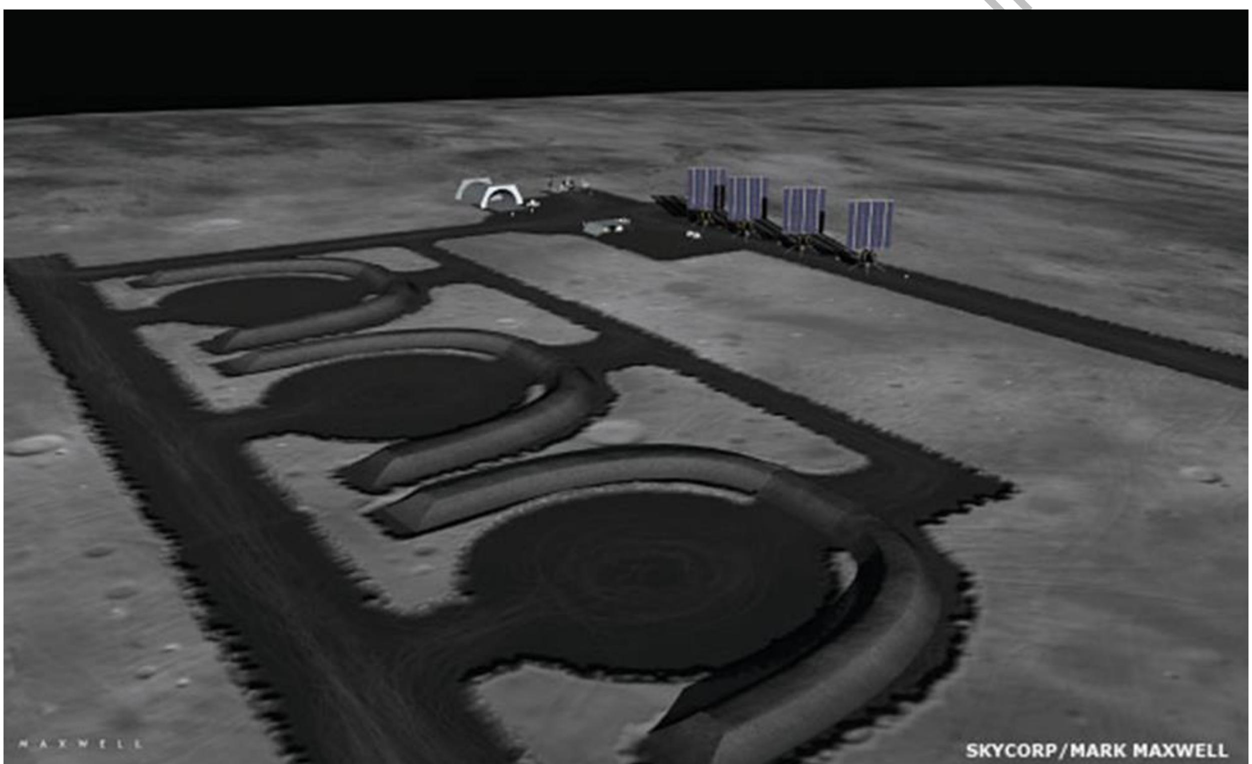
1. INTRODUCTION

1. Lunabotics 2024 and Beyond
The necessary lunar surface tasks are evolving to meet the NASA Artemis Mission requirements. In the past Lunabotics challenges we gathered data to support Lunar mining for consumables in the Lunar regolith. Now the task is to gather data on Lunar construction by designing and building a robot that will traverse the chaotic Lunar terrain and construct a regolith-based berm. The goal is to build a berm structure which would be useful to the Artemis Mission for blast and ejecta protection during lunar landings and launches, shading cryogenic propellant tank farms, providing radiation protection around a nuclear power plant and other mission critical uses.



Drawing 1. - Typical concept of Lunar Landing Pads with Berms (Source: NASA/ SkyCorp)

Lunabotics will consist of three separate events this year. The first event is NASA's Lunabotics Project Development Challenge, where teams submit various deliverables to be scored by judges. The second event will be the University of Central Florida (UCF) Lunabotics Qualification challenge, where teams will put their designs to the test. The top scoring teams from the Qualification challenge are then invited to the final event, NASA's Lunabotics On-Site Challenge.

The rules, rubrics, and other relevant information pertaining to NASA's Project development challenge and NASA's On-Site Challenge will be contained in this document. The rules and logistics for the UCF Qualification Challenge will be issued separately by UCF in their own document.

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Event 1 - NASA's Lunabotics Project Development Challenge

This is the gateway to the overall challenge. To apply to the challenge a team will follow the directions listed in Section 3. Eligibility, Deliverables & Application. You will receive an email letting you know the selection status of your application. Those teams selected will be required to complete the following in order to advance to the next competition event:

1. STEM Engagement Report
2. Presentation and Demonstration Slides
3. Systems Engineering Paper
4. Proof of Life Video.

Teams failing to submit any one of these items will be removed from the competition.

A list of the teams who completed the deliverables will be forwarded to the University of Central Florida's (UCF) Lunabotics Qualification Challenge. From there, UCF will issue invitations to the UCF Lunabotics Qualification Challenge.

Event 2 - University of Central Florida's (UCF) Lunabotics Qualification Challenge
The qualification challenge is to be held on-site at the University of Central Florida's (UCF) Center for Lunar and Asteroid Surface Science (CLASS) Exolith Lab in Orlando, Florida. UCF will issue their information document separately.

The 10 highest scoring teams from UCF's Qualification Challenge will be invited by the NASA Lunabotics team to run their robots once again in NASA's Lunabotics On-Site Challenge at the Kennedy Space Center. Teams that do not reach the top 10 will also be invited to this event, but they will not be given the opportunity to run their robot.

Event 3 - NASA's Lunabotics On-Site Challenge
The 10 highest scoring teams from the UCF Lunabotics Qualification Challenge will be invited to the Kennedy Space Center (KSC) in Merritt Island, Florida to compete in the on-site challenge in the Artemis Arena located in the Astronauts Memorial Foundation's Center for Space Education Building.

Teams that do not qualify for NASA's Lunabotics On-Site Challenge are still invited to attend this challenge, watch the robotic runs, participate in educational seminars, and get a complimentary, limited access ticket (which can be upgraded) to tour the Kennedy Space Center Visitor Complex.

2. Why the Moon
NASA's human lunar exploration plans under the Artemis program call for sending the first woman and first person of color to the surface of the Moon and establishing sustainable exploration by the end of the decade. Working with U.S. companies and international partners, we will uncover new scientific discoveries and lay the foundation for private companies to build a sustainable lunar economy. The agency will use what we learn on the Moon to prepare for humanity's next giant leap – sending astronauts to Mars (https://www.nasa.gov/topics/moon-to-mars/overview)

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3. Mission Impacts to Lunabotics
Be advised the Kennedy Space Center is an active launch range. NASA mission requirements / security requirements may change deadlines, deliverables and or cancel the event itself without prior notice.

4. Social Media
The Lunabotics Facebook page allows us to post notifications to the teams and the teams to communicate with each other, post photos, etc. Remember to "Like Us".

5. Media Advisory
All participants and visitors to Lunabotics at the Kennedy Space Center, or to the Lunabotics Qualification Challenge at the University of Central Florida (UCF) Center for Lunar and Asteroid Surface Science (CLASS), give permission to be photographed/videotaped by NASA or its representatives for potential use in future media products, unconditionally releasing NASA and its representatives from any claims and demands.

6. Waiver
Participants hereby waives any claims against NASA, its employees, its related entities, (including, but not limited to, contractors and subcontractors at any tier, grantees, investigators, volunteers, customers, users, and their contractors and subcontractors, at any tier) and employees of NASA's related entities for any injury, death, or property damage/loss arising from or related to NASA's Lunabotics, whether such injury, death, or property damage/loss arises through negligence or otherwise, except in the case of willful misconduct.

7. Roles and Responsibilities
It is the responsibility of the NASA Chief Judge and Project Manager to ensure the integrity of the challenge as to the interpretation and enforcement of the rules and rubrics in the Guidebook. The goal is to apply the content of the Guidebook equally to the competitors without passion or prejudice. The Lead Judges are responsible for creating the rules and rubrics and judging the deliverables received from the teams for their events. In matters associated with the overall Lunabotics Challenge, the Chief Judge and Project Manager's decision shall prevail.

8. Code of Conduct / Appeals
Lunabotics is a National Aeronautics and Space Administration (NASA) Artemis Student Challenge and is held in a positive and safe environment. Competitors shall be professional, courteous and respectful to all individuals. Students and faculty shall conduct themselves with integrity as to the spirit and intent of the rules, rubrics and regulations. Violation of the intent of a rule is a violation of the rule itself. A team found in violation of the rules, rubrics, or exhibiting unsportsmanlike conduct may be disqualified from the challenge individually or as a team. All scoring decisions are final. If an appeal is warranted, the advisor or the team leader shall submit the appeal in writing for consideration to the Chief Judge / Project Manager within 30 minutes of the posting of score(s) in question. The Chief Judge and the Project Manager shall review and issue a decision on the issue.

9. Frequently Asked Questions / Ask For Help
There will be no response to requests for information already contained in the Guidebook, to change a date(s), to change/waive a deadline, a rule or a rubric. The team is responsible for monitoring the Lunabotics website and the Lunabotics Facebook page for notices, updates,

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feedback requests and responses to FAQ's. The Guidebook and the FAQ's shall be read together as one document. Communications to the Lunabotics staff shall be through the advisor and/or team lead. Provide your school name, cite the relevant rule/paragraph number and send to KSC-Lunabotics@mail.nasa.gov

10. MENTOR / PROTÉGÉ TEAMS

NASA collaborates with space agencies around the globe on many programs including the International Space Station, Earth observation and the Artemis missions headed to the Moon and Mars. Building and nurturing an eligible, diverse, and inclusive workforce is imperative to the future success of NASA and to our Nation. Veteran schools are encouraged to mentor and collaborate with first-time schools or schools classified as Minority Serving Institutions (MSI's). This is a means for teams to take advantage of the economies of scale as to costs, resources and overall experience. NASA will make the award to the mentor school. The distribution of work, costs, awards, etc. is an arrangement between the schools. As an example, awards to winning mentor / protégé teams would read as follows: "Grand Lakes University" in collaboration with "Faber College"

Decades of research by organizational scientists, psychologists, sociologists, economists, and demographers show that socially diverse groups (that is, those with a diversity of age, race, ethnicity, gender, and sexual orientation) are more innovative than homogeneous groups:

1. MSI Capability Gateway - https://beta.nasa.gov/learning-resources/minority-university-research-education-project/the-minority-serving-institution-msi-exchange/

2. Scientific American - https://www.scientificamerican.com/article/how-diversity-makes-us-smarter/

"Lunabotics is Good for NASA, Good for America, Good for All of Us"

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2. TIMELINE

(Effective 08/29/2023)

Dates Are Subject to Change
All deadlines at 5:00 PM EDT/EST
(the Gateway portal for deliverables opens two weeks prior to the deadline)

Guidebook Release ………………………………...	TDB
Applications in Gateway ……………………………	Fri Sep 08, 2023 – Fri Sep 22, 2023
Team Selections Announced ……………………..	Wed Oct 18, 2023
Registration for Selected Teams Opens …………	Fri Oct 20, 2023
Registration for Selected Teams Closes ………….	Wed Nov 01, 2023
Team in Action Photos Due ………………………...	Wed Jan 01, 2024
Deliverables Due …………………………………… 1. STEM Engagement Report 2. Presentation and Demonstration Slides	Fri Mar 01, 2024
Deliverables Due …………………………………….. 3. Systems Engineering Paper	Wed Mar 27, 2024
Deliverables Due …………………………………….. 4. Proof of Life Video Link	Wed Apr 03, 2024
UCF's Lunabotics Qualification ……………………... Challenge at the University of Central Florida (UCF) Center for Lunar and Asteroid Surface Science (CLASS) in Orlando, Florida	Sat May 11 - Tues May 14, 2024
NASA's Lunabotics Challenge at ………………….. NASA Kennedy Space Center, The Astronauts Memorial Foundation, Center for Space Education (CSE), Merritt Island, Florida	Wed May 15, 2024 - Fri May 17, 2024

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3. ELIGIBILITY, DELIVERABLES, APPLICATION

1. **ELIGIBILITY**
   1. Accredited institutions of higher learning (post high school, vocational/technical schools, colleges, universities, etc.) in the United States, its Commonwealths, territories and or possessions. One team per school only.

   2. Students shall: be 18 years old at registration on the NASA STEM Gateway portal, currently enrolled and in good standing with their school, be from the same school as their team, and can only participate on one team.

3. Teams shall: be composed of enrolled undergraduate and graduate students and shall include at least two undergraduate students, have its own working robot(s), be accompanied by an adult employed by the institution and shall accompany the team to KSC. The number of students on the team is at the discretion of the school. Students who have graduated in the same semester/quarter as this challenge are eligible to be on the team.

2. **DELIVERABLES**

   A team failing to submit any one of these deliverables will be removed from the competition.
   1. STEM Engagement Report
   2. Presentation and Demonstration Slides (optional but is required for the grand prize).
   3. Systems Engineering Paper
   4. Proof of Life Video

   It is your responsibility to comply with the requirements, you are encouraged to put a second set of eyes when reviewing all your work items. Do not wait until the day before or day of a deadline to upload your files, allow for delays, errors, computer/system lockouts, etc. There will not be a second opportunity to upload your work.

3. **APPLICATIONS**

   1. NASA Gateway OSTEM Application Website

      1. The number of teams accepted to this challenge is not predetermined but is based on the deliverables received, the scores, and other factors. You are advised to start the application/registration process as soon as feasible after the "Upload Start Date". You are advised not to wait until the last days or day of a deadline to upload your files. For more information on how to navigate the NASA Gateway OSTEM Application Website see "Appendix A. Gateway Team Application Instructions" at the end of the Guidebook. The Team Lead starts the team application process and then invites students and faculty advisor(s) to apply within the website. When you run into an issue on the NASA Gateway OSTEM application website, send your inquiries to the website Help Desk. You may encounter a one or two-day turnaround time on responses to your inquiries. Do not contact Lunabotics about issues on the website, we do not own the website, we cannot unlock your account(s), we cannot trouble shoot issues, etc.
      2. Before you upload your PDF File(s), put a second set of eyes on what you are uploading, ensure you are uploading the correct file(s). There are issues involved in deleting,

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changing, etc. files. This process also takes time and if you are doing this near a looming deadline, you may miss the upload window. You cannot "delete" a file from the Gateway system. Lunabotics will review the most recent deliverable file that is received prior to the deadline listed in the Guidebook. NASA reserves the right to question or reject any letter if submitted by a party not authorized to represent the institution in question.

3. NASA STEM Gateway – The Team Lead starts the application process and then invites student members and advisor to apply within the NASA Gateway system. The team lead will be the responsible party to upload the deliverable PDF files to NASA STEM Gateway. Name your deliverable PDF files with the following format:

    1. Deliverables required to apply to Lunabotics:
        1. Upload the following 2 item(s) as one PDF File:
            1. Statement from Supervising Faculty and
            2. Statement of Rights of Use: School Name-Doc

        2. Upload the following item as one PDF File:
           Project Management Plan: School Name-PMP

    2. Your team will be notified of your application status.

    3. Deliverables required to remain in Lunabotics:
        1. Upload the following item as one PDF File:
           STEM Engagement Report.
           School Name-STEM

    4. Upload the following item as one PDF File:
        1. Presentation and Demonstration.
           School Name-PD (each school will be notified of the platform, date, and time of this event).

    5. Upload the following item as one PDF File:
        1. Systems Engineering Paper.
           School Name-SEP

    6. Upload the following item as one PDF File:
        1. Proof of Life YouTube Link.
           School Name-POL

4. Statement of Supervising Faculty
   A statement of support from a faculty/advisor indicating a willingness to supervise and work with the team during all stages of the activity. There will be no consideration for teams working without a faculty advisor. The faculty advisor must also sign off on the cover of all deliverables as evidence he/she has seen the application and approves of the submission. The following statement should appear on an institution letterhead and include the signature of the faculty advisor:

   As the faculty advisor for a team of higher education students from

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_______________________________________university/college,
I concur with the concepts and methods by which the students plan to compete in "NASA Lunabotics". I will ensure the student team members complete all project requirements and meet deadlines in a timely manner. I understand any default by this team concerning any project requirements (including submission of final report materials) could adversely affect selection opportunities of future teams from their institution.

____
Signature and Date

5. Statement of Rights of Use
These two statements grant NASA, acting on behalf of the U.S. Government, rights to use the team's technical data and design concept, in part or in entirety, for government purposes. This statement is not required. However, teams with a Statement of Rights of Use may receive greater consideration in the application selection. If choosing to include these statements, all team members and faculty advisors must sign. The statements read as follows:

Statement of Rights of Use - Agreement 1
As a team member for a(n) application entitled "NASA Lunabotics" proposed by a team of undergraduate students from

______________________________________ university/college,
the undersigned will and hereby do grant the U.S. Government a royalty-free, nonexclusive and irrevocable license to use, reproduce, distribute (including distribution by transmission) to the public, perform publicly, prepare derivative works, and display publicly, any data contained in this application in whole or in part and in any manner for Federal purposes and to have or permit others to do so for Federal purposes only.

Statement of Rights of Use - Agreement 2
As a team member for a(n) application entitled "NASA Lunabotics" proposed by a team of undergraduate students from

______________________________________ university/college, the undersigned will and hereby do grant the U.S. Government a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States an invention described or made part of this application throughout the world.

	Name (print):	Signature:	Advisor / Faculty / Student
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4. CHALLENGE AWARDS

1. Competing teams in NASA's Lunabotics Project Development Challenge will have a NASA peer review of their Project Management Plan (PMP) and Systems Engineering Papers (SEP) with an opportunity to Present and Demonstrate their SEP and robots to the NASA Team.

2. The 10 highest scoring teams from UCF's qualification challenge will attend NASA's Lunabotics On-Site Challenge at the Kennedy Space Center. Based on the operations tempo at KSC, students may get a behind the gate, behind the scenes tours and/or seminars (ex: systems engineering, patent applications, etc.) by NASA subject matter experts.

3. The teams that do not qualify for NASA's Lunabotics On-Site Challenge are still invited to attend this challenge, watch the robotic runs, participate in educational seminars. Students attending will be provided complimentary limited access tickets (which can be upgraded) to tour the Kennedy Space Center Visitor Complex.

4. For the Grand Prize the winning team shall compete in all the events, submit the required items as stated and score the most points, a cumulative of the scores.

5. <u>The Points (see the rubrics)</u>
    1. Project Management Plan …………… 10 Points
    2. STEM Engagement Report ………….. 15 Points
    3. Presentation and Demonstrations …... 15 Points
    4. Systems Engineering Paper …………. 25 Points
    5. Robotic Berm Building ………………... 25 Points

6. <u>The Awards</u>
    1. STEM Engagement - (1st, 2nd, 3rd Places) best inspiration to study STEM-related topics in their community to include collaboration with middle school student and present a high number of quality activities to a large and wide range of audiences.
    2. Presentation and Demonstrations - (1st, 2nd, 3rd Places) present intent and technical outcome of their design project. Allows the students to develop their public speaking skills.
    3. Systems Engineering - (1st, 2nd, 3rd Places) application of the Systems Engineering process used to design, build, test and evaluate their robot.
    4. Nova Award for Stellar Systems Engineering by a First Year Team - awarded to team(s) who perform exceptional systems engineering in their College/University's first year in the Lunabotics Challenge as demonstrated in their systems engineering paper.
    5. Leaps & Bounds Award - for significant improvement over the previous year(s) in the team's application of systems engineering to the development of their robot system.
    6. Innovation Award - for the best design based on creative construction, innovative technology, and overall architecture.

