Lunar Surface Innovation CONSORTIUM

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

SEMI-ANNUAL MEETING REPORT:

Lunar Surface Innovation Consortium Fall Meeting 2021

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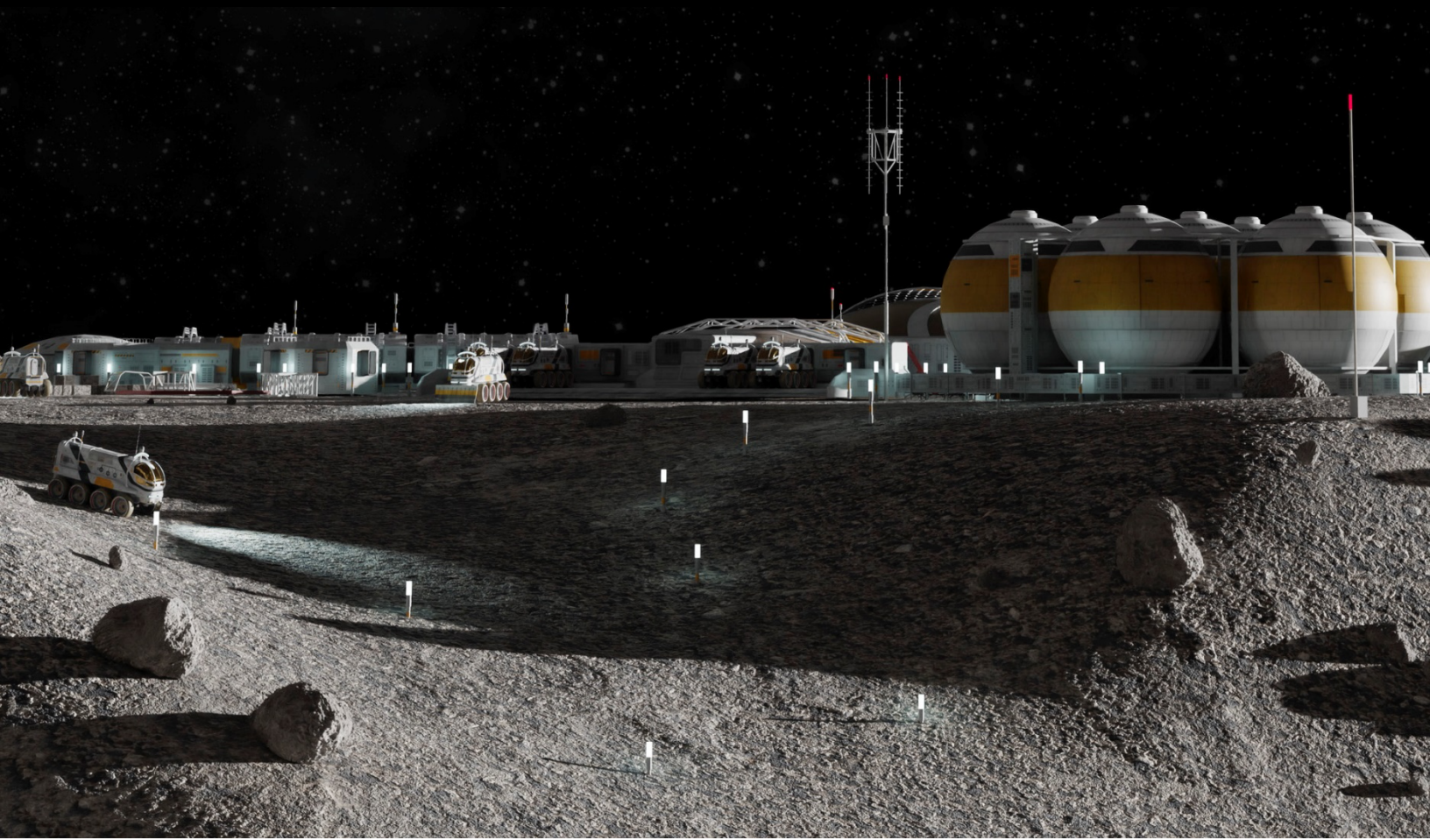


EXECUTIVE SUMMARY

The Lunar Surface Innovation Consortium (LSIC) 2021 Fall Meeting was held on November 3-4, 2021 at Bowie State University in Bowie, MD. The objective of this meeting was to provide a forum for NASA and the space technology community to discuss technology development for establishing a sustained presence on the lunar surface, focusing in particular on investments, needs, and concerns associated with autonomy and robotics. Attendance included 418 people representing over 125 institutions that met over the course of two days. Over one third (39%) of those who registered for the meeting had not previously attended an LSIC event. The meeting was run in a hybrid format, with questions being taken only via a digital tool to try to provide a more equitable experience for online attendees.

Bowie State University, founded in 1865, is the first Historically Black College and University (HBCU) established in Maryland. The Fall Meeting, sponsored through a partnership with SAIC, provided an opportunity to share the work that Bowie and SAIC have done to involve students in space research, and also introduce some of the opportunities in the space industry to the students at Bowie State. Presentations from Bowie State and SAIC highlighted how industry can work with academia to foster opportunities in the growing space sector.

The meeting featured an update on the Space Technology Mission Directorate by Jim Reuter, NASA Associate Administrator for Space Technology, as well as technical presentations on Trustworthy AI and Autonomy, NASA Autonomous Systems & Robotics: Roadmap and Investments, and a discussion about a new effort aimed at understanding supply and demand issues relating to technologies needed to survive the lunar night. Panel discussions focused both on community building and technical issues related to robotics and autonomy. On the first day, a venture capitalist panel shared their experience in investing in space or related technology, including their considerations when evaluating companies to invest in. A second panel included members from government, industry, and academia to discuss efforts to foster innovation across sectors. Panels on the second day focused on autonomy and robotics, with the first describing flight demonstrations that are in development, and the second discussing robotics and autonomy in the context of the bigger picture of establishing lunar infrastructure. Videos of the event can be accessed at https://lsic.jhuapl.edu/Events/Agenda/index.php?id=148.

Breakout discussions centered on evaluating the autonomy and robotics-related concerns related to the scenario presented in NASA's Break the Ice Challenge asking the question: What robotic or autonomy capabilities are critical to establish, operate, and maintain the infrastructure assumed in that challenge? Three in-person groups and four online groups discussed the issues separately, but most had two high-level findings in common:

- Some of the most critical technology gaps for autonomous operations on a Lunar base are free space optical communications and radiation hardened computer hardware. *Government needs to prioritize investment in communications and position, navigation, and timing (PNT) as well as ensuring standards for these are developed*.
- An understanding of the resources available and their extractability is critical, and currently lacking. *A resource prospecting campaign for water ice reduces risk and focuses the direction of technology development to build towards a sustained presence on the Moon.*

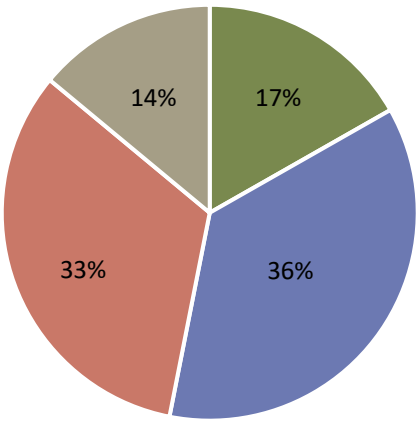
MEETING ATTENDANCE AND DEMOGRAPHICS

The Lunar Surface Innovation Consortium (LSIC) 2021 Fall Meeting was held on November 3-4, 2021 at Bowie State University in Bowie, MD. The objective of this meeting was to provide a forum for NASA and the space technology community to discuss technology development for establishing a sustained presence on the lunar surface, focusing in particular on investments, needs, and concerns associated with *autonomy and robotics*. Attendance included 418 people representing over 125 institutions that met over the course of two days. Over one third (39%) of the 497 who registered for the meeting had not previously attended an LSIC event, and 42% had never worked with NASA's Space Technology Mission Directorate before. More than half of those (99) who registered but had not previously participated in LSIC also signed up to join LSIC.