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7. The Caterpillar Autonomy Award – (1st through 6th Place) awarded for successfully completing the activities autonomously.
8. Robotic Construction Award - (1st, 2nd, 3rd Places) awarded to the teams that scores the most points during the berm building operations in the Artemis Arena.
9. Lunabotics Grand Prize - the winning team shall compete in all the events, submit the required items as stated and score the most points, a cumulative of the scores.

7. <u>The Prizes</u>
   1. Project Management Plan …………… points only
   2. STEM Engagement Report ………….. $1,000 - $500 - $250
   3. Presentation and Demonstrations …... $2,000 - $1,000 - $500
   4. Systems Engineering Paper …………. $2,000 - $1,000 - $500
   5. Proof of Life Video …………………….. required to stay in the challenge
   6. Robotic Berm Building ………………... $2,000 - $1,000 - $500
   7. Grand Prize ……………………………. $5,000

8. <u>Note:</u>
   Awards are given to a qualified team in each category, some are not awarded every year and are subject to change without notice.

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5. RUBRICS

Teams shall submit a complete deliverable based on the rubrics listed below. A partial deliverable is not a deliverable, it shall be rejected and the team shall be removed from this challenge.

1. Project Management Plan
2. STEM Engagement Report
3. Presentation and Demonstration Slides (optional)
4. Systems Engineering Paper
5. Proof of Life Video.

1. PROJECT MANAGEMENT PLAN (PMP)

Resources available:

1. A video series introducing the key project management and systems engineering products and how to apply them to your project can be viewed at Systems Engineering for University-level Engineering Projects and Competitions | NASA .
2. A video of the Project Management and Systems Engineering Seminar presented at the 2022 Lunabotics competition at KSC can be viewed Here.
3. Each team shall submit a complete Project Management Plan (PMP) electronically in one PDF file. This is an initial plan. As you execute your project, things will change and your project will evolve, which is okay and expected. In your Systems Engineering Paper you can discuss the changes to your plan and how your project adapted. Include your school name on the PMP. Maximum length of the plan is 5 pages. If you include a cover page, it will not count towards the page limit. Any content over 5 pages will not be judged. Format: The Project Management Plan shall be formatted professionally, organized clearly so that each required rubric element is easy to find, with correct spelling and grammar, with text no smaller than size 12 point font in the main body, with text no smaller than size 9 point font in graphics and tables, and using professional margins.

    1. Project Management Plan (PMP) Tip #1 - Make sure your Gantt Chart (if using) and tables are readable if you are providing them to satisfy a rubric element. If we can't read it, we can't give you points. If you provide graphics with unreadable (less than 9-point text as viewed in the pdf) text, make sure the information to satisfy the rubric elements are discussed in the main body (at least 12- point font).
    2. Project Management Plan (PMP) Tip #2 - Initial Project Schedule: Major Reviews. Make sure at least 3 show up on your schedule: SRR, PDR, and CDR. If you are using an alternate review instead of SRR, PDR, and CDR, then identify in the discussion the name of the review that replaces each.
    3. Project Management Plan (PMP) Tip #3 - Developing any management plan boils down to two things: making decisions and writing them down. It's important to document those decisions at the beginning of the project and share with your team. Update your plan as you learn more and your project progresses. The Project Management Plan rubric identifies an important subset of the decisions you will

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have to make in your Lunabotics project planning process, and simply asks you to tell us what those specific decisions were.

4. Project Management Plan (PMP) Tip #4 - Initial Project Budget: Budget evolution. As your design matures, you will learn more about how much your project is to actually going to end up costing. To be sure you don't run out of money before the end of the project, set up periodic reviews of your cost budget. In case your costs are much greater (or much less) than you expect, decide at the beginning of the project how you will address budget shortfalls, and what you will do with budget excesses. Don't forget to make these decisions and discuss them in your PMP.
5. Project Management Plan (PMP) Tip #5 - Initial Technical Performance Measures (TPM): Allocation to System Hierarchy. The system hierarchy is the backbone of your project. At the very start of a project, it may only consist of two levels. That early decomposition allows you to allocate how much time you plan to spend on each sub-element in the hierarchy, how much money you plan to spend on each sub-element, and how much of the technical performance each sub-element will have to provide so the system can accomplish the mission. As your design matures, these early allocations guide you through the design process to deeper levels in the system hierarchy, and enable sub-allocations at these new levels. And of course, you may learn things in the design process that might change even those earliest allocations. There is an example of allocations down through the system hierarchy in SE Video 2: 'The Central Elements of Project Management'. That video describes budget allocation; the approach is similar for mass and other TPM allocations. Don't forget to include the TPM allocations in your PMP.

Scoring Rubric - Project Management Plan	
Element	**Points**
Initial Project Schedule Provide a Gantt Chart or equivalent that shows the project's major due dates and events to include at least the five items listed below. Discuss these only as needed. 1. Start Date 2. Completion Date: (after project decommissioning; this is the date when you have disposed of your robot system after the challenge; for example, you hand the system over to next year's team, dispose of it or other) 3. Dates for the Major Review milestones: as a minimum, these must include ○ Systems Requirements Review ○ Preliminary Design Review ○ Critical Design Review ○ others may be identified as you find appropriate	**There are 3 points total for 6 elements**

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4. Product delivery dates to the Lunabotics Engineering Challenge, including as a minimum ○ delivery of Systems Engineering Paper, ○ the planned date to submit "Proof of Life" 5. Dates for important milestones related to Project Cost Budget and Technical Performance Measurement budget as identified in the Initial Project Budget and Initial Technical Performance Measurement budget sections of your Project Management Plan. (Optionally, you may also identify any major Systems Engineering activities in your Initial Project Schedule.) 6. Discuss how you will manage the evolution of the schedule during the life of the project (how often and when you plan to review the project schedule, and how you plan to adapt to schedule slips or schedule advance opportunities).	
Initial Project Cost Budget Provide an estimate of the total project cost, inclusive of all possible costs. Provide a Table of Major Budget Categories and Items including the following list items as a minimum. Discuss only as needed. 1. Breakdown of total project cost estimate for at least the following major items. (Total should add up to the estimate of the total project cost.) a. Cost estimates for elements in the earliest level System Hierarchy b. Labor costs, if any c. Material costs for challenge (for production and completion of Lunabotics deliverables) d. Travel costs including costs to travel to UCF and KSC if you intend to accept a proffered invitation to UCF to participate in UCF's Lunabotics Qualification Challenge and to KSC to participate in NASA's Lunabotics On-Site Challenge 2. Critical scheduling milestones (and dates) for budget items or other categories if any (These should be reflected in item 5 for the Initial Project Schedule; for example, dates funds will be needed, planned activities to raise funds, or others). 3. Discuss how you will manage the evolution of the budget during the life of the project (how often you plan to review	**There are 3 points total for 3 elements**

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your project budget and when, and how you plan to adapt to budget shortfalls or possible cost savings should they occur).	
Project Technical Objectives List and discuss the specific technical criteria or characteristics that your team intends to achieve (typically some technical parameter or measure you want to minimize or maximize, increase to some limit, or decrease to some limit) in your system design and operations to win the competition. These provide the technical direction and focus for the entire team in design and operations. For example: you might choose to minimize mass, or maximize automation, or minimize bandwidth, or some combination of these (or any other criteria or combination of criteria) to produce a system that will win the competition.	**There is 1 point for 1 element**
Initial Technical Performance Measures (Technical Budgets) Provide Table of Technical Performance Measures that you deem are important to your design approach (for example, mass, size, bandwidth, speed, or others) including the following as a minimum. Discuss only as needed. 1. Identification of Technical Performance Measures 2. Initial Target for each Technical Performance Measure to be achieved by the challenge 3. Allocation of each Technical Performance Measure across the elements of the earliest System Hierarchy (should combine to the total at the highest level) 4. Discuss any critical schedule milestones (and dates) for achieving critical technical performance levels (for example, decision points in the design process where if you are unable to achieve the desired level you would change the design). (These should be reflected in item 5 for the Initial Project Schedule.) 5. Discuss how you will manage the evolution of the Technical Performance Measurement budgets during the life of the project (how often you plan to review current Technical Performance Measure values, and how you plan to adapt to performance shortfalls or exceedances should they occur).	**There are 3 total points for 5 elements**

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2. STEM ENGAGEMENT REPORT

Each team must participate in at least two engagement activities with at least one middle/high school student group in their local community. This project is designed to engage students in STEM (Science, Technology, Engineering and Math) by introducing students to robotics and coding. Remember to discuss your experience with Lunabotics, the need for coding, robotics, and how they relate to careers in STEM and NASA's Artemis Mission with the students. Each team must submit a copy of the STEM Engagement Report electronically in PDF by the deadline. The STEM Engagement Report will be judged according to the following rubric. If there is a tie, the winner will be chosen at the judges' discretion. The Engagement report must include at least two engagement activities, with individual requirements outlined below. Teams will be required to include data regarding the students reached with the engagement activities. We suggest using a table like the one shown below.

Activity Date	Activity	Outreach recipient group	In person or remote?	# of Participants by Grade level		
				4th and under	5th – 8th	9th-12th
1/1/2023	Artemis Mission Presentation	Sunnydale High	In Person	0	0	25
1/2/2023	Hands on robotics	Sunnydale High	In Person	0	0	25

1. Teams will also be required to include a table recording the total hours dedicated to the engagement activities by each team member in their report.
2. Be sure to describe the outcome of the activities. What did the students accomplish and learn? Provide evidence, such as survey/quiz results before and after activities or examples of their work.
3. Indirect Educational Engagement
    1. The report must include at least one Indirect Educational Engagement focused on NASA's Artemis Mission, Lunabotics, In-Situ Resource Utilization (ISRU), Lunar Regolith, NASA STEM careers, and ways that students can get involved with NASA and robotics at their current age/experience level. This engagement should give context for the robotics/coding activity and connect it to NASA and Artemis.
    2. Indirect Educational Engagement - Participants are engaged in learning a STEM concept through instructor-led facilitation or presentation.
    3. Example: Students learn about why lunar regolith presents design challenges for robotics/space systems through a presentation or lecture.

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4. Direct Educational Engagement

   1. The report must include at least one Direct Educational Engagement centered around coding and lunar robotics. Ideally, this activity could be conducted inside NASA's Artemis Arena at the Kennedy Space Center. This Activity must have a direct connection to the Artemis Mission and lunar surface operations.

   2. Direct Educational Engagement - Instructional, hands-on activities where participants engage in learning a STEM related concept by actively participating in an activity. This includes instructor-led facilitation or inquiry around an activity regardless of media (e.g., face-to-face, video, conference, etc.).

   3. Example: Students learn about lunar robotics by creating their own robotics experiment with the help of the team to go on an Artemis-themed "mission," such as collecting resources or surveying craters.

   4. The activities may be conducted at the same event and with the same student group, but both must be completed by the submission deadline. Additional completed engagement activities may be included in the body of the report but are not required. Plans for future engagement may be included in the appendix (not body of the report) but are not required.

Lunabotics STEM Engagement Report Rubric		
Section	Element	Point Value
Structure, Content, and Formatting	Maximum of 5 pages plus 1 cover page and appendix. Cover page must include team name, title of paper, full names of all team members, university name and faculty advisor's full name. Formatted professionally, clearly organized, correct grammar and spelling, size 12 font, single spaced.	1
	The appendix details the team's engagement activities using the 5E model of instruction.	1
	Pictures or video clips must appropriately demonstrate the activities (provide a link in the document or include images in the report body or appendix).	1
	The report must include a table describing how the Lunabotics Competition team participated, the number of team members present, and the number of hours each team member contributed.	1
	The report identifies lessons learned and plans for improvement.	1
	The report describes student outcomes and accomplishments. What did they learn? Provide evidence.	1
	The report must show statistics on the participants.	1

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Structure, Content, and Formatting Subtotal		*7*
Indirect Educational Engagement Activity	The report describes how the team educated students about NASA's Artemis mission, Lunar Regolith, ISRU, and NASA STEM careers.	1
	The Report identifies how the team members shared their STEM journey with the students.	1
	The Report describes how the team teaches students about how they can get involved with Robotics and NASA at their current experience level	1
Indirect Educational Engagement Activity Subtotal		*3*
Direct Educational Engagement Activity	The report describes a hands-on activity that teaches middle/high school students about robotics and coding.	1
	The activity is themed around NASA's Artemis Mission, and teaches students about the moon.	1
	The report identifies the robotics kit/components used, the coding language featured, and the rationale behind these decisions (cost, user-friendliness, access, etc.).	1
	The report identifies the level of familiarity students had with coding and robotics prior to the activity.	1
	The report identifies the concepts (Logic, Loops, variables, utilizing sensors, etc.) utilized in the activity, and how they were taught to the students (analogies, diagrams, examples, etc.).	1
Direct Educational Engagement Activity Subtotal		*5*
STEM Engagement Report Total		15

NASA Resources

Artemis
Forward to the Moon Explorer Activities
In-Situ Resource Utilization
NASA's Next Generation STEM: Moon

Crew Transportation with Orion
Propulsion With the Space Launch System
Habitation With Gateway

Get Ready for Artemis
Artemis I: We are Capable
Artemis I: NASA's Plans to Travel Beyond the Moon
NASA 2022: A Year of Innovation
Time-lapse of Core Stage Stacking for the Artemis I Mission

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3. PRESENTATION AND DEMONSTRATION

This is an optional event. You do not have to participate, however, you will not be eligible to win the grand prize. Teams choosing to compete in this event shall submit a complete Presentation and Demonstration slideshow electronically in one PDF file.

1. The Presentation and Demonstration will be judged by a panel of NASA and private industry personnel. Each team will be allotted 25 minutes in front of the judging panel. It is expected that the presentation and demonstration will last approximately 20 minutes with an additional 5 minutes for questions and answers. There is a hard cut-off at the 25-minute mark in order to maintain the judging schedule. NASA will project these slides onto the screen during the presentation. Please note that updates and modification to slides are not possible after the deadline, as judges will pre-score the content.

2. Each subcomponent of the Scoring Elements will be ranked using an adjective rating system, with an "Excellent" score receiving full credit, "Very Good" receiving 70% credit, "Satisfactory" receiving 50% credit, "Marginal" receiving 20% credit, and "Unsatisfactory" receiving 0% credit. The "Excellent" rating is used to account for exceptional work (there are no bonus points this year). In case of a tie, the judges will choose the winning presentation. The judges' decision is final.

Notes on Demonstration

1. Safety is of the utmost importance. You are expected to be aware of the specific hazards associated with your robot and plan safe practices for demonstration. Everyone shall adhere to safe practices at all times during the demonstration, especially when troubleshooting unexpected issues in real-time. A clear zone shall be established around the robot, and no one shall enter that zone while the robot is in operation. All content from this paragraph shall be addressed when presenting the "Safety plan" topic.

2. "Demonstration" defined: We prefer that you perform a live demonstration of all functions via the control system, however we recognize that this is not always possible. If parts or the entire robot cannot be controlled at the time of demonstration, it is acceptable to move parts by hand (once the power has been turned off), show video from practice runs, etc. to communicate the functionality and attributes of the system and/or subsystems.

3. Safety: Re-read the above note on safety, and plan how to safely handle the unexpected!

Scoring Rubric – Presentation and Demonstration	
Element	**Points**
Scoring Element 1: Individual Slides 1. Judging Criteria a. Content, Formatting, and Illustrations: Each topic is addressed in sufficient depth. Include illustrations to support slide	**There are 15 base points for this element.** **Lack of "innovation" topic coverage will not count**

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content (technical content, progression of the project, etc.). Ensure that formatting is readable and there is a good balance of text to graphics. Utilize proper grammar and spelling. b. Presenter's Delivery: Body language, preparedness, slide handling, knowledgeable, passion, effective communication. 2. Topics to Cover a. Introduction i. Include team name, university name, names of team members, and faculty advisor's name. b. Safety Plan i. Robot-Specific Details: Discuss hazards and safety features. ii. Demonstration Safety: Discuss your plan for the demonstration. Include hazards that could be encountered during the demonstration and how you have addressed them to ensure a safe demonstration. c. Project and System Performance Goals i. Qualitative ii. Quantitative: Specify target values/ ranges d. Project Management – Management of budget, schedule, team, risk, etc. e.) Design and Testing i. General Philosophy and Process ii. System-level Alternatives Considered iii. Subsystem Alternative Analysis and Design Development (Mining, Mechanical, Electrical, Software and Controls) iv. Final Configuration v. Performance Testing (include comparison of testing results to goals) f.) Innovation i. Comparison to last year and evolution from previous years ii. Identify efforts to evolve processes, features, components, etc.	**against teams in their first year at the challenge.**
Scoring Element 2: Overall Package 1. General organization and flow of the slides as a package 2. General organization and flow between presenters. Time management: appropriate number of slides and material for time allotted and a professional cadence. 3. Question and Answer session	**There are 6 base points for this element.**

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4. Overall Performance	
Scoring Element 3: Demonstration Live demonstration will not be permitted if the "Demonstration Safety" component of the Safety Plan was not addressed prior to the intended movements. Scoring: 1. Pass/Fail criteria: a. Adherence to the safety plan. b. Executing the demonstration safely. 2. Extent of organization, integration, and planning 3. Extent of demonstration 4. Depth of explanation	**There are 4 base points for this element.** **Failure to adhere to safe practices will automatically result in a score of "0" points.**

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4. SYSTEMS ENGINEERING PAPER

Resources available:

1. A video series introducing the key products and techniques of systems engineering and how to apply them to your project can be viewed Here.
2. A video of the Project Management and Systems Engineering Seminar presented at the 2022 Lunabotics competition at KSC can be viewed Here.
3. An example of undergraduate course materials in systems engineering is available Here.
4. Each team shall submit a complete Systems Engineering Paper electronically in one PDF file.
5. The purpose of the Systems Engineering Paper is for the team to demonstrate how they used the systems engineering process in designing, building, and testing their robot.
6. A minimum score of 20 out of 25 possible points must be achieved to qualify to win in this category. In the case of a tie, the judges will choose the winning Systems Engineering Paper.
7. Either one column or two column formatting is acceptable. The "professional journal margins" note is to remind authors to provide appropriate white space at the margins and between sections.

Scoring Rubric - Systems Engineering Paper	
Element	**Points**
Content 1. Format: Provide a cover page. The cover page shall include: team name, title of paper, full names of all team members, university name, and faculty advisor's full name. The Systems Engineering Paper shall consist of a maximum of 25 pages not including the cover page, title page, table of contents, and a list of references pages. If a team chooses to use appendices, they must be within the 25 page count and referenced and discussed in the main body of the paper. ***Only the first 25 pages of the paper will be judged.*** The Systems Engineering Paper shall be formatted professionally as if for submission to a professional journal: organized clearly so that each required rubric element is easy to find; with correct grammar and spelling; with text no smaller than size 12-point font in the main body and appendices; text no smaller than size 9 point font in graphics and tables; using professional journal margins; and single spaced. 2. Faculty Signature: The cover or title page shall include the signature of the	**There are 3 points for 3 elements, one point each**

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sponsoring faculty advisor and a statement that he/she has read and reviewed the paper prior to submission to NASA. 3. Reason for using Systems Engineering: A statement shall be included early in the main body explaining the reason the team used systems engineering in this Engineering Competition (beyond that it is required). (For example: What benefit did it provide? How was systems engineering valuable to your project? You may have other reasons.)	
Project Management Merit 1. Project Technical Objectives: List and discuss the specific technical criteria or characteristics that your team intends to achieve (typically some technical parameter or measure you want to minimize or maximize, increase to some limit, or decrease to some limit) in your system design and operations to win the competition. These provide the technical direction and focus for the entire team in design and operations. For example: you might choose to minimize mass, or maximize automation, or minimize bandwidth, or some combination of these (or any other criteria or combination of criteria) to produce a system that will win the competition. *[1 point]* 2. Is your system a New Design or Design Update: Clearly state that the system is an entirely new design, or an updated design from a previous competition. If you have an updated design, clearly identify the specific subsystems or components that were changed on a previous system. If you have an updated design, provide the system hierarchy for the previous system and identify on it which items were changed for this year's competition. If you have an updated design, explain how you arrived at your decisions for these changes and focus the rest of the paper on the systems engineering work you performed to develop the new/updated subsystems/components and integrate them into the whole system to perform the mission. *[2 points]* 3. Major Reviews: At a minimum, describe how you conducted the System Requirements Review (SRR), Preliminary Design Review (PDR), and Critical Design Review (CDR) and explain how these reviews served as control gates. Provide examples of changes that occurred to: 1) the system design (in terms of	**8 points for 5 elements.** **2 bonus points may be awarded for exceptional work on Project Management Merit elements**

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requirements changes); 2) the schedule; 3) the cost budget; and 4) Technical Performance Measurements, specifically as a result of external reviewers' comments at each review. *[3 points]* 4. Schedule of work: Discuss the project schedule and how it evolved from inception to disposal of robot system. Provide the original planned schedule before project start, and as a minimum the actual final schedule (or schedule at the time the paper is delivered). You may provide other interim schedules at relevant milestones as well. Explain what changed between the provided schedules, why it changed, when it changed, and how these changes affected the cost budget and relevant technical requirements. When you go through a major review, it's not unusual for the schedule to change. Demonstrate in the discussion that the schedule was used to manage the project. *[1 point]* 5. Cost budget: Discuss the cost budget for total project costs (including travel, especially the travel costs if you intend to accept an invitation to UCF to participate in UCF's Lunabotics Qualification Challenge and to KSC to participate in NASA's Lunabotics On-Site Challenge if proffered) and how it evolved from inception to disposal of robot system. Provide the original estimated cost budget before project start, and as a minimum the actual final cost budget (or cost budget at the time the paper is delivered). You may provide other interim cost budgets at relevant milestones as well. Explain what changed between the provided cost budgets, why it changed, when it changed, and how these changes affected the schedule and relevant technical requirements. When you go through a major review, it's not unusual for the cost budget to change. Demonstrate in the discussion that the cost budget was used to manage the project. *[1 point]*	

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Systems Engineering Merit 1. System Hierarchy: Provide a top-down breakdown of the system design. Show that a new more detailed level in the hierarchy was the central topic reviewed and baselined at each control gate or major review (SRR, PDR, CDR). 2. Requirements: Identify the key driving requirements for robot system design, operations, interfaces, testing, safety, reliability, etc., stated in proper "shall" language. Address system and lower level derived requirements. These are the requirements that should specifically be addressed when you discuss verification – see Systems Engineering Merit element 8 "Verification of system meeting requirements." 3. Interfaces: Identify the key important interfaces between elements in the system hierarchy at each system hierarchy level and their type (i.e., mechanical, electrical, human, signal, data, communication, etc.). Include key important external interfaces. Discuss how the interfaces possibly affected system design. Indicate which of the key driving requirements are interface requirements 4. Engineering Specialties: Discuss design and operations considerations that address the engineering specialties captured as key driving requirements. Indicate which of the key driving requirements resulted from considerations of the engineering specialties. Also indicate which of the engineering specialties played a role in trade studies. [The following are examples of a few engineering specialties that may be important for your system design. Those important in your system design may include some of these examples, and others not mentioned in this list of examples. • **Reliability** (what did you have to design into your system to assure that the system will operate properly until the end of the competition), • **Maintainability** (what did you have to design into your system to assure that you can maintain and repair your system if it fails at the competition, and what tools you might need for repairs and maintenance), • **Logistics** (what did you have to design into your system to assure that if you have a failure at the	**8 points for 8 elements, one for each element.** **Up to 4 additional points for exceptional work and additional systems engineering methods used.**

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competition that you have on hand parts for repairs and maintenance, possibly bringing spare parts with you or finding parts sources local to the competition), • **Transportability** (what did you have to design into your system to be able to transport your system to and from the competition in a working condition, including possibly design features and tools needed for easy disassembly for packing/transport/shipping and reassembly at the competition), • **Safety** (what did you have to design into your system to assure that it cannot cause injury or damage during the mission from pack up to leave until return home and disposal)]. 5. <u>Concept of Operations (ConOps):</u> Describe how the team will operate the robot system elements, at each system hierarchy level and under the environmental conditions of the competition, to accomplish the robot system mission. Indicate which of the key driving requirements are operations requirements. 6. <u>Technical Performance Measurement:</u> Identify and discuss technical measures that are important to achieving your Project Technical Objectives (for example: mass, power, data – any technical characteristic that you consider important, difficult to achieve, or particularly risky to project success), how they are allocated initially to system elements in the system hierarchy, and how that allocation changes as the system design evolves through verification. Demonstrate that the budgeting and management of these important technical quantities was used in the design process. 7. <u>Trade Studies:</u> Discuss how important robot system decisions were made using trade studies, i.e., using weighted evaluation criteria scorings, with key decision results captured as robot system derived requirements. Indicate which of the key driving requirements resulted from trade studies. 8. <u>Verification of system meeting requirements:</u> Discuss how you assure or intend to assure that the as-built system satisfies, in the context of the concept of operations and under the environmental conditions of the competition, each of the key driving requirements identified and discussed in the section addressing Systems Engineering Merit element 2 "Requirements." Discuss how the key important interfaces were verified or plan to be verified.	

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5. PROOF OF LIFE (PoL) VIDEO

1. Your arena can use beach, play, construction or outdoor volleyball sand as an acceptable granular material for the purposes of the "Proof of Life" video (PoL). The PoL recording shall serve as a verification that the robot is fully functioning.
2. There are no points for this, but it is a required deliverable, failure to submit will result in disqualification from the challenge.
3. A video recording of the robot being weighed on a scale shall be provided in the Proof of Life video. The team faculty member is required to supervise this weighing operation and shall appear on the video certifying that the weight is correct and meets the 80 kg limit.
4. The dimensions shall also be certified in the video recording by the faculty member by showing in the video that the dimensions have been verified with a measuring tape.
5. The video shall be of one complete cycle of operations or 15 minutes of continuous operations. The PoL video will be provided as a You Tube link. The spirit and intent is that you have a fully functioning robot to present to the NASA judging staff.

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6. ROBOTS

Components (i.e. electronic, mechanical, etc.) are not required to be space qualified for atmospheric, electromagnetic, thermal or Lunar environments. Students on the team shall perform 100% of this project (including design, construction and task components of their vehicle and deliverables, and including performing or supervising work that is supported by a professional machinist for the purpose of training or safety).

1. ROBOT REQUIREMENTS

1. Robot(s) shall be contained within a payload envelope measuring 1.50 m length x 0.75 m width x 0.75 m height with a maximum mass of 80kg. It may deploy or expand beyond the envelop after the start of each attempt but may not exceed 1.75 m in additional height which is 2.5 m above the surface of the regolith (dimensions correspond to the typical payload volume available on today's Lunar landers that are commercially available).
2. Robots shall have a central hoist point or sling system based around the robot's center of gravity (CG). The hoist point or sling system will allow the robot to be picked up by an overhead crane for placement into an arena.
3. Robots shall have a minimum of four (4) lifting points, safe for human hands and
4. clearly marked (ISO 7000-1368) for students and NASA staff to use. Teams are responsible for placement and removal of their construction robot onto the BP-1 surface. There must be one person per 20 kg of mass of the construction robot, requiring a minimum of four people to carry the maximum allowed mass of 80 kg. Assistance will be provided if needed.
5. Robots will be inspected for the volume constraint in the stowed configuration during the Safety Inspection. A "jig" frame will be placed over the rover for volume constraint verification. No modifications or team robot interaction is permitted during this verification.
6. Multiple robot systems are allowed, but the total mass and starting dimensions of the whole system must comply within the volumetric dimensions given in this rule. subsystems on the robot used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.
7. The robot can separate itself intentionally, if desired, but all parts of the SP robot must be under the team's control at all times. The robot does not have to re-assemble prior to the end of the competition run.
8. The robot can run either by telerobotic (remote control) or in autonomous operations and cannot have any touch sensors to sense and avoid obstacles.
9. The launch volume dimensions of the robot may be oriented in any way (length, width, height - could be defined along any of the X, Y, Z axes, dimensions correspond to the typical payload volume available on today's Lunar landers). The team must declare the robot orientation by length and width to the inspection judge.
10. Reference Point Arrow - must mark the forward direction of the mining robot in the starting position configuration (the reference location and arrow pointing forward can point any direction of the team's choosing, except up or down). The judges will use this reference point and arrow to orient the mining robot in the randomly selected direction and position (you can use a permanent-type marker) indicating the team's choice of forward direction on any location on the robot is acceptable if multiple arrows do not conflict. The arrow does not have to indicate the robot's preferred forward direction. The arrow is used only to orientate the robot prior to starting the robot run to face the robot arrow either north, east, south, or

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west after spinning the direction wheel.

11. Subsystems used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.
12. The "KILL SWITCH" - The robot shall be equipped with an easily accessible red emergency stop button or "Kill Switch" as follows: Use sound engineering practices and principles in placing the "Kill Switch" on your robot(s), failure to do so may result in a safety disqualification. The "Kill Switch" shall have a minimum diameter of 40 mm; it shall be located on the surface of the construction robot and require no additional steps to access it. Only one "Kill Switch" per robot and in the case of multiple robots, each robot will have its own "Kill Switch." It shall be easily accessible and activated in an easy and quick manner. Disabling the "Kill Switch" without authorization from the Staff shall result in a safety disqualification. The emergency stop button must stop the construction robot's motion and disable power with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the robot. This rule exists in order to have the capability to safe the construction robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only onboard laptop computers and data-logger(s) may stay powered on if powered by its own, independent, internal computer battery. For example: it is acceptable to have a small battery onboard that only powers a (ex:) Raspberry Pi (or equal) control computer, and whose power does not flow through the main robot kill switch.
13. The robot must provide its own onboard power. No facility power will be provided to the robot during the attempt. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit. The energy consumed must be recorded with a "Commercial Off-The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each attempt must be shown to the judges on the data logger immediately after the attempt) The 'immediate' part refers to the judge climbing into the arena, finding the logger and recording the power reading. If the logger is independently powered, then the robot can be remotely powered off after the run. Although this is acceptable, it is not recommended in case the robot needs to be commanded to complete an operation so that it can be removed from the arena.
14. To ensure the robot is usable for an actual mission, it cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in an off-world environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Lunar environment and if such resources used by the robot are included in the mass of the robot. Closed pneumatic systems are allowed if the gas is supplied by the robot itself. Pneumatic systems are permitted if the gas is supplied by the robot and self-contained.
15. The rules are intended for robots to show an off-world plausible system functionality, but the components do not have to be traceable to an off-world qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and

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proximity detectors and/or Hall Effect sensors, but proceed at your own risk since LHS-1 & BP-1 regolith simulant is very dusty and abrasive. Teams may use honeycomb structures as long as they are strong enough to be safe and the edges sealed to prevent dust intrusion, a wheel with a large honeycomb structures that is open on both sides is allowed as long as the edges are not so sharp that they would be a cutting hazard. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on an off-world mission.

2. ROBOTIC OPERATIONS

1. The site preparation robot cannot be anchored to the sand prior to the beginning of the proof of life demonstration.
2. At the start of the competition run, the mining robot may not occupy any location outside the defined starting position in the regolith arena.
3. The site preparation robot must operate within the regolith arena; it is not permitted to pass beyond the confines of the outside perimeter of the arena or hit the walls during the demonstration .
4. The site preparation robot may not use any process that causes the physical or chemical properties of the regolith simulant to be changed or otherwise endangers the uniformity between competition attempts. The mining robot may not penetrate the regolith simulant surface with more force than the weight of the mining robot before the start of each competition attempt.
5. No ordnance, projectile, far-reaching mechanism, etc. may be used. The mining robot must move on the regolith simulant surface.
6. Beacons or fiducial targets may be attached to the designated arena frame area for navigation purposes only. The designated area is anywhere on the bin frame structure along the perimeter of the starting zone (2 sides). Tape, clamps, or rods pushed into the regolith may be used, but screws or other fasteners requiring holes may not be used. This navigational aid system must be attached during the setup time and removed afterwards during the removal time.
7. The outline of the berm target area will be marked on the surface of the regolith with colored chalk and the coordinates of the berm target area with respect to the 0,0 origin point will be given in the final version of the guidebook.
8. The mass of the navigational aid system is included in the maximum mining robot mass limit of and must be self-powered. A video recording of the robot being weighed on a scale shall be provided in the Proof of Life video. The team faculty member is required to supervise this weighing operation and shall appear on the video certifying that the weight is correct and meets the 80 kg limit. The dimensions of the robot shall also be certified in the video recording by the faculty member by showing in the video that the external robot dimensions have been verified with a measuring tape.
9. The beacon may send a signal or light beam or use a laser-based detection system which have not been modified (optics or power). Only Class I or Class II laser or low powered lasers (< 5mW) are allowed. Supporting documentation from the laser instrumentation vendor must be provided to the responsible faculty member for “eye-safe” lasers.
10. Inertial measurement units (IMU) are allowed on the mining robot. Teams have to explain in the Proof of Life video how the compass feature will be switched off or how the compass data is subtracted to ensure the internal calculations do not make use of the compass (from any magnetic field surrounding the robot). The Moon does not have a consistent magnetic

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field.

11. Global Positioning Satellite (GPS) or IMU-enabled GPS devices are not allowed. Teams must explain in the Proof of Life video how the device will be switched off or the data is subtracted and ensure the internal calculations do not make use of the GPS or IMU-enabled GPS device.
12. Autonomous robot operations are highly encouraged but not required.

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7. ARTEMIS ARENA SPECIFICATIONS

1. The Artemis Arena at KSC is filled with Black Point-1 (BP-1) crushed basalt rock lunar regolith simulant.
2. The arena area measures ~6.8 m long and ~5 m wide.
3. The Artemis arena contains ~45 cm depth of BP-1 (basalt regolith simulant).
4. Larger rocks may also be mixed in with the sand/gravel in a random manner (gravel is ~2cm in diameter).
5. The robot will be placed in the starting zone of the arena in a randomly selected starting position and direction.
6. Boulder Obstacles - there will be at least three (3) obstacles placed on top of the BP-1 surface within the obstacle zone area before each competition attempt is made. The placement of the obstacles will be randomly selected before the start of the competition. Each obstacle may have a diameter of approximately 30 cm to 40 cm and will have random heights.
   1. The **obstacles may not be pushed to the side of the arena in the obstacle zone**.
   2. The **obstacles may only be pushed to the side of the arena in the construction zone.**
7. Crater Obstacles - there will be at least three (3) craters of varying depth and width, being no wider or deeper than 40 - 50 cm in the obstacle zone. There will be at least one (1) crater, being no wider or deeper than 40 - 50 cm in the excavation zone. These craters may be filled in with regolith simulant.
8. The Artemis Arena has a central support structure column which is an obstacle and must be avoided.

Photo 1 - Artemis Arena Photo

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8. LUNAR SITE PREPARATION & BULK REGOLITH BERM CONSTRUCTION CATEGORY

1. Lunabotics Challenge at The Astronauts Memorial Foundation, Center for Space Education, Kennedy Space Center, Florida. Lunar bulk regolith construction requires teams to consider several design and operation factors such as high robot dust tolerance and minimizing dust projection, efficient communications, minimizing vehicle mass, minimizing energy/power required, and maximize autonomy. In each of the two official competition attempts, the teams will score cumulative construction points. The teams with the first, second and third most construction points averaged from both attempts will receive 25, 20 and 15 points, respectively. Teams not winning first, second or third place in the construction category can still earn one bonus point for each 0.013 cubic meters of berm constructed up to a maximum average of ten points.

2. **<u>SCORING</u>**

Construction Points Calculator – Artemis Arena				
Construction Category Elements	Units	Specific Points	Example Actuals	Example Construction Points
1. *Pass All Inspections (Comm/Vehicle).*	1,000=Pass / 0=Fail	0 or 1,000	1,000.00	1000.00
2. *Berm Construction* – A volumetric scan before and after the run will be performed. Only the berm volume within the target berm location will be counted. The team will earn 2500 construction points for each cubic meter of berm constructed above grade.	cubic meters m^3	2500	0.06	1500.00
3. *Average Data Bandwidth Use* - During each competition attempt, the team will lose one (1) construction point for each 50 kilobits/second (kb/s) of average data used (-1/50kb/sec).	Kbps/sec	-0.02	1066.00	-21.32
4. *Camera bandwidth Use* - During each competition attempt, the team will lose 200 pts for each situational awareness camera used (camera bandwidth usage 200 kb/camera).	Kpbs/camera	-200.00	400.00	-8.00

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5. *Construction Robot Mass* - During each competition attempt, the team will lose 8 Construction points for each kilogram of total construction robot mass. (For example, a construction robot that weighs 80 kg will lose 640 Construction points)(-8/kg).	kg	-8.00	80.00	-640.00
6. *Report Energy Consumed* - During each competition attempt, the team will lose one (1) Construction point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic data logger and verified by a judge (-1/watt-hour).	watt-hour	-1.00	9.00	-9.00
Dust Tolerant – see below				
Dust Free – see below				
9. *Autonomy* - See Construction Points – Autonomy	task	75, 150, 175, 250, 325, 400, or 500	250.00	250.00
10. *Total Points*				671.68

(Note 1: During each competition attempt, the team will earn construction points for each cubic meter of berm constructed above grade. There is no minimum threshold).

(Note 2: Obstacles may be part of the berm volume, but only from the Excavation Zone. Prefabricated berm structures are not allowed to be part of the berm – regolith simulant form the arena must be used).