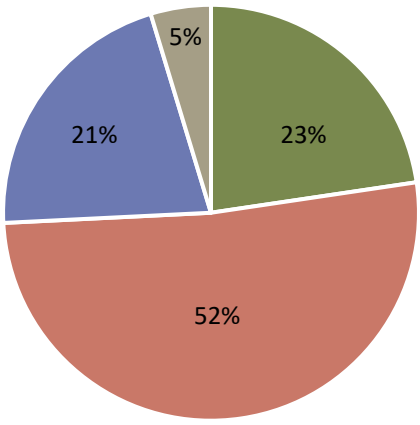
Just under two-thirds (59%) of the individuals who attended the Fall Meeting were also registered as participants of LSIC. Of attendees whose institution classification was known, a majority (36%) were from government, followed closely by industry (33%) and then academia (17%) and nonprofits (14%). Relative to the last LSIC-wide meeting in Spring of 2021, this represents a slight increase in government and non-profit individuals, and the same proportion of academic participants.

When attendance is examined by institution, the largest proportion of attending institutions came from industry (52%), followed by academia (23%), government (21%), and then non-profits (5%). This discrepancy between individuals and organizational breakdown is not surprising, as most industrial or academic institutions were represented by one or only a few individuals, while organizations like NASA and APL (classified as non-profit) had a larger number of representatives at the meeting. Government organizations, other than NASA centers, that were represented at the Fall Meeting included AFWERX, the National Geospatial Intelligence Agency, United States Geological Survey, National Renewable Energy Laboratory, and the Office of the Under Secretary of Defense.

Distribution of Individual Attendees



Distribution of Attending Institutions



KEY FINDINGS

- Promotion of LSIC meetings is still reaching new individuals and broadening the LSIC community.
- LSIC participation continues to be dominated by industry; LSIC should continue efforts to grow the academic and non-profit membership in the LSIC community to include more varied perspectives.

MEETING CONTENT

This LSIC Fall Meeting was the first to be hosted with an in-person component at a member institution. Bowie State University, founded in 1865, is the first Historically Black College and University (HBCU) established in Maryland. The Fall Meeting, sponsored through a partnership with SAIC, provided an opportunity to share the work that Bowie and SAIC have done to involve students in space research, and also introduce some of the opportunities in the space industry to the students at Bowie State.

The meeting was run in a hybrid format, with questions during plenary sessions being taken only via a digital tool (Slido) to try to provide a more equitable experience for online attendees. Because not all questions submitted to slido were able to be answered live, we have posted the full list of questions on the meeting website along with any answers that we were able to obtain from each speaker after the meeting. Plenary presenters and panelists were welcome to participate virtually or in-person, with some panels including a mix of both. Poster sessions were held in GatherTown for virtual attendees, and in-person for those who attended the meeting at Bowie. Hybrid-format lightning talks highlighted selected posters to the full group in a plenary session. Breakout groups were convened virtually and in-person, but without mixing modes of attendance. Of the attendees, roughly a quarter were in-person, with the remainder online.

Each LSIC Fall Meeting is centered on a specific, but crosscutting, category of technology, and in this case, the focus was autonomy and robotics. The objectives of this meeting were to: (1) highlight a Member Institution, in this case Bowie State University; (2) discuss concerns, advancements, investments and NASA's plans in the field of robotics and autonomy; (3) highlight partnerships among academia, industry, and government, and how these partnerships can provide opportunities for new innovators throughout the country to join in on the efforts to return to the lunar surface.

Plenary Sessions

INDIVIDUAL PRESENTATIONS

The LSIC Fall Meeting began with a series of welcome addresses from the university, local government, NASA and APL. Dr. Aminta Breaux, president of Bowie State University, welcomed the community and share the history of Bowie State as Maryland's oldest historically black university and one of the ten oldest in the country and highlighted their focus on investing in STEM and enpreneurial opportunities for their students. Her address was followed by the Honorable Angela Alsobrooks, County Executive of Prince Georges County, who recognized the growth and achievements of Bowie State University and welcomed the group to the county. She discussed the benefits of NASA and space technology research for providing technology sector jobs to people in the county and throughout the nation and for spurring innovation and fostering economic growth.

The introductions and welcomes were followed by a brief recorded message from NASA Deputy Administrator Pam Melroy. Deputy Administrator Melroy stressed the importance of building a community effort to close technology readiness level (TRL) gaps in the LSIC focus areas, so that we will be prepared to build a sustained presence on the Moon. She emphasized that advancing technology and closing knowledge gaps for living off-world and harnessing local resources on the Moon would also advance the goal of eventually sending humans to do the same on Mars. She also provided a short overview of the status of the Artemis program and conveyed the importance of autonomy and robotics for both Artemis and the Commercial Lunar Payload Services (CLPS) program.