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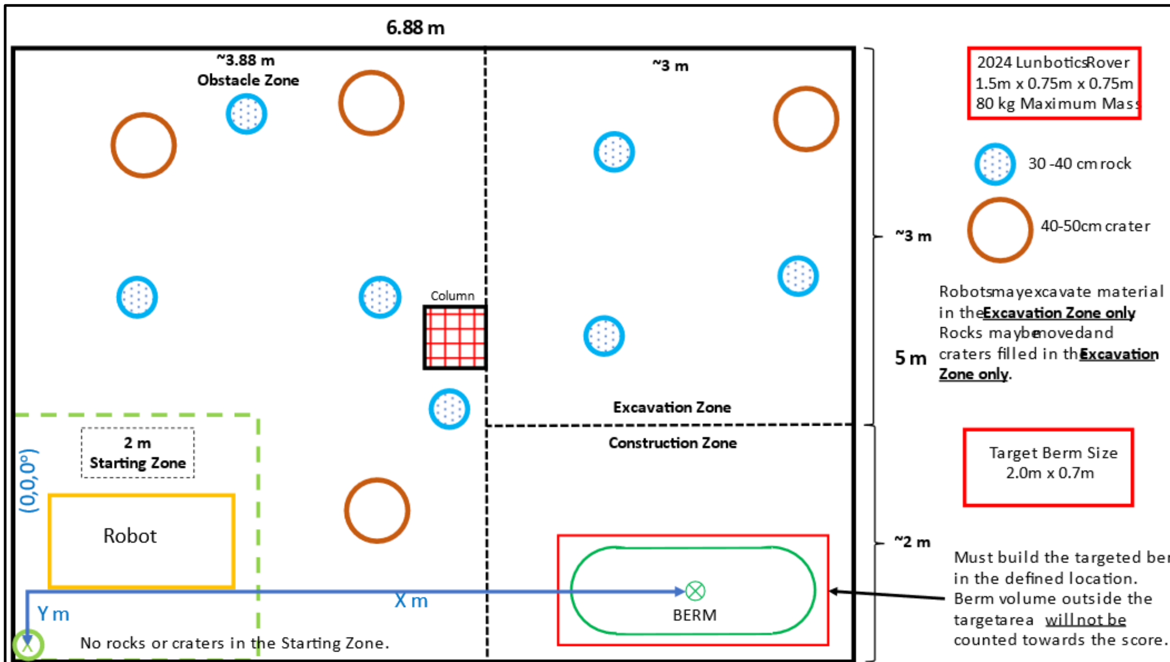
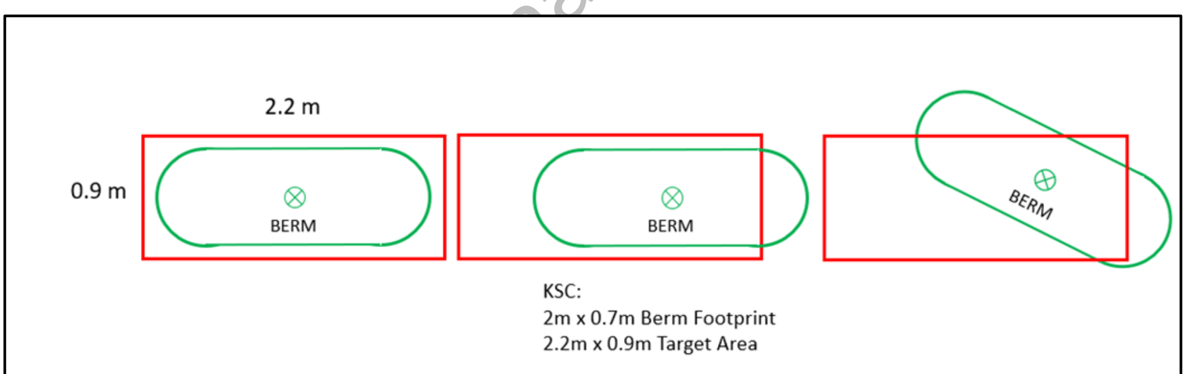
3. CONSTRUCTION POINTS



Drawing 2. Artemis Arena Layout 1 – Starting Location



Drawing 3. Artemis Arena Layout 2 - Berm Positioning

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(Note 1: only the green actual berm volume inside the red box will count towards the berm volume measurement)

1. Each team will earn 1000 Construction points after passing the safety inspection and communications check.
2. During each competition attempt, the team will earn 2,500 Construction points for each cubic meter of berm constructed above grade. . (For example, 0.126 cubic meters of berm constructed will earn 315 Construction points). Only the portions of the constructed berm within the target area for berm placement will be counted. The target area has perimeter dimensions of 2.2 m x 0.9 m.

3. During each competition attempt, the team will lose one (1) construction point for each 50 kilobits/second (kb/s) of average data used.
4. During each competition attempt, the team will lose 200 points for each situational awareness camera used (Camera Bandwidth Usage 200 kb/camera).
5. During each competition attempt, the team will lose 8 Construction points for each kilogram of total construction robot mass. (For example, a construction robot that weighs 80 kg will lose 640 Construction points).
6. During each competition attempt, the team will lose one (1) Construction point for each watt-hour of energy consumed. The electrical energy consumed must be displayed by an (commercial off the shelf or "COTS") electronic power data logger and verified by a judge.
7. BP1 Arena only. During each competition attempt, a team can earn up to 30 Construction points for dust tolerant design features on the construction robot. Teams are encouraged to point out dust tolerant and dust free features to the judges during setup. The judges will allocate these points based on an inspection.
8. BP1 Arena only. During each competition attempt, a team can earn up to 70 Construction Points for dust free operation. The judges will allocate these points based on actual performance during the competition attempts. If the construction robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Construction points will be earned in this category. If the construction robot raises a substantial amount of airborne dust or projects it due to its operations, fewer construction points will be earned. Ideally, the construction robot will operate in a clean manner without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. All decisions by the judges regarding dust tolerance and dust projection are final.)
9. DUST-TOLERANT DESIGN (BP1 Arena Only)
   The 30 points for dust-tolerant design will be broken down as follows:
   1. Drive train and components enclosed/protected: 10 points
   2. Active dust control (brushing, electrostatics, etc.): 10 points
   3. Custom dust sealing features (bellows, seals, etc.): 10 points
10. DUST-FREE OPERATION (BP1 Arena Only)
    During each competition attempt, a team can earn up to 70 Construction Points for dust free operation. The judges will allocate these points based on actual performance during the competition attempts. (If the construction robot has exposed mechanisms where dust could accumulate during a lunar mission and degrade the performance or lifetime of the mechanisms, then fewer Construction points will be earned in this category. If the construction robot raises a substantial amount of airborne dust or projects it due to its operations, fewer construction points will be earned. Ideally, the construction robot will operate in a clean manner, without dust projection, and all mechanisms and moving parts will be protected from dust intrusion. The construction robot will not be penalized for airborne dust while dumping into the berm footprint area. All decisions by the judges are final.
    The 70 points for dust-free operation will be broken down as follows:
    1. Driving without dusting up crushed basalt (20 points)
    2. Digging without dusting up crushed basalt (30 points)
    3. Transferring crushed basalt without dumping the crushed basalt on your own robot (20 points).

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4. COMMUNICATION POINTS

1. Each team is required to command and monitor their construction robot over the NASA provided network infrastructure.
2. This configuration must be used for teams to communicate with their robot.
3. The “Lander” camera is staged in the Construction Arena. Lander Control Joystick and camera display will be located with the team in the Mission Control Center (MCC).
4. The MCC will have an official timing display. The excavated mass will be displayed after the end of the competition run.
5. Handheld radios will be provided to each team to link their Mission Control Center team members with their corresponding team members in the construction arena during setup.
6. Each team will provide the wireless link (access point, bridge, or wireless device) to their construction robot, which means that each team will bring their own Wi-Fi equipment/router and any required power conversion devices. Teams must set their own network IP addresses to enable communication between their construction robot and their control computers, through their own wireless link hosted in the Construction arena.
7. In the construction arena, NASA will provide an elevated network drop (male RJ-45 Ethernet plug) that extends to the Mission Control Center, where NASA will provide a network switch for the teams to plug in their laptops.
    1. The network drop in the Construction arena will be elevated high enough above the edge of the regolith bed wall to provide adequate radio frequency visibility of the Construction arena.
    2. A shelf will be set up next to the network drop at a height 0 to .5 meter above the walls of the arena and will be placed in a corner area on the same side as the collection bin. During robot system operations during the competition, there may be some dust accumulation in this area. This shelf is where teams will place their Wireless Access Point (WAP) to communicate with their construction robot.
    3. Teams are strongly encouraged to develop a dust protection cover for their wireless access point (WAP) that does not interfere with the radiofrequency signal performance.
    4. The WAP shelves for side A and side B of the Construction arena will be at least 6 meters apart to prevent electromagnetic interference (EMI) between the units.
8. Power Interfaces
    1. NASA will provide a standard US National Electrical Manufacturers Association (NEMA) 5-15 type, 110 VAC, 60 Hz electrical jack by the network drop. This will be no more than 1.5 meters from the shelf.
    2. The team must provide any conversion devices needed to interface team access points or Mission Control Center computers or devices with the provided power sources.
9. During the setup phase, the teams will set up their access point and verify communication with their construction robot from the Mission Control Center.
10. The teams must use the USA IEEE 802.11b, 802.11g, or 802.11n standards for their wireless connection (WAP and rover client).
    1. Teams cannot use multiple channels for data transmission; meeting this rule will require a spectral mask or “maximum spectral bandwidth setting” of 20MHz for all 2.4 GHz transmission equipment.
    2. Encryption is not required, but it is highly encouraged to prevent unexpected problems with team links.
    3. During a match, one team will operate on channel 1 and the other team will operate on channel 11, See Figure 2. These channels will be monitored during the competition by NASA to assure there are no other teams transmitting on the assigned team frequency.

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11. Teams must be able to use and switch between channel 1 and channel 11 for the competition within 15 minutes of being notified to accommodate real-time scheduling changes.
12. Each team will be assigned an SSID that they must use for the wireless equipment for channel 1 and channel 11.
    1. Teams SSID will be "Team_##."
    2. Teams are required to broadcast their SSID.
13. The use of specific low power (these power consumers are not part of the total power consumed COTS meter) Bluetooth transmission equipment in the 2.4 GHz range is allowed for sensors and other robot communications. Bluetooth is allowed only at power levels of Classes 2, 3, and are limited to a maximum transmit power of 2.5 mW EIRP. Class 1 Bluetooth devices are not allowed.
14. The use of 2.4 GHz ZigBee technology is prohibited because of the possibility of interference with the competition wireless transmissions.
15. Technology that uses other ISM non-licensed radio frequencies outside of the 2.4 GHz range, such as 900 MHz and 5 GHz, are allowed for robot or sensor systems, but these frequencies will not be monitored during the competition. Interference avoidance will be the responsibility of the Team and will not be grounds for protest by any team.
16. Radio Frequency Power:
    1. All Team-provided wireless equipment shall operate legally within the power requirements set by the FCC for Unlicensed Wireless equipment operating in the ISM radio band. The FCC Federal Regulations are specified in the Electronic Code of Federal Regulations, Title 47, Telecommunication, Part 15, and must be followed if any commercial equipment is modified. All unmodified commercial off the shelf access point equipment and computers already meet this requirement.
    2. If a team inserts any type of power amplification device into the wireless transmission system, this will likely create a violation of FCC rules and this is NOT allowed in the competition.
    3. This radio frequency power requirement applies to all wireless transmission devices at any ISM frequency.
17. Data Utilization Bandwidth Constraints
    1. Use of the NASA provided situational awareness camera in the control room will add 200 kb/s of data use for each camera. If the team elects to turn on the camera during the match, they will be charged for the full 200 kb/s of data use.
    2. The communications link is required to have an average data utilization bandwidth of no more than 5,000 kb/s. There will not be a peak data utilization bandwidth limit.
18. For every kg of robot mass, a typical commercial lunar lander vendor will allow 10 kbps bandwidth. Higher bandwidth will result in additional mission costs. All teams are encouraged to stay within this bandwidth allocation and the judges will assess this metric as part of the Communications bandwidth prize.
19. Radio Frequencies and Communications Approval
    1. Each team must demonstrate to the communication judges that their construction robot and access point are operating only on their assigned channel. Each team will have approximately 15 minutes at the communication judges' station.
    2. To successfully pass the communication judges' station, a team must drive their construction robot by commanding it from their construction robot driving/control laptop through their wireless access point. The judges will verify the course of travel and verify that the team is operating only on their assigned channel.

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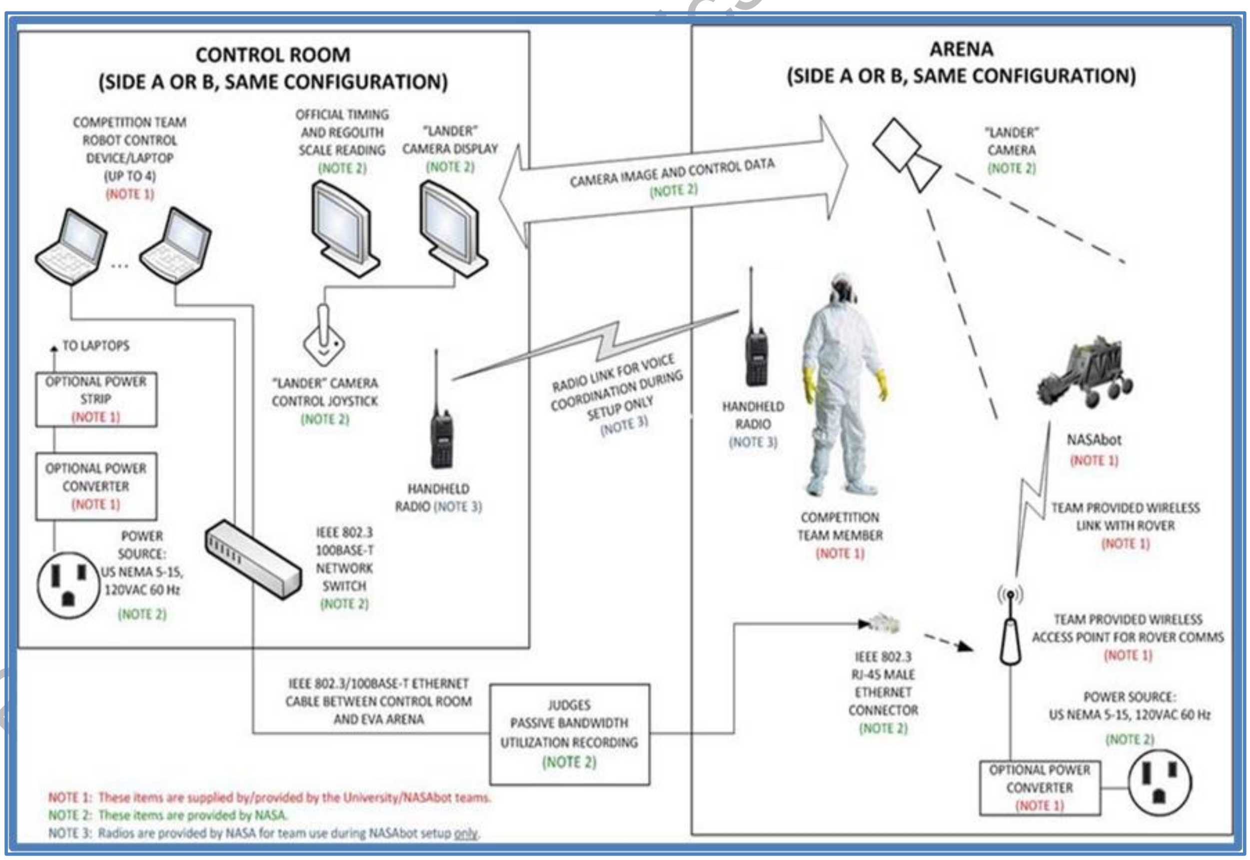
3. The teams must identify and show to the judges all the wireless emission equipment on the robot, including amplifiers and antennas. If the team has added an amplifier, written documentation shall be submitted to the judges demonstrating that the limits as designated in these rules for power transmission levels are not being exceeded.
4. If the team robot is transmitting low power Bluetooth, or is using any non-2.4 GHz frequency equipment, the following information must be provided to the judges during the communications checkout. Printed documentation from the manufacture with part numbers of all wireless transmission equipment. This printout must be from the manufacturer's data sheet or manual, and will designate the technology, frequency, and power levels in use by this type of equipment.
5. If a team cannot demonstrate the above tasks in the allotted time, the team will be disqualified from the competition.
6. The teams will be able to show the communication judges their compliance with the rules.
7. The NASA communications technical experts will be available to help teams make sure that they are ready for the communication judges' station.
8. Once the team arrives at the communication judges' station, the team can no longer receive assistance from the NASA communications technical experts.
9. If a team is on the wrong channel during their competition attempts, the team will be disqualified and required to power down.



Layout 1. - Control Room and Arena Layout

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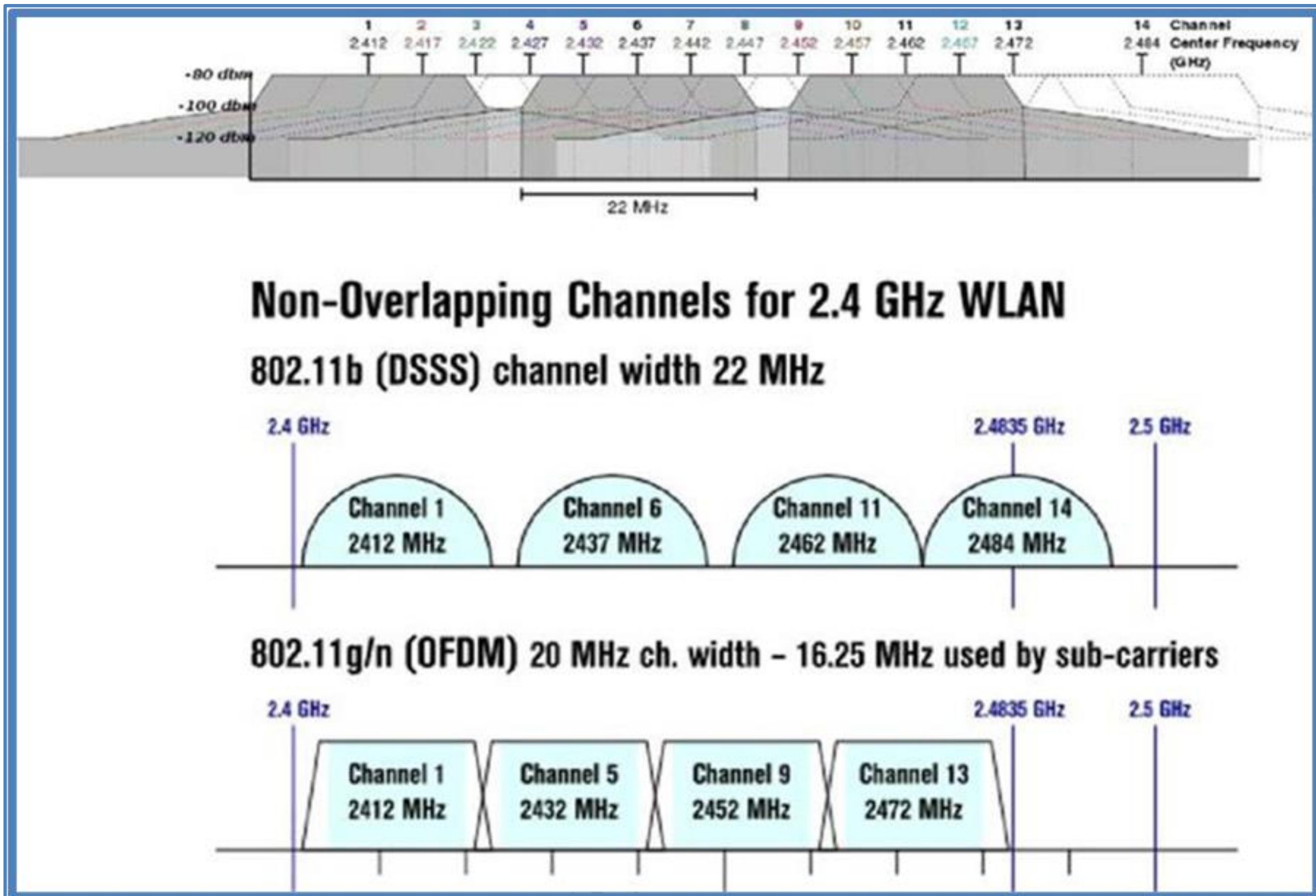

Layout 2. – Channel and Frequency Diagram

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9. AUTONOMY POINTS

AUTONOMOUS OPERATION - During each competition attempt, the team will earn up to 500 Construction points for autonomous operation. As Mission Control Judges (MCJ) are not intimately familiar with each robot's concept of operations (ConOps) procedures, it is the sole responsibility of the team members in the control room to coordinate with and inform the MCJ of each attempt for autonomy points to make sure their autonomous attempts are recognized and therefore scored correctly. In each of the two official competition attempts, the teams will score cumulative autonomy points towards The Caterpillar Autonomy Award. Construction points will be awarded for successfully completing the following activities autonomously:

1. Excavation Automation: 75 pts

1. Teams are allowed to traverse to the Excavation Zone via remote control.
2. Once in the Excavation zone they need to indicate to the MCJ that they are going hands free for the excavation attempt.
3. The robot must execute machine control commands itself during the excavation task.
4. The robot must demonstrate the ability to dig regolith and reach a point to be able to transport regolith. Hands free operation must begin before the robot engages the regolith to begin the excavation process. Some examples
   1. Blade type implement – Start with the blade just above the surface and then hands free the robot would make an excavation cut loading the blade with material. The team can then take back remote-control and "carry" the material across the terrain surface. Carry means the blade height is kept basically at the height of the terrain so the material in front of the blade does not flow under the blade and is lost as the robot progresses forward.
   2. Bucket type implement - Start with the bucket just above the surface and then hands free the robot would make an excavation cut loading the bucket with material. Bucket must be completely removed from the regolith before returning to remote-control operation.
   3. Auger type implement - Start with the auger just above the surface and then hands free the robot would make an excavation cut loading the auger with material. Auger must be completely removed from the regolith before returning to remote-control operation.
5. Regolith must be excavated for the robot to transport to the construction zone per the robot's design. Successful regolith excavation for robot transport will be at the MCJ judgement (the intent is to show that the robot can excavate regolith and be prepared to transport regolith with completely hands-free operation). MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
6. Once excavation is complete the team must indicate they are going to remote control before taking control.
7. This level of automation will require teams to master the lower-level machine control of their robot platform associated with excavation. It is noted that past teams have proven this capability to be helpful in achieving better excavation results, as the coordination of the robot for excavation can be difficult to master.

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2. Dump Automation: 75 pts

1. Teams are allowed to transport regolith after excavation to the construction zone via remote control.
2. The team must go into autonomous operation immediately after crossing (the front wheels or front of tracks) the boundary between the excavation and construction zones. The intent is that there is not any remote-control operation in the construction zone allowing the operator to "align" the robot to the berm construction location. The remote operator needs to coordinate communication with the MCJ to show hands-free operation when entering the construction zone.
3. The robot must align, approach, stop, and place regolith at the berm construction location. A discernable amount of regolith must be place at the berm location as determined by the MCJ. MCJ may engage the arena judges for confirmation if camera angle/performance does not allow confirmation in Mission Control.
4. This level of automation will require the team to master localization in the construction zone as well as path planning to align and place regolith at the designated berm construction location. Also, lower-level machine control of the robot for regolith placement will be mastered.

3. Travel Automation: 175 pts

Teams may begin in remote control and move the robot within the starting zone only in order to lock in their localization solution. The teams must then indicate to the MCJ that they are going into hands free mode while still in the starting zone. The robot must remain in hands free mode while crossing the obstacle field and crossing into the excavation zone. The robot must start in the starting zone and remain hands free until any part of the robot has crossed into the excavation zone (as determined by the MCJ) This level of automation will require the team to master the following:

1. Localization across the entire competition arena
2. Object detection and location relative to the robot
3. Navigational planning based on location and obstacles/traversable area
4. The competition judges will attempt to construct the obstacle field in such a way as to require obstacle detection, mapping, and navigation planning to determine a "slalom" route to reach the excavation zone. The teams should not architect a "Point and traverse" approach for this automation step.
5. If the robot moves a rock or drives across a crater in the obstacle zone, as determined by the MCJ/Arena judges, a 35 point reduction will be applied.
6. For maximum points the attempt must be made at the start of the run when first leaving the starting zone. In order to discourage the approach of "bread crumbs", a penalty of 50 points will be applied to any attempt that occurs after the traversing the obstacle zone in remote control.
7. If attempting excavation automation in coordination with travel automation the robot must remain in "hands free" control during travel and excavation.
8. Example: Robot cross the obstacle course in remote control before the attempt and hits an obstacle and drives across a crater during the attempt. 175 points – 50 – 35= 90 points.

4. Full Autonomy (One cycle): 400 pts

1. The robot must be in hands free control for one entire cycle
2. Teams may begin in remote control and move the robot within the starting zone only to localize. Teams must begin with hands free control from the starting area and remain in

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hands free mode while crossing the obstacle field and crossing into the excavation zone. Remaining in hands free control the robot must excavate regolith, transport to the berm construction location within the construction zone, and place/dump the regolith at the berm construction location. A discernable amount of regolith, as determined by the MCJ/Arena judges must be dumped at the berm construction location.

3. If the robot moves a rock or drives across a crater, as determined by the MCJ/Arena judges, a 35 point reduction will be applied. This is only true in the obstacle zone. The robot is allowed to move rocks and fill in craters in the excavation zone.
4. For maximum points the attempt must be made at the start of the run when first leaving the starting zone. In order to discourage the approach of "bread crumbs", a penalty of 50 points will be applied to any attempt that occurs after the traversing the obstacle zone in remote control.
5. This level requires mastery of all aspects of autonomy associated with this competition. Example: Robot cross the obstacle course in remote control before the attempt and hits an obstacle and drives across a crater during the attempt. 400 points – 50 – 35= 315 points.

5. Full Autonomy: 500 pts

1. The robot must be in hands free control for all 30 minutes of the competition run completing two or more cycles of excavation and placement at the berm construction location of regolith. Berm construction points as determined by the volumetric scan must be achieved for this level of autonomy.
2. If the robot moves a rock or drives across a crater, as determined by the MCJ/Arena judges, a 35 point reduction will be applied. This is only true in the obstacle zone. The robot is allowed to move rocks and fill in craters in the excavation zone.
3. This level requires mastery of all aspects of autonomy associated with this competition and demonstrates a level of robustness to complete at least two full cycles. System robustness is essential for terrestrial and extra-terrestrial construction.
Example: Robot hits an obstacle and drives across a crater during the attempt. 500 points – 50 = 450 points.

6. Autonomous Operations Scoring

Sample Autonomous Operations Scoring						
	Excavation	Dump	Travel	Full – One Cycle	Full Autonomy	Total
Ex: 1	75	-	-	-	-	75
Ex: 2	-	75	-	-	-	75
Ex: 3	75	75	-	-	-	150
Ex: 4	-	-	175	-	-	175
Ex: 5	75	-	175	-	-	250
Ex: 6	-	75	175	-	-	250
Ex: 7	75	75	175	-	-	325
Ex: 8	-	-	-	400	-	400
Ex: 9	-	-	-	-	500	500

Autonomous Score Sheet

Any three successful completions of the Excavation, Dump, and Travel attempts will be combined for scoring. These could occur over separate passes within the run. Points will only count for one successful completion – i.e., you can only get 75 points for excavation automation even if you use it for every pass of the run.

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10.CONSTRUCTION ARENA PROTOCOL

1. **CONSTRUCTION ROBOT REQUIREMENTS**
    1. Student teams are expected to design, construct and test their own robots, students shall do 100 percent of the work. Reuse of structure and systems shall be identified and explained in the Systems Engineering Paper and Slide Presentation and Demonstration. It is the teams' responsibility to demonstrate to the judges they have met this requirement.
    2. The construction robot can run either by telerobotic or autonomous operation.
    3. The Artemis Arena dimensions: 6.8 m x 5.0 m footprint
    4. The robot shall:
        1. be contained within a payload envelope of 1.50 m x 0.75 m x 0.75 m and have a maximum mass of 80 kg.
        2. the orientation of these dimensions may be chosen by each team for their specific design subsystems on the robot used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit.
        3. may deploy or expand beyond the envelop after the start of each competition attempt with the deployed height must be lower than the ceiling height, which is 2.5 m above the surface of the regolith.

        The commercial cost of delivering payloads to the Moon is about $1.2 Million per kg (estimate). This competition aims to simulate a Lunar mission where a robot is delivered to the Moon. This corresponds to an approximate mission cost of $72 Million. Lower masses will result in lower mission costs so this competition rewards teams that have a lower robot mass.
    5. Multiple robot systems are allowed but the total mass and starting dimensions of the whole system must comply with the volumetric dimensions given in this rule.
    6. KILL SWITCH - The robot must be equipped with an easily accessible red emergency stop button or "Kill Switch." Use good engineering practices and principles in placing the "Kill Switch" on your robot(s), failure to do so may result in a safety disqualification. The "Kill Switch" shall have a minimum diameter of 40 mm; it shall be located on the surface of the construction robot and require no additional steps to access it. Only one "Kill Switch" per robot and in the case of multiple robots, each robot will have its own "Kill Switch." It shall be easily accessible and activated in an easy and quick manner. Disabling the "Kill Switch" without authorization from the Competition Staff shall result in a safety disqualification. The emergency stop button must stop the construction robot's motion and disable power with one push motion on the button. It must be highly reliable and instantaneous. For these reasons an unmodified "Commercial Off-The-Shelf" (COTS) red button is required. A closed control signal to a mechanical relay is allowed as long as it stays open to disable the robot. This rule exists in order to have the capability to safe the construction robot in the event of a fire or other mishap. The button should disconnect the batteries from all controllers (high current, forklift type button) and it should isolate the batteries from the rest of the active sub-systems as well. Only onboard laptop computers and data-logger(s) may stay powered on if powered by its own, independent, internal computer battery. For example: it is acceptable to have a small battery onboard that only powers a Raspberry Pi control computer, and whose power does not flow through the main robot kill switch.

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7. The robot must provide its own onboard power. No facility power will be provided to the robot during the competition runs. There are no power limitations except that the robot must be self-powered and included in the maximum mass limit. The energy consumed must be recorded with a "Commercial Off-The-Shelf" (COTS) electronic data logger device. Actual energy consumed during each competition run must be shown to the judges on the data logger immediately after the competition attempt) The 'immediate' part refers to the judge climbing into the arena, finding the logger and recording the power reading. If the logger is independently powered, then the robot can be remotely powered off after the run. Although this is acceptable, it is not recommended in case the robot needs to be commanded to complete an operation so that it can be removed from the arena.
8. To ensure the robot is usable for an actual mission, it cannot employ any fundamental physical processes, gases, fluids or consumables that would not work in an off-world environment. For example, any dust removal from a lens or sensor must employ a physical process that would be suitable for the Lunar surface. Teams may use processes that require an Earth-like environment (e.g., oxygen, water) only if the system using the processes is designed to work in a Lunar environment and if such resources used by the robot are included in the mass of the robot. Closed pneumatic systems are allowed if the gas is supplied by the robot itself. Pneumatic systems are permitted if the gas is supplied by the robot and self-contained.
9. Components (i.e. electronic and mechanical) are not required to be space qualified for Lunar or atmospheric, electromagnetic, and thermal environments. Since budgets are limited, the competition rules are intended to require robots to show an off-world plausible system functionality, but the components do not have to be traceable to an off-world qualified component version. Examples of allowable components are: Sealed Lead-Acid (SLA) or Nickel Metal Hydride (NiMH) batteries; composite materials; rubber or plastic parts; actively fan cooled electronics; motors with brushes; infrared sensors, inertial measurement units, and proximity detectors and/or Hall Effect sensors, but proceed at your own risk since BP-1 is very dusty and abrasive. Teams may use honeycomb structures as long as they are strong enough to be safe and the edges sealed to prevent dust intrusion. Teams may not use GPS, rubber pneumatic tires; air/foam filled tires; open or closed cell foam, ultrasonic proximity sensors; or hydraulics because NASA does not anticipate the use of these on an off-world mission.

2. CONSTRUCTION INFORMATION

1. Team members shall "Suit-Up" and don their Personal Protective Equipment (PPE) to place their robot into the arena. The Arena Chief will make the final decision as to who places the robot into the arena, the number of team members allowed into the arena and any other operational process/procedure as required.
2. Teams in the final at KSC will be required to perform one, 30-minute, construction attempt.
3. Surface features will consist of randomly placed craters and obstacles. The construction robot will be placed in the arena in a randomly selected starting position and direction. Assume there are positive and negative obstacles, assume you cannot drive over the obstacles.
    1. The **obstacles may not be pushed to the side of the arena in the obstacle zone**.
    2. The **obstacles may only be pushed to the side of the arena in the construction zone.**

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4. No physical access to the construction robot will be allowed during each competition attempt.
5. Arena team members are prohibited from pointing out obstacles/arena surface conditions to the Mission Control Center team members. In addition, telerobotic operators are only allowed to use data and video originating from the construction robot and the NASA video monitors.
6. Visual and auditory isolation of the telerobotic operators from the construction robot in the Mission Control Center is required during each competition attempt. Telerobotic operators will be able to observe the construction arena through overhead cameras in the construction arena via monitors that will be provided by NASA in the Mission Control Center. These color monitors should be used for situational awareness only.
7. No other outside communication via cell phones, radios, other team members, etc. is allowed in the Mission Control Center once each competition attempt begins. During the setup period, a handheld radio link will be provided between the Mission Control Center team members and team members setting up the construction robot in the construction arena to facilitate voice communications during the setup phase only. Violation of these rules will lead to disqualification.

3. CONSTRUCTION PROTOCOL

1. The robot will be inspected during the practice days and before each competition attempt. Teams will be permitted to repair or otherwise modify their construction robots while the RoboPits are open.
2. Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot. Teams must explain to the attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with competition rules.
3. Teams are responsible for placement and removal of their construction robot onto the BP-1 surface. There must be one person per 20 kg of mass of the construction robot, requiring a minimum of four people to carry the maximum allowed mass of 80 kg. Assistance will be provided if needed.
4. Each team is allowed up to 10 minutes to place the construction robot in its designated starting position within the arena and 5 minutes to remove the robot after the attempt has ended and as directed by the Construction Judges.
5. Teams in the final at KSC will be required to perform one, 30-minute, construction attempt.
6. The robot's starting direction and location will be randomly selected immediately before the competition attempt.
7. The robot is required to move from the starting area, across the obstacle area to the construction zone.
8. The robot may not acquire regolith simulant for the berm from inside the construction zone, all bulk regolith simulant for berm construction must be acquired from the excavation zone
9. The robot may start excavation operations as soon as any part of it crosses into the excavation zone.
10. The robot may start construction operations as soon as any part of it crosses into the construction zone.
11. At the start of each competition attempt, the robot may not occupy any location outside the defined starting position in the arena. The starting direction will be randomly selected

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by the Construction judges.

12. The robot must operate within the arena; it is not permitted to pass beyond the confines of the outside wall of the arena during each competition attempt.
13. The robot can separate itself intentionally, if desired, but all parts of the construction robot must be under the team's control at all times. The robot does not have to re-assemble prior to the end of the competition run.
14. The robot **shall not:**
    1. be anchored to the BP-1 surface prior to the beginning of each competition attempt.
    2. ram the wall (may result in a safety disqualification for that attempt).
    3. use any aspect of the arena (wall, structure, column, etc.) in attempting any operations.
    4. use any process that causes the physical or chemical properties of the BP-1 to be changed or otherwise compromises the uniformity between attempts.
15. The robot will end operations immediately when the power-off command is sent, and/or as instructed by the Construction Judge.

4. NAVIGATION PROTOCOL

1. The team must declare the robot orientation by length and width to the inspection judge. An arrow on the reference point (the reference location and arrow pointing forward can be any point and direction of the team's choosing, except up) must mark the forward direction of the construction robot in the starting position configuration. The judges will use this reference point and arrow to orient the construction robot in the randomly selected direction and position (you can use a permanent-type marker) indicating the team's choice of forward direction on any location on the robot is acceptable as long as multiple arrows do not conflict. The arrow does not have to indicate the robot's preferred forward direction. The arrow is used only to orientate the robot prior to starting the robot run to face the robot arrow either north, east, south or west after spinning the direction wheel).
2. Compasses (analog, digital, etc.) are not allowed on the robot.
3. Global Positioning Satellite (GPS) or IMU-enabled GPS devices are not allowed. Teams must explain to the judges how the device will be switched off or the data is subtracted and ensure the internal calculations do not make use of the GPS or IMU-enabled GPS device.
4. The mass of the navigational aid system is included in the maximum construction robot mass limit of 80.0 kg and must be self-powered.
5. Target Beacons – beacons may be attached to the any of the four corners of the berm box which will be marked on the regolith simulant surface with colored chalk. The beacons may be mounted on rods that are pushed into the regolith for anchoring.
6. The target/beacon may be a passive fiducial or it may send a signal or light beam or use a laser-based detection system which have not been modified (optics or power). Only Class I or Class II laser or low powered lasers (< 5mW) are allowed. Supporting documentation from the laser instrumentation vendor must be provided to the inspection judges for "eye-safe" lasers.
7. Inertial measurement units (IMU) are allowed on the construction robot. Teams have to explain to the judges how the compass feature will be switched off or the compass data is subtracted to ensure the internal calculations do not make use of the compass (from any magnetic field surrounding the robot).
8. During each competition attempt, the construction robot is limited to autonomous and

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telerobotic operations only.

9. Telemetry to monitor the health of the construction robot is allowed during the autonomous period. Teams shall explain to the inspection/attending judge before each competition run how they are interacting with the telemetry system and the judge will observe to ensure compliance with all competition rules.
10. Teams shall not touch the controls during the autonomous period. Orientation data cannot be transmitted to the construction robot in the autonomous period.
11. The walls shall not be used for the purposes of mapping autonomous navigation and collision avoidance (there are no walls on off world locations). Touching or having a switch sensor spring wire that may brush on a wall, or any other surface, as a collision avoidance sensor is not allowed. Teams shall not use the walls of the construction arena for sensing by the robot to achieve autonomy.
12. The team must explain to the inspection judges how their autonomous systems work and prove that the autonomy sensors do not use the walls (there are no walls on off-world locations and teams shall operate as closely as possible on that scenario of operations). Integrity is expected of all team members and their faculty advisors.
13. Teams are allowed to interact with an interface that allows different pieces of telemetry data to be viewed as long as there is no real time or other interaction to control or influence the robot.
14. Teams are not permitted to update or alter the autonomy program to account / detect or upload information about obstacle locations.
15. Failure to divulge the method of autonomy sensing shall result in disqualification from the competition.

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11. ON-SITE COMPETITION AT THE KENNEDY SPACE CENTER

Information about KSC and KSCVC parking passes, tickets, etc. will be provided at a later date.

1. **EMERGENCY SITUATIONS, CALLING FIRST RESPONDERS**
   1. If you see something, say something.
   2. Notify the Lunabotics Staff, the RoboPit Boss or Arena Chief.
   3. If in doubt call KSC First Responders (fire, paramedics, etc.) at **321.867.7911**.
   4. You are located in the Astronauts Memorial Foundation's Center for Space Education **Building M6-306,** located on the westside of the Kennedy Space Center Visitor Complex.
   5. There is no judgement on calling for First Responders, better safe.

2. **The RoboPits**
   Teams are advised to bring additional LED lighting, power strips, and first-aid kits to the RoboPits. This is where you will be working on your robots, meeting other competitors, and after spending months designing and building, this is where your robot gets inspected before it goes to work. The RoboPits are equipped with emergency eyewash stations and disposal containers for industrial waste. You cannot remove your robots/equipment and check them back in the next day. Once removed, the robots and equipment stay removed from the challenge. Check-In is Wednesday May 15, 2024 and will be open 11:00 a.m. - 12:00 p.m. (noon) in Parking Lot 4. It is strongly recommended that you and your team be here when check-in opens. The RoboPits will be open Thursday / Friday from 7:00 a.m. - 6:00 p.m. Robot Runs are Thursday May 16 - Friday May 17, 2024.

3. **Mission Control**
   This is the operations area where teams will operate or autonomously control their robotic excavator to simulate a Lunar In-Situ Resource Utilization (ISRU) construction mission. It is located outside of the Artemis Arenas. Only students from the team are allowed into the Mission Control Rooms during the robot run. A team will be disqualified for having faculty / advisors or non-team members in the mission control rooms during the robot run.

4. **ROBOT INSPECTION AND RUN PROTOCOL**
   1. The RoboPits Chief will give the team leader the Communication/Inspection (C/I) card. The C/I card is to ensure that all teams have had their robot(s) checked out prior to entering the arena.
   2. Communication and Inspection (C/I) locations will be identified.
   3. Either inspection can be performed first, they are not scheduled, they are on a first-come, first-served basis.
   4. Return the C/I card when you have passed both checks and are ready for a practice run.
   5. The RoboPits Chief will schedule the team for the next available practice (run) slot.
   6. Check with the RoboPits Chief before heading to the arena for any schedule changes.
   7. An escort will come to the RoboPit to guide the team to the Artemis Arena; do not leave without the escort.

5. **ROBOPIT HOUSEKEEPING**
   1. Your robopit measures 8'x10' with two chairs and one table and two power outlets.