NASA Associate Administrator for Space Technology Jim Reuter kicked off the technical discussions with a briefing on the Space Technology Mission Directorate (Space Tech) portfolio. He described the LSII technology areas and

provided examples of relevant technology demonstrations planned for flight and deployement on the Moon, including ISRU, power, communications and mobility (extreme access), and construction. He highlighted specifically the array of funding opportunities specifically targeted towards the academic community, and how these awards, in particular, have provided NASA funds to researchers across the full extent of the country. He highlighted the investments that Space Tech has made in industry through prizes and challenges, public private partnerships, and the SBIR program. Finally, he described two new flight oppotunties for suborbital and balloon flights, NASA TechLeap and NASA TechRise Student Challenge, geared towards providing payload build experience to non-traditional researchers and students throughout the US. Several of the questions during and after the talk focused on the timing and **funding levels for upcoming opportunities**, as well as request for more **details on the scope of planned demonstrations** such as the Nokia network and laser communications. Other questions concentrated on **power systems**, current **challenges in space robotics**, and how to better **leverage the CLPS missions to mature complementary as well as alternative technologies** (for instance different methods for O_2 extraction).

After Associate Administrator Jim Reuter's talk, Dr. Rachel Klima, the LSIC Director, provided an update on LSIC and focus group activities, including sharing the main findings from the Spring Meeting and how those would be addressed in consortium efforts going forward. She shared the updated LSIC website and the facilities directory effort, and walked through recent and upcoming events for each of the focus groups. Following the LSIC briefing, Ms. Yolanda Tully introduced the partnership between SAIC and Bowie State University before turning the floor over to Mr. Mark Fuerst, senior program manager at SAIC and Dr. Anika Bissahoyo, Assistant Vice President for Research at Bowie State University. They discussed the SAIC and Bowie partnership in more detail, including the student intern work on the NASA OMES II project. Dr. Bissahoyo described how working with SAIC has provided hands-on opportunities for the students to develop research skills and technical expertise, and Mr. Fuerst encouraged others to consider partnerships like the one between Bowie and SAIC to foster new opportunities for students. Questions from the community included asking **what is the best way to start a new partnership with an HBCU like Bowie state**, specifically, whether is it more helpful to partner in proposals, support the school directly with research funding, or to focus on promoting career or internship opportunities for the students.

The morning of the first day wrapped up with two early-career features, the first of which was an overview of the Next Generation Lunar Scientists and Engineers (NLGSE or NextGen) group, formed in 2008 to provide a forum for lunar scientists and engineers to develop research and communication skills, network , and to create a more inclusive community. Amanda Stadermann shared recent and planned activities for the group, and shared some of the resources available on the NextGen website. Finally, a cohort of student interns from the APL CIRCUIT program, which focuses on bringing teams of students from underprivledged backgrounds together to tackle technical projects, shared the work that they have been doing to create a conceptual design for a lunar base. Each of the team members has worked with one of the LSIC focus groups to help identify areas of overlap and synergy with other groups, to improve inter-group communication. On the technical side, the project has focused on creating a simulator that allows parameters, such as number of crew members or type of power source, to be defined, and then use those inputs to create a lunar base design.

The afternoon of day one began with a discussion about advancing development of tehnologies necessary to survive the lunar night by Kevin Somervill, Technical Integration Manager for Extreme Environments at NASA Space Tech. For this presentation, the goal was to understand the community's perspective on both needs and capabilities. Several ways to engage the community were proposed, including a workshop focused on a specific mission, a technical showcase of capabilities, or a workshop concentrating on NASA thermal technologies. Questions from the audience included asking **whether the main gaps are in knowledge, technology development, or something else**, and whether Space Tech has the **capacity and/or interest to have new radioisotope technology** developed **to enable surviving the lunar night**.

The second day began with an introduction by Niki Werkheiser, the Director fo Technology Maturation at NASA, who stressed that the driving goal of LSIC was to foster communication between NASA and the community and to find new ways to work together. She discussed the focus groups and ongoing technical information and highlighted the growth of the consortium to include international participants.