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2. Teams headed to the arena for competition runs have first priority on carts.
3. Following the inspection, the escort will take the team to the arena, where arena escorts will take over.
4. If the team is not ready or cannot be located, the competition run time will be given to another team that is ready.
5. All pits have power strips provided. Do not daisy chain power strips.
6. It is recommended that the team be ready with the robot on a cart, 30 minutes prior to the scheduled competition start time, to ensure a smooth flow.
7. NASA provided carts are for shared use by all teams. Use carts to transport robots only. Carts are NOT for use in your pit. Vacuums are provided. They are for shared use by all teams as needed. Return vacuums to the designated area. Notify the RoboPits Chief about vacuums that need to be cleaned.
8. On competition days, teams will be brought to inspection 30 minutes before the
9. scheduled competition run start time.
10. Clean-up and Check-out - each team will leave their RoboPit as they found it. Teams are required to clean their pit and the area around it. Teams will request a RoboPit inspection from the RoboPit Chief.
11. Keep the RoboPit and the surrounding area neat and generally clean; use the provided vacuums as necessary. You are encouraged to bring floor coverings/mats to facilitate this cleaning.

6. <u>INDUSTRIAL WASTE</u>

1. Teams shall comply with Federal and Kennedy Space Center hazardous and controlled waste program requirements. Regulation requires that you coordinate with the RoboPit Chief before disposing of the items listed below (specially marked containers will be provided):
2. Batteries (Alkaline, Lithium, Ni-Cd)j.
3. Spray Paint
4. Oily wipes/IPA solvent wipesk.
5. Spray Foam
6. Solder wastel.
7. Spray Adhesives
8. Acetone wipes / WD40
9. PCV cement – brushes, wipes, and cansn.
10. PB Blaster
11. PVC primer – brushes, wipes, canso.
12. Silicone Spray
13. Super Glue (cyanoacrylates)
14. Oil Cans
15. Epoxy Tubes
16. 3 in 1 oil
17. Aerosol Cans
18. any as required by regulations
19. for more information see: https://www.epa.gov and https://floridadep.gov

8. **<u>PERSONAL PROTECTIVE EQUIPMENT (PPE) / SAFETY</u>**

1. Without exception, protective eyewear must be worn in the RoboPits and the BotShop. This is not an all-inclusive list. Remember to use good workshop, safety and engineering

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practices and principles. The RoboPit Chief and the Arena Chief are authorized to rule on any safety and health issues in their respective areas. Volunteers and students who wear N-95 masks or other tight-fitting respirators shall be clean shaven. According to the National Institute for Occupational Safety and Health (NIOSH), that facial hair growing in or protruding into the area of the primary sealing surfaces of the respirator will prevent a good seal, and that workers should not enter a contaminated work area when conditions prevent a good seal of the respirator facepiece to the face. For this reason, only clean-shaven individuals wearing who wear N-95 masks or other tight-fitting respirators will be allowed entry into the Artemis Arena during the competition. The requirement for personal protective equipment (PPE) is to protect the individual from the inherent dangers of crystalline silica (from the crushed lava basalt aggregate). There are very few options, but the best choice would be for the individual to purchase a hooded powered air purifying respirator (PAPR) – especially if they intend to stay in a career that requires the occasional use of PPE. This requirement exists for the safety of the participants. Whatever respirator is selected, it must be NIOSH-approved. **[Statement from OSHA** – Under OSHA, an employee cannot sign a waiver in order to be exempted from stated requirements. A release or waiver is not possible for employees. That being said when an employer is looking to accommodate a religious practice, they may have to explore respiratory protection alternatives like helmets or loose-fitting hoods].

2. Clothing - ALLOWED - Shirts/tops that cover upper torso. Long pants that cover the wearer to the ankle. Completely enclosed shoes that cover the instep of the foot, preferably leather which can be wiped clean. Baseball caps and other headgear as long as they are kept far enough back on the head so that vision is not impaired and also do not interfere with protective eyewear.
3. Clothing: The following are NOT ALLOWED - Hair must not impede vision or come in contact with the work. Hair must be kept away from the eyes. Long hair must be tied back. Hair longer than 6 inches from the nape of the neck must also be pinned up (use of hair nets or hats is acceptable). Flowing garments and neckwear such as ties and scarves that hang loose. Caps worn low over the eyes so as to impede vision. Cropped shirts, plunging necklines, spaghetti straps, or ripped shirts. Ripped jeans, shorts, capris, or skirts. Loose or flowing tops with wide/bell sleeves, outerwear such as coats or shawls. Sandals, open toe, open back, or open weave shoes, shoes with holes in the top or sides, no Birkenstocks, TEVA's, Choco's, Croc's, cloth shoes, or equivalents that will expose the skin to regolith or retain regolith.
4. Workshop, Safety & Engineering Practices - It is your responsibility to use the correct Personal Protective Equipment (PPE) for the situation. Remember to use hearing protection and eye protection (e.g., safety glasses, goggles or face shield) as needed. Use the right tool for the right job, wear gloves/gauntlets to de-energize robots and equipment as needed, bring jack-stands to support your robot instead of folding chairs, wire strippers should be utilized instead of knives. etc. Bring your own LED lighting for your pit. Surgical or N95 masks are required inside for COVID precautions. Address any safety concerns to the RoboPit Chief immediately.
5. BotShop - Protective eye wear shall be worn in the BotShop. Any work requiring protective equipment must be performed in the BotShop. The NASA Prototype Development Laboratory's (PDL) Bot Shop is a "mobile machine shop" with grinding, sanding, mini-mill and mini-lathe, band saw, drill press and hand tools. There is no welding capability. They can help repair broken robots but do not have the capability to

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finish a started robot. The Bot Shop is busy throughout the competition. The PDL is a team of NASA engineers and engineering technicians whose primary purpose is the design, fabrication and testing of prototypes, test articles, and test support equipment.

6. Regolith Simulant - Black Point-1 (BP-1) is a crushed lava basalt aggregate with a natural particle size distribution similar to lunar soil. It is alkaline and may cause skin and eye irritation. If you are allergic to talcum powder, it is a good indication that you may be allergic to the BP-1. Participants are required to don Personal Protective Equipment (PPE) before coming into contact with the BP-1. BP-1 contains a small percentage of crystalline silica, which is a respiratory nuisance. Respiratory protection shall be used in accordance with the manufacturer's operating instructions and your school's respiratory protocols at a minimum.
7. Fire Exits / Eyewash Stations - Know where the fire exits, fire extinguishers and eyewash stations are located. Each team is responsible for bringing a First-Aid kit and respirator masks for use in the RoboPits for team members. Report any safety concerns to the RoboPit Chief.
8. Stop Work Order (SWO) - Lunabotics staff are authorized to issue a SWO to a team on any suspected safety issue. The team will immediately stop all activity. The Faculty Advisor must meet with the RoboPit Chief to resolve the issue. The SWO will remain in effect until the RoboPit Chief has issued a ruling on the issue. The RoboPit Chief decision is final.
9. Reminder - If your team uses any kind of military container, (ex. "ammo cans") please spray- paint or cover up the former military content signage so we can avoid any work stoppages due to extra security checks.
10. Controlled Substances - The consumption of alcoholic beverages or use of any controlled substances by a team member during the event is prohibited. Violation is grounds for disqualification of the team.
11. Weapons - *No weapons of any kind are permitted inside Kennedy Space Center Visitor Complex*, including those belonging to off-duty law enforcement. Please leave items secured within your vehicle to expedite your entry into the visitor complex. Violation is grounds for disqualification of the team. For example, COTS wire strippers should be utilized instead of knives.
12. Unmanned Aerial Vehicles (UAV), Unmanned Aerial Systems - The use of Unmanned Aircraft Systems (Drones) is prohibited at the Kennedy Space Center Visitor Complex and the Astronauts Memorial Foundation Center for Space Education. The UAV/UAS will be confiscated and not returned. Violation is grounds for disqualification of the team.
13. Wildlife - There are alligators, ants, armadillos, mosquitoes, raccoons, snakes, and wild hogs. Do not attempt to feed or interact with the wildlife in any manner.
14. Florida Weather - Stay hydrated, drink plenty of water. You and your off-world mining robots will be exposed to the Florida weather so be prepared for heat, humidity, wind and rain. You are responsible for protecting your robot from the elements while outdoors. Remember to have hats, sunglasses, insect repellent, sunscreen (SPF 50 or better) and a raincoat / poncho on hand for the competition. Florida is the Lightning Capital of the U.S., and the lightning phase conditions are as follows:
15. Phase I Lightning Condition - prepare to seek shelter.
16. Phase II Lightning Condition - seek shelter NOW in any building.

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APPENDIX A. NASA GATEWAY TEAM APPLICATION INSTRUCTIONS

WARNING:

Please carefully select the person that will be submitting your team application. The person who creates the application is the person who will receive all official notices (IE acceptance letter, rejection letter, etc.), and will be responsible for uploading deliverables throughout the project. These responsibilities CANNOT be assigned to others in the Gateway system. Furthermore, the creator of the application cannot be changed after submission. It should be noted that while the application does ask for both a "Team Lead" and a "Faculty Member", these fields are datapoints only, and does not replace any of the responsibilities held by the creator of the application.

Team Application InstructionsHow to Register Your Team in Gateway

To be considered for participation in the 2023 Lunabotics competition you will have to complete a Team Registration in NASA STEM Gateway. This is a very important step as the Team lead will have to create an application and then invite the rest of the team including the faculty advisor. The person that creates the team application will be responsible for uploading all required documentation and deliverables throughout the competition. This person cannot be changed, so please make sure whoever submits the team application is the person you want to receive official communication and be responsible for uploading deliverables.

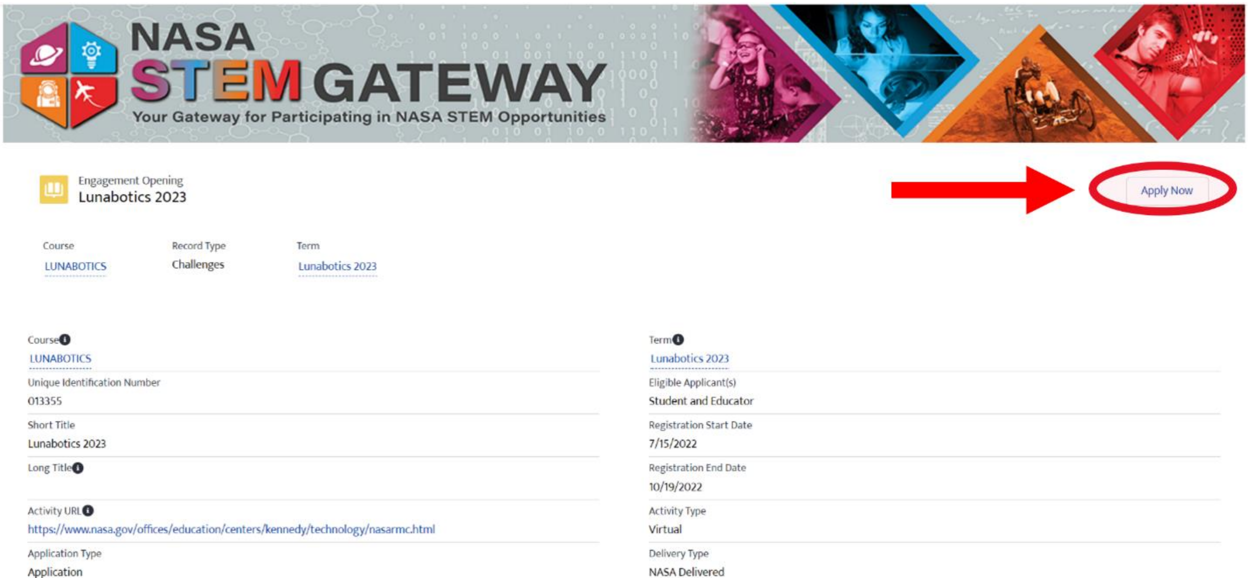
1. **Once you enter the page from** NASA STEM Gateway select "Explore Opportunities"

2. **Then select "Challenges"**

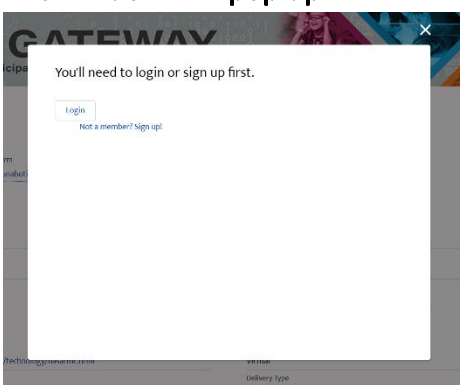
3. **Select Lunabotics 2023**

	Unique Identification N...	Short Title	Physical Location	Session	Eligible Applicant(s)	Activity Type	Registration End Date
1	013355	Lunabotics 2023	nnedy Space Center	Lunabotics 2023	Student and Educator	Virtual	10/19/2022
2	012900	HERC 2023	U.S. Space and Rocket Center	HERC 2023	Student and Educator	In-person / Virtual	10/6/2022

4. **Select "Apply Now"**



5. **This window will pop up**



6. If Team Lead already has a profile in Gateway (from a previous NASA engagement) please log in with the Username and password you used previously and go to step 17. If this is the first time continue to next step:

Select your Category

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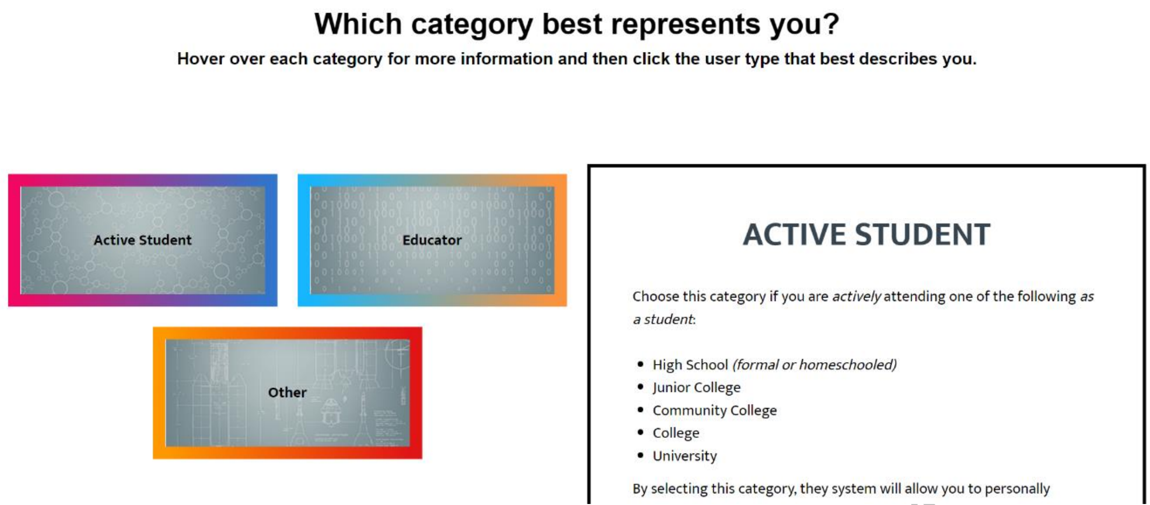
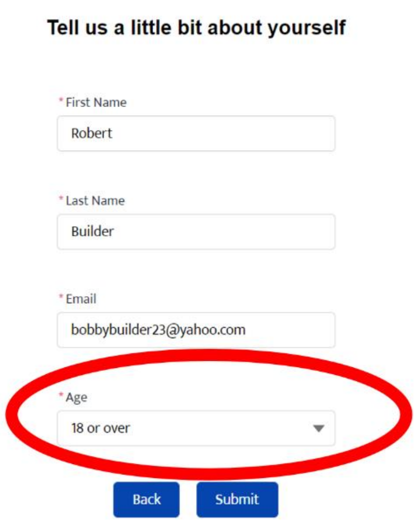


7. Fill out the requested information

Make sure all information is entered correctly and that you select the correct age range**. NASA requires all Lunabotics participants to be 18 years or over. If you are not at least 18 you are ineligible to participate.**



8. Follow the "Next Steps…"

Next Steps...

1. Check your inbox for the email address you just entered. You should receive a messsage from hq-nasa-stem-gateway@mail.nasa.gov

2. When you've logged in, you'll be directed to your profile where you will register your account.

3. Once your profile has been completed, you may apply to the available opportunities and track the status of your applications within NASA STEM Gateway.

Close

9. Once you click on the link provided in the email, click "Next"

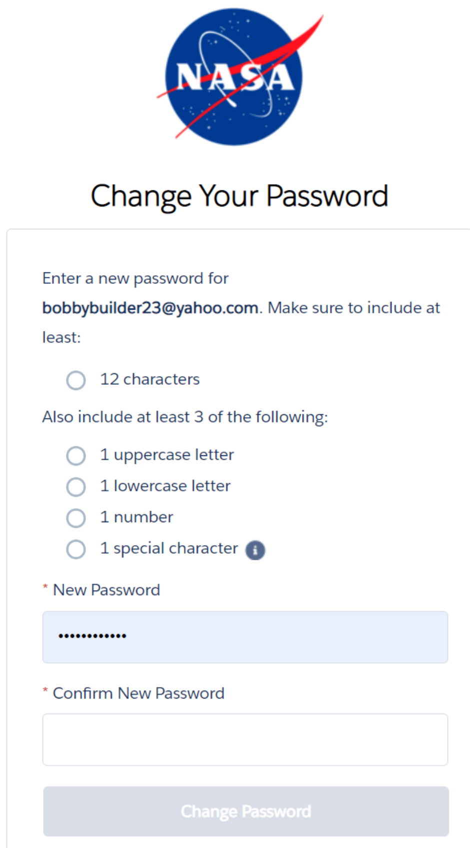
bobbybuilder23@yahoo.com Log Out

By accessing and using this information system, you acknowledge and consent to the following:

You are accessing a U.S. Government information system, which includes: (1) this computer; (2) this computer network; (3) all computers connected to this network including end user systems; (4) all devices and storage media attached to this network or to any computer on this network; and (5) cloud and remote information services. This information system is provided for U.S. Government-authorized use only. You have no reasonable expectation of privacy regarding any communication transmitted through or data stored on this information system. At any time, and for any lawful purpose, the U.S. Government may monitor, intercept, search, and seize any communication or data transiting, stored on, or traveling to or from this information system. You are NOT authorized to process classified information on this information system. Unauthorized or improper use of this system may result in suspension or loss of access privileges, disciplinary action, and civil and/or criminal penalties.

Next

10. Create your password by following the minimum requirements



11. Fill out your personal information

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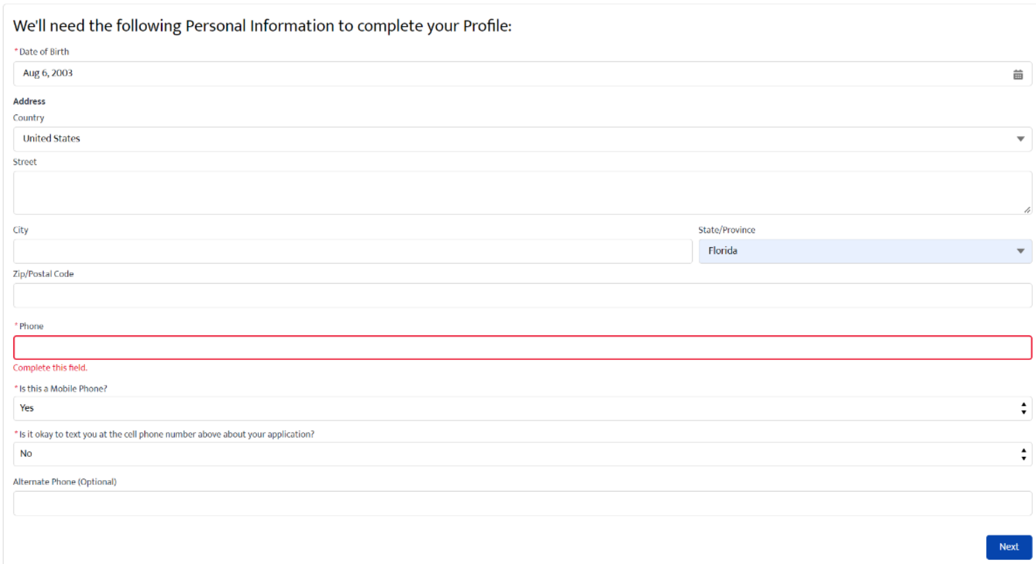
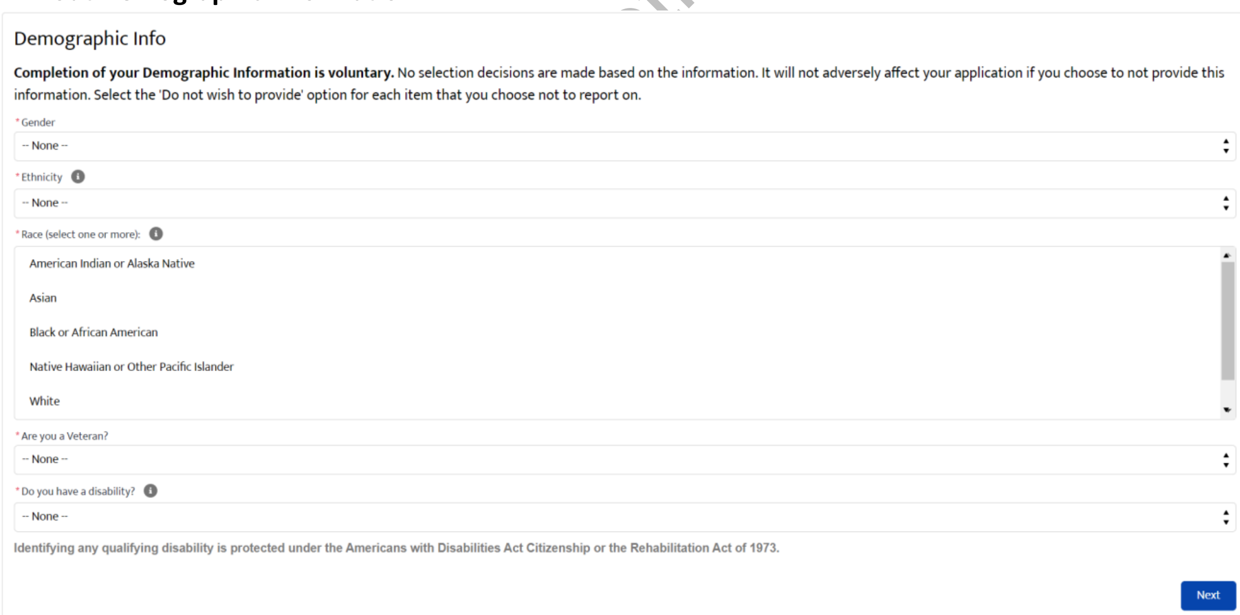

We'll need the following Personal Information to complete your Profile:

* Date of Birth
Aug 6, 2003
Address
Country
United States
Street
City
State/Province
Florida
Zip/Postal Code
* Phone
Complete this field.
* Is this a Mobile Phone?
Yes
* Is it okay to text you at the cell phone number above about your application?
No
Alternate Phone (Optional)
Next

12. Fill out Demographic information


Demographic Info

Completion of your Demographic Information is voluntary. No selection decisions are made based on the information. It will not adversely affect your application if you choose to not provide this information. Select the 'Do not wish to provide' option for each item that you choose not to report on.

* Gender
-- None --
* Ethnicity
-- None --
* Race (select one or more):
American Indian or Alaska Native
Asian
Black or African American
Native Hawaiian or Other Pacific Islander
White
* Are you a Veteran?
-- None --
* Do you have a disability?
-- None --
Identifying any qualifying disability is protected under the Americans with Disabilities Act Citizenship or the Rehabilitation Act of 1973.
Next

13. Fill out Citizenship

Citizenship

* Citizenship

-- None --

Previous Next

NASA - National Aeronautics and Space Administration

INSPIRE - ENGAGE - EDUCATE - EMPLOY
The Next Generation of Explorers

Related Links No Fear Act | FOIA | PRA | Privacy | OIG | Agency Financial Reports | Help

14. Enter “applicant type”, Grade Level” and “Academic Institution”

Education or Affiliate Organization

Please search for your institution's name below. Only the top 5 results will appear in the preview. If you do not see your institution please select "Show All Results" and continue your search in the full view. In this view you can search by your institution's name, address, phone, or website.

If you still cannot find your institution, please return to this page and select the "Can't find my institution" checkbox and enter your institution's information directly.

* Applicant Type

-- None --

* Search for your Academic Institution

Search Accounts...

Complete this field.

Can't find my institution.

* *This can be a Junior College, Community College, College, University, High School, Middle or Elementary School, Museum, Science Center, Planetarium, or Youth Serving Organization*

I am registering for opportunities on behalf of a minor (younger than 14)

Previous Next

15. Fill out Authorization for Media Release

Authorization for NASA Media Release

I hereby give my permission to be interviewed, photographed, and/or videotaped by NASA or its representatives in connection with a NASA production.

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* **Please select your acknowledgement response below:**

YES
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I authorize NASA to collect and report data about my participation in STEM Engagement opportunities for continuous improvement purposes

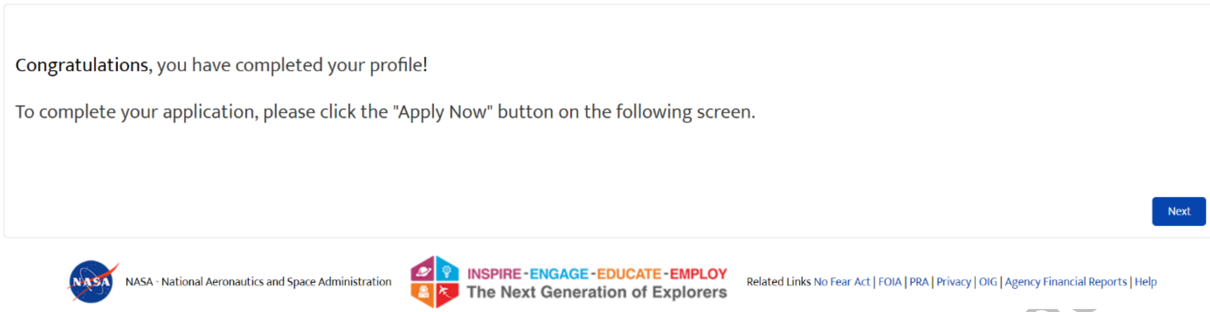
* **Please select your acknowledgement response below:**

YES
NO

For information about NASA STEM Engagement, you may visit https://www.nasa.gov/stem

Previous Next

16. Now you can click “Next” to apply for the challenge


Congratulations, you have completed your profile!

To complete your application, please click the "Apply Now" button on the following screen.

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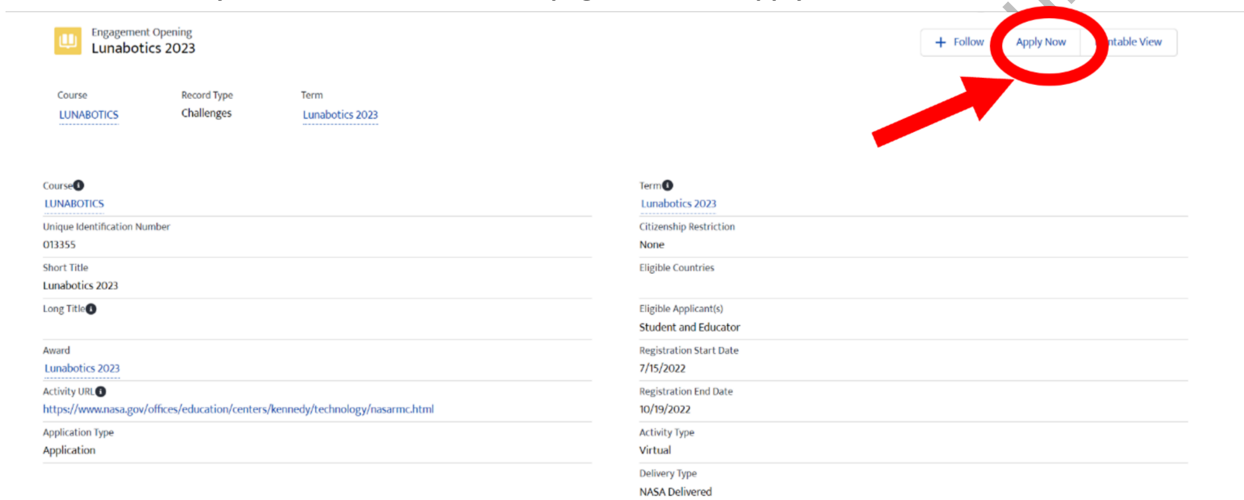
Related Links No Fear Act | FOIA | PRA | Privacy | OIG | Agency Financial Reports | Help

17. This will take you to the Lunabotics 2023 page. Click on “Apply Now”


Engagement Opening
Lunabotics 2023

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Course	Record Type	Term
LUNABOTICS	Challenges	Lunabotics 2023

Course: LUNABOTICS	Term: Lunabotics 2023
Unique Identification Number: 013355	Citizenship Restriction: None
Short Title: Lunabotics 2023	Eligible Countries:
Long Title:	Eligible Applicant(s): Student and Educator
Award: Lunabotics 2023	Registration Start Date: 7/15/2022
Activity URL: https://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html	Registration End Date: 10/19/2022
Application Type: Application	Activity Type: Virtual
	Delivery Type: NASA Delivered

From this point all fields are required to be able to properly proceed forward

18. Enter your institution’s information

Please look carefully for your institution in the auto populate list. Almost every school is in the database. If you can't find your institution, consider entering slight variations such as hyphens, order of words, campus name, etc. This can increase the likelihood that you find your correct institution.

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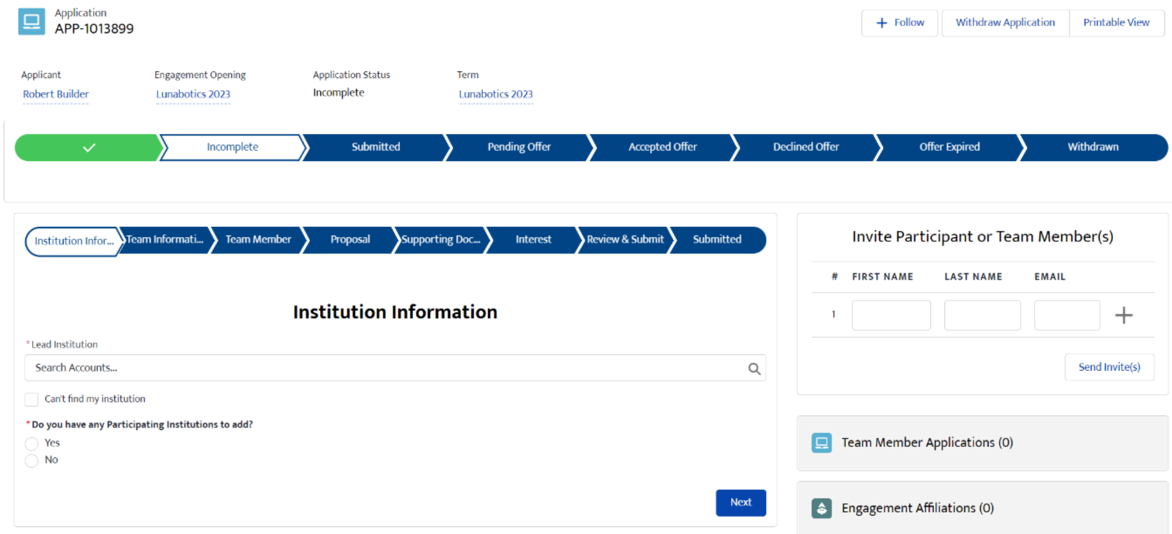
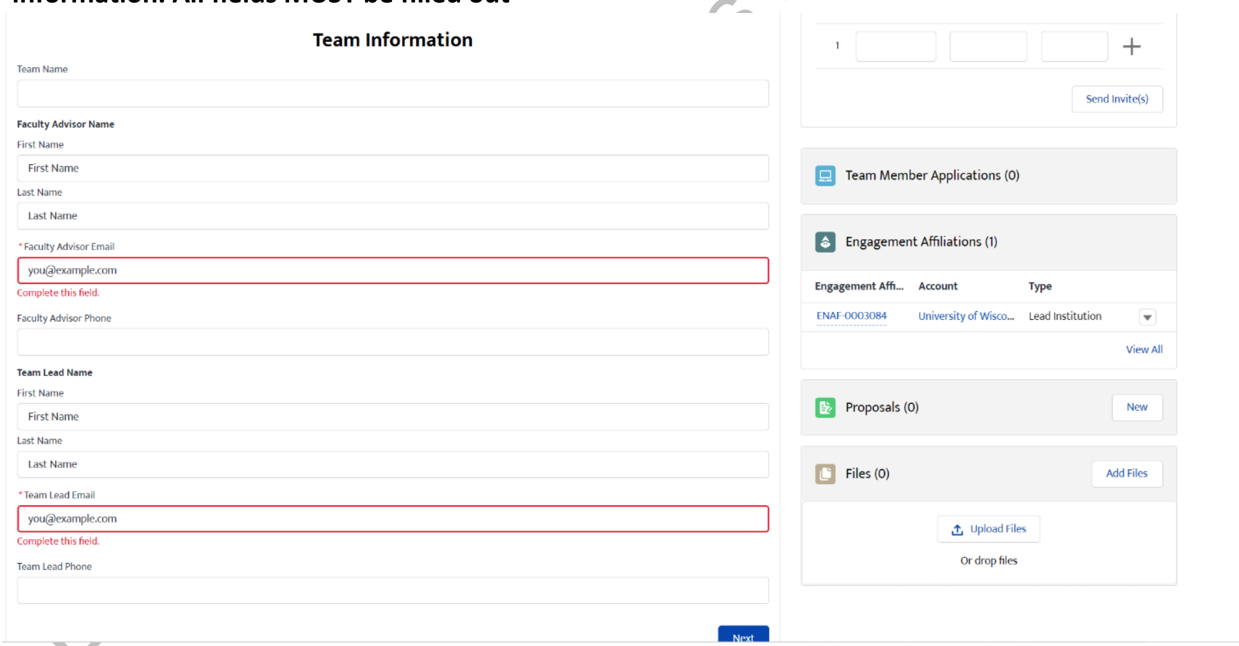
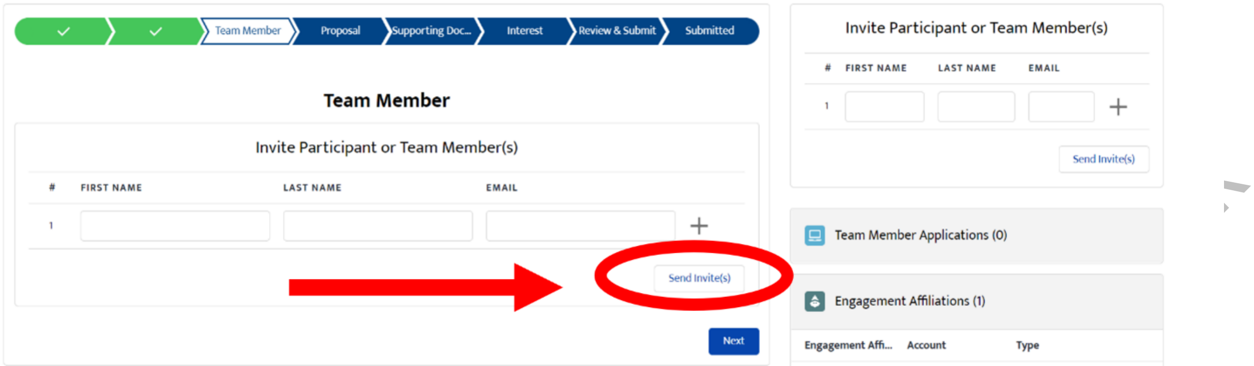


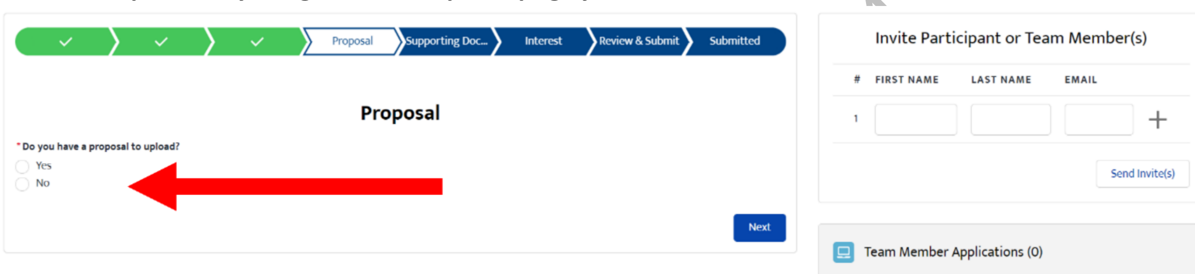
19. **Enter your Team's information, make yourself the lead and re-enter your information, enter Faculty's information. All fields MUST be filled out**



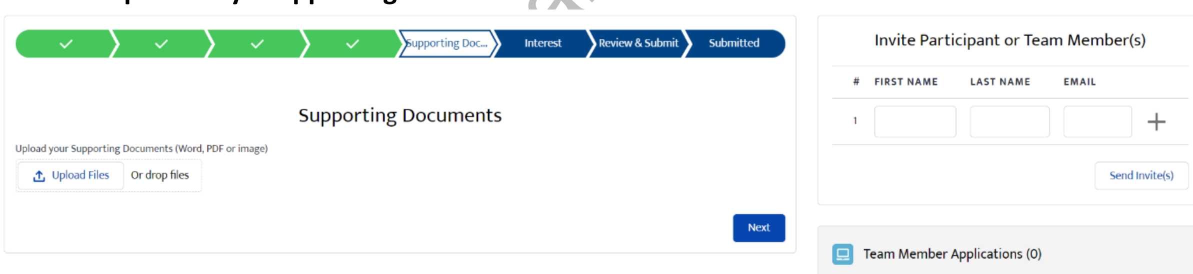
20. **Add your team members and also add your Faculty member. Don't worry if you miss any team members, you will be able to enter them once you complete application. Make sure to click "send invites" before you click next otherwise your invites will not be sent.**



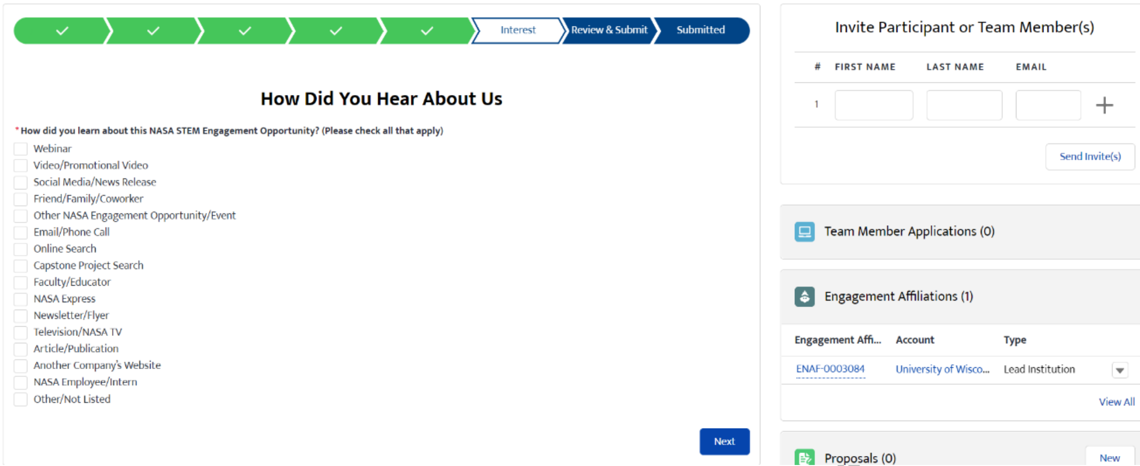
21. **DO NOT upload anything on the Proposal page just check "no" and click next**



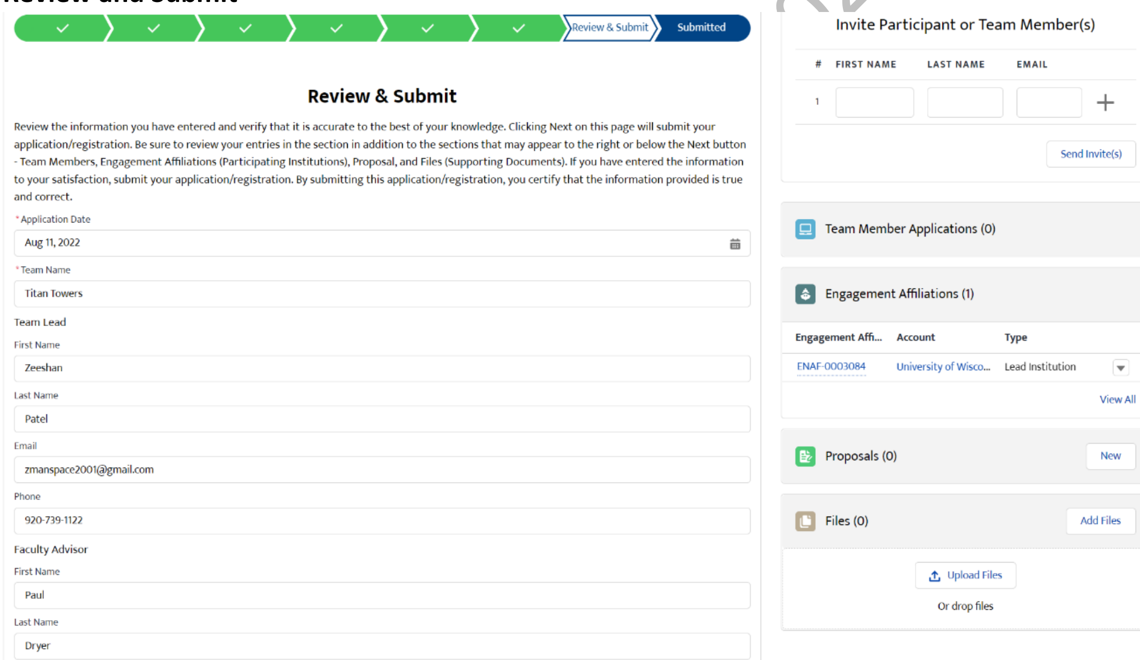
22. **DO NOT upload any "Supporting Documents" at this time**



23. Fill out the "how did you hear about us"



24. Review and Submit



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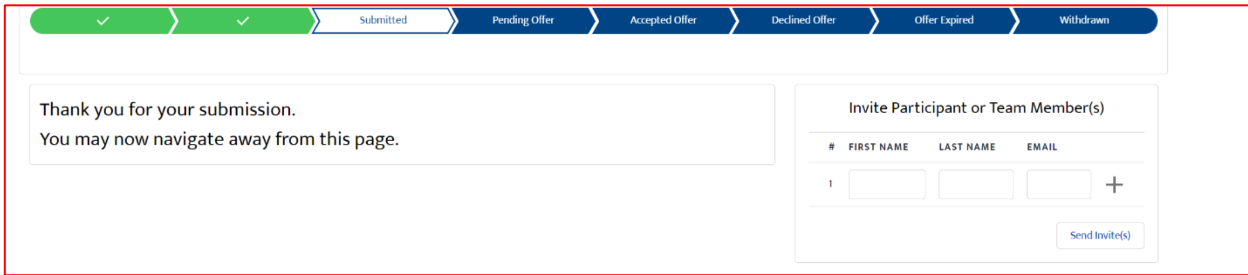

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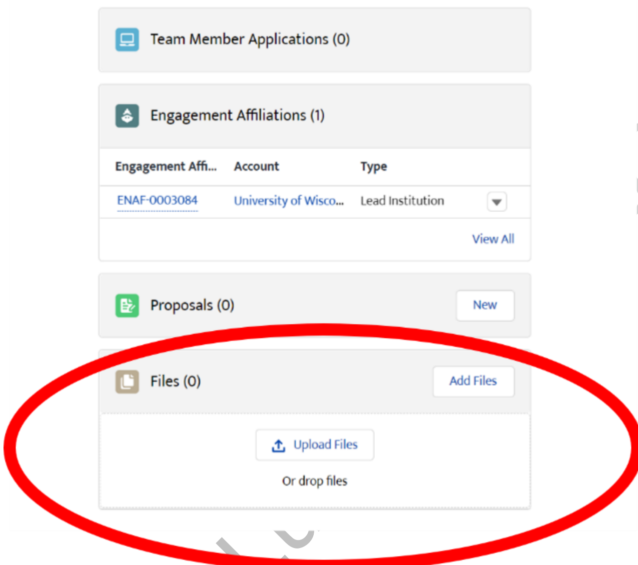
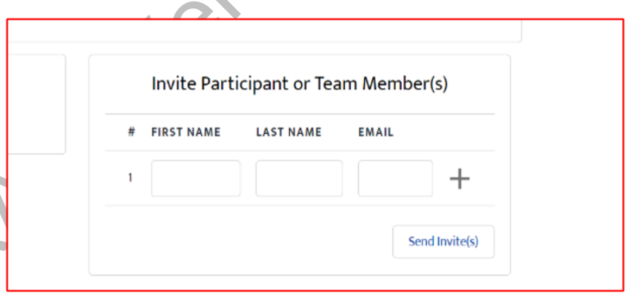
25. **Now you can upload your required application documents. You have the option to upload now, or at a later time, provided it is done before the deadline in the Guidebook.**
    a. (1) Statement from Supervising Faculty; and (2) Statement of Rights of Use. Together as one PDF file
        i. Use the name format" **School Name_DOCS**" It is important to use this exact format so reviewers can properly locate your submission in the database
    b. Project Management Plan (one PDF document). Please see instructions regarding required PMP content found in section 4.1 of the Guidebook
        i. Use the name format **"School Name_PMP**" It is important to use this exact format so reviewers can properly locate your PMP submission in the database

Go to the bottom of the page to the "Files" section and upload the files separately



26. **You can always add team members by going to the "Invite Participants or Team Member(s)" section. Remember to add your Faculty as a member of the team even if you list them in the original application field. A Faculty member is only officially linked to your team if they have been invited via the "Invite Participants or Team Members"**



If you have any questions concerning the technical aspects of using the NASA Gateway system please contact the NASA Gateway helpdesk at: hq-nasa-stem-gateway@mail.nasa.gov

APPENDIX B. GLOSSARY OF TERMS

1. **Accreditation Board for Engineering and Technology (ABET)** (http://www.abet.org) - the Competition rules and rubrics are aligned the ABET requirements for engineering and engineering technology accreditation.
2. **Artemis Arena:** Located in the Astronaut Memorial Foundation's Center for Space Education (CSE) where the robots will perform each competition attempt. The arena area measures ~6.8 m long and ~5m wide and contains ~45 cm of Black Point-1 (BP-1) (basalt regolith simulant).
3. **Astronaut Memorial Foundation's Center for Space Education (CSE)** https://www.amfcse.org/about-cse **-** Located adjacent to the northwest end of the Kennedy Space Center Visitor Complex (KSCVC), at the Eastern terminus of Florida S.R. 405 in building M6-306.
4. **Autonomous:** The operation of a robot with no human interaction.
5. **Basaltic Regolith Properties**: Since the properties of regolith vary and are not well known, this competition will assume that basaltic regolith properties are similar to the Lunar regolith as stated in the "Lunar Sourcebook: A User's Guide to the Moon", edited by G. H. Heiken, D. T. Vaniman, and B. M. French, copyright 1991, Cambridge University Press (https://www.lpi.usra.edu/lunar_sourcebook/) .
6. **Black Point-1 (BP-1)** https://ares.jsc.nasa.gov/projects/simulants/bp-1.html - both parameters (coefficient of friction and cohesion) are highly dependent on the humidity and compaction (bulk density, porosity) of the Lunar soil. Note the following:
   1. It does not behave like sand.
   2. The coefficient of friction has not been measured.
   3. There are naturally occurring rocks in the aggregate.
   4. BP-1 is made from crushed basalt fines and not commercially available.
   5. See "Soil Test Apparatus for Lunar Surfaces"
   6. The density of the compacted BP-1 aggregate will be between 1.5 g/cm3 and 1.8 g/cm3
   7. BP-1 behaves like a silty powder soil with most particles under 100 microns in diameter.
   8. Will be compacted and the top layer will be raked to a fluffy condition of approximately 0.75 g/cm3, similar to the Lunar surface.
   9. Teams are encouraged to develop or procure simulants based on basaltic minerals and lunar surface regolith particle size, shape, and distribution.
7. **Center for Lunar & Asteroid Surface Science (CLASS)** https://sciences.ucf.edu/class/ **-** is at the intersection of NASA science and exploration for rocky, atmosphereless bodies.
8. **Black Point-1 (BP-1) Reflectivity:** NASA performed tests to answer questions about BP-1 reflectivity for LIDAR (or other LASER-based) navigation systems. The laser is not a beam – it is spread out as a sheet that is oriented in the vertical direction, so it is draped across the BP-1 and across a white/gray/black target that is standing up behind the BP-1 in the images. The BP-1 is the mound at the bottom of each image. Teams can get the reflectivity of the BP-1 by comparing the brightness of the laser sheet seen reflected from the BP-1 with the brightness of the same sheet reflected from the white and black portions of the target. The three images are for the three angles of the laser. Note the BP-1 is mounded so they need to account for the fact that it is not a flat surface if they choose to analyze the brightness in the images. The three pictures below were shot with the camera at 10, 16, and 21 degrees relative to the surface. The laser was at an angle of 15 degrees. The camera speed and aperture were set to (manual mode): 1/8 s, f/4.5.

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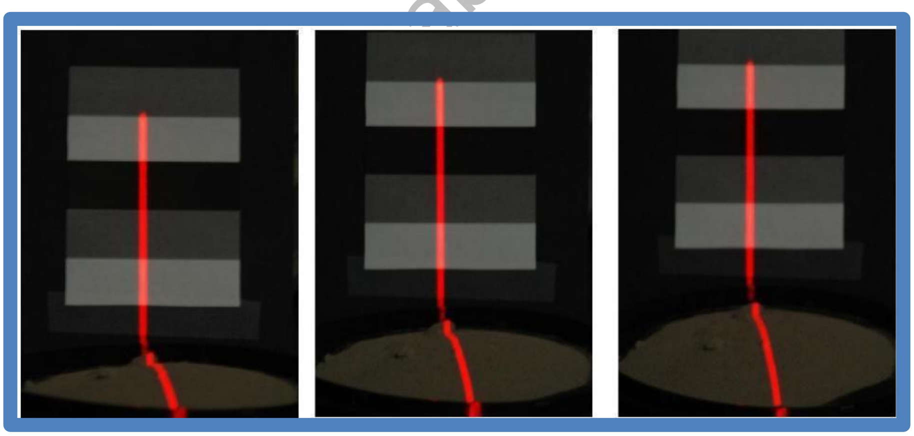
9. **BotShop** (https://public.ksc.nasa.gov/partnerships/capabilities-and-testing/testing-and-labs/prototype-development-laboratory/) - the Prototype Development Laboratory's (PDL) Bot Shop is a "mobile machine shop" with grinding, sanding, mini-mill and mini-lathe, band saw, drill press and hand tools. There is no welding capability. Help teams in repairing broken robots but do not have the capability to finish a started robot. The Bot Shop is busy throughout the competition.
10. **Exolith Lab** (https://exolithsimulants.com/) - enable space development and growth by providing high-fidelity analogs to researchers and educators globally. **Lunar Highlands Simulant (LHS-1) (**https://sciences.ucf.edu/class/simulant_lunarhighlands/) - the LHS-1 Lunar Highlands Simulant has been developed by the CLASS Exolith Lab. It is a high-fidelity, mineral-based simulant appropriate for a generic or average highlands location on the Moon.
11. **In-Situ Resource Utilization (ISRU)** (https://beta.nasa.gov/mission/in-situ-resource-utilization-isru/) - To live and work in deep space for months or years may mean crew members have less immediate access to the life-sustaining elements and critical supplies readily available on Earth. However, the farther humans go into deep space, the more important it will be to generate products with local materials,
12. **Kennedy Space Center Visitor Complex (KSCVC)** (https://www.kennedyspacecenter.com/) **-** As a Smithsonian Affiliate, we offer the chance to view artifacts of NASA's Mercury, Gemini, Apollo and Space Shuttle Programs in the context of exhibits and attractions that tell the NASA story.
13. **Lunar regolith density:** The density of regolith at the Apollo 15 landing site averages approximately 1.35 g/cm3 for the top 30 cm, and it is approximately 1.85g/cm^3 at a depth of 60 cm. The regolith also includes breccia and rock fragments from the local bedrock. About half the weight of lunar soil is less than 60 to 80 microns in size.



10 Degree 16 Degree 21 Degree
Diagram – LIDAR/Laser Deflection

14. **NASA Gateway OSTEM Application Website** (https://stemgateway.nasa.gov/public/s/explore-opportunities/challenges) - the Team Lead starts the team application process and then invites students and faculty advisor(s) to apply within the website. When you run into an issue on the NASA Gateway OSTEM application website, send your inquiries to the website Help Desk.
15. **Regolith Construction robot:** An autonomous or tele-operated robotic excavator including mechanical and electrical equipment, batteries, gases, fluids, and consumables delivered by a team to compete in the competition.
16. **Regolith Construction points:** Points earned from the competition attempt will be used to

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determine ranking in the on-site robotic operations category.

17. **Robot:** will have a maximum mass of 80 kg, be contained within a payload envelope of 1.50 m x 0.75 m x 0.75 m (these dimensions correspond to the typical payload volume available on today's Lunar landers that are commercially available), the orientation of these dimensions may be chosen by each team for their specific design subsystems on the robot used to transmit commands / data and video to the telerobotic operators are counted toward the mass limit. Equipment not on the robot used to receive data from and send commands to the robot for telerobotic operations is excluded from the mass limit and may deploy or expand beyond the envelop after the start of each competition attempt but may not exceed a 1.5 m initial height and the deployed height must be lower than the ceiling height, which is 2.5 m above the surface of the regolith.
18. **Mission Control:** Mission Control is the operations area where teams will operate or autonomously control their robotic excavator to simulation a lunar In-Situ Resource Utilization (ISRU) construction mission. It is located outside of the Artemis Arenas. Only students from the team are allowed into the Mission Control Rooms during the robot run. A team will be disqualified for having faculty / advisors or non-team members in the mission control room during the robot run.
19. **Reference point:** A fixed location signified by an arrow showing the forward direction on the mining robot that will serve to verify the starting orientation of the mining robot within the mining arena.
20. **RoboPits** - The RoboPits are equipped with emergency eyewash stations and disposal containers for industrial waste. Teams are advised to bring additional LED lighting, power strips, and first-aid kits to the RoboPits. This is where you will be working on your robots, meeting other competitors, and after spending months designing and building, this is where your robot gets inspected before it goes to work.
21. **Rock/Gravel:** The gravel is #57 limestone gravel (~2 cm in diameter) and is intended to simulate the icy-regolith buried in the South Polar region of the Moon. It will have random particle sizes larger than that also mixed into the gravel. The rock/gravel may be mixed in with the BP-1 in small quantities.
22. **Swamp Works (**https://www.nasa.gov/sites/default/files/atoms/files/swamp_works_brochure_2015.pdf) - The Swamp Works is a lean-development, rapid innovation environment at NASA's Kennedy Space Center. It was founded in 2012, when four laboratories in the Surface Systems Office were merged into an enlarged facility with a modified philosophy for rapid technology development.
23. **Telerobotic:** Communication with and control of the mining robot during each competition attempt must be performed solely through the provided communications link which is required to have a total average bandwidth of no more than 5.0 megabits/second on all data and video sent to and received from the mining robot.
24. **University of Central Florida (UCF) (**https://www.ucf.edu/**)** - The University of Central Florida is a public research university with its main campus in unincorporated Orange County, Florida. It is part of the State University System of Florida.

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APPENDIX C. FROM GOOGLE SCHOLAR

NASA's Plan for Sustained Lunar Exploration and Development
https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf

Nasa Lunabotics Robotic Mining Competition 10th Anniversary (2010-2019): Taxonomy Technology Review
https://ntrs.nasa.gov/citations/20200003009

Novel Approaches to Drilling and Excavation on the Moon
https://arc.aiaa.org/doi/pdf/10.2514/6.2009-6431

Preparing for Mars: Evolvable Mars Campaign "Proving Ground" approach
https://ieeexplore.ieee.org/abstract/document/7119274

NASA Human Spaceflight Architecture Team: Lunar Surface Exploration Strategies
https://ntrs.nasa.gov/citations/20120008182

NASA Centennial Challenge: 3D-Printed Habitat
https://ntrs.nasa.gov/api/citations/20170009010/downloads/20170009010.pdf

Lunar Spaceport: Construction of Lunar Landing & Launch Pads
https://commons.erau.edu/cgi/viewcontent.cgi?article=1017&context=spaceport-summit

TOWARDS IN-SITU MANUFACTURE OF MAGNETIC DEVICES FROM RARE EARTH MATERIALS MINED FROM ASTEROIDS
https://robotics.estec.esa.int/i-SAIRAS/isairas2018/Papers/Session%2010c/1_iSAIRAS_Ellery_2018_final-11-40-Ellery-Alex.pdf

NASA Centennial Challenge: 3D Printed Habitat, Phase 3 Final Results
https://ntrs.nasa.gov/citations/20190032473

A Process Plant for Producing Rocket Fuel From Lunar Ice
https://asmedigitalcollection.asme.org/IMECE/proceedings-abstract/IMECE2019/V006T06A108/1073266

Robotic Construction on the Moon
https://ntrs.nasa.gov/api/citations/20210018912/downloads/Design%20for%20Robotic%20Construction%20on%20the%20Moon%20ISU%20SSP%2021%20STRIVES.pdf

ISRU: The Basalt Economy.
https://www.researchgate.net/profile/Rodrigo-Romo-2/publication/322567782_ISRU_The_Basalt_Economy/links/5a5fff9c458515b4377b89cb/ISRU-The-Basalt-Economy.pdf

RASSOR - Regolith Advanced Surface Systems Operations Robot

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https://ntrs.nasa.gov/citations/20150022134

Building a Vertical Take Off and Landing Pad Using in situ Materials
http://ssi.org/2010/SM14-proceedings/Building-a-Vertical-Take-Off-and-Landing-Pad-using-in-situ-Materials-Hintze.pdf

Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study
https://mepag.jpl.nasa.gov/reports/Mars_Water_ISRU_Study.pdf

Affordable, Rapid Bootstrapping of the Space Industry and Solar System Civilization
https://arxiv.org/abs/1612.03238

Additive Construction with Mobile Emplacement (ACME)
https://www.researchgate.net/profile/Rodrigo-Romo-2/publication/322567924_Additive_Construction_with_Mobile_Emplacement_ACME/links/5a5ffe7faca2727352458863/Additive-Construction-with-Mobile-Emplacement-ACME.pdf

A Review of Extra-Terrestrial Mining Concepts
https://ntrs.nasa.gov/citations/20120008777

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