Individual presentations on the second day focused more explicitly on issues concerning robotics and autonomy. The day began with a presentation by Dr. Cara LaPointe, Co-Director of the Johns Hopkins Institute for Assured Autonomy about Trustworthy AI and Autonomy. Dr. LaPointe focused on many of the concerns for developing autonomous systems on Earth, including reliability, monitoring, fault diagnosis and assessment, and interactions among different systems in a crowded ecosystem. She then transitioned to discussing policy and cybersecurity concerns, and the tools that the JHU Institute is working on to manage all of these concerns. The community expressed a great deal of interest in the issues of how to **establish trustworthy AI for the Moon**, where many **applications would be life-critical** for astronauts. One member asked **how different players (e.g. NASA, Space Force, commercial ventures) might value different aspects of autonomy assurance**, and another was concerned about **potential vulnerability of AI systems on the Moon**.

Dr. Terry Fong followed with a detailed presentation about NASA Autonomous Systems & Robotics roadmap and investments. Dr. Fong detailed the overarching strategic goals for NASA, before moving to share the objectives and approach for autonomous systems and robotics (ASR). He described an array of technologies that NASA has invested in, including advanced robotics for mobility and excavation and autonomous operations for landing or navigation. He explained the taxonomy for ASR technology, and how it would all feed into complex tasks such as preparing a lunar landing site for long-term human habitation and operations. The audience was extremely interested in Dr. Fong's presentation, and eager to learn more about specific details. Several of the questions were geared towards understanding how **external partners could contribute**, and **opportunities for positioning technology infusion**. Other questions centered around surviving the lunar night, asking **whether NASA would begin to require autonomous systems to survive the night** and **what type of power supplies** would be available for it.

KEY FINDINGS

- The community is eager for more details from NASA on funding opportunities, the nature of already identified knowledge gaps, and the scope of planned flight demonstrations. A number of questions also surrounded lunar communications-related demonstrations, suggesting a desire to understand what lunar communications infrastructure could be on the horizon.
- For the challenge of developing technology to survive the lunar night, expected power availability and type (e.g., whether new radioisotope power was being considered) were of great interest. A "survive the night" workshop or similar would likely draw substantial interest.
- The presentation of the autonomous systems and robotics roadmap was extremely well-received, and the community was looking forward to understanding how they can contribute. Similar deep-dives for other focus areas are likely to be of great interest.
- The community recognizes that establishing trustworthy AI on the Moon is going to be of great importance, and will include a number of different stakeholders, both public and private. It would be worthwhile to connect interested community members with any organizations working on this issue, and/or to periodically invite speakers to update the community on this topic.

PANEL DISCUSSIONS

Four plenary sessions were held with panel discussions at the fall meeting. On the first day, these panels focused on community development, with the first panel including venture capitalists discussing the space economy, and the

second emphasizing fostering innovation in industry and academia. On the second day, the panels were geared towards autonomy and robotics, with the first centered on planned flight demonstrations, and the second discussing big picture issues for autonomy and robotics on the Moon.

The venture capital panel included four panelists: Candice Matthews Brackeen of Lightship Capital; Michael Mealling of Starbridge Venture Capital; Curtis Rodgers of Brick and Mortar Ventures; and Josephine Millward of Seraphim Capital. Lightship Capital is a venture fund that invests in women, people of color, and other underestimated technology founders, most commonly in the healthcare sector. Starbridge focuses on investments that combine traditional tech investments with space development opportunities. Brick and Mortar Ventures invests in new technology and process improvement, including construction technology and 3-D printing building designs. Finally, Seraphim Capital primarily focuses on funding Earth-orbiting space technology. The panel discussed a range of questions posed by the community, including **how companies can cross over into space**, **advice for early stage companies** and **how they should communicate their vision and business model to investors**, and the **expected time for return on investment for space ventures**. All of the panelists stressed a number of points throughout the discussion, including that venture capital funds have to **anticipate a return on investment in a short time (<5 years)**, even for space companies. **Dual use technology** that includes either terrestrial or low-Earth orbit application is more likely to be appealing. It is critical for companies to make it clear that they **understand the needs of their customer**, but also to **show that they are willing to listen and grow** based on investor or customer feedback. Several of the investors also stressed that companies should **strongly consider the diversity of their team**, especially as we build to a space future where the country needs to see themselves reflected as a critical part of that future.

The second panel on day one included three panelists: Brett Lindenfeld of Motiv Space, Dr. Angel Abbud-Madrid of Colorado School of Mines, and Lt. Col. Rock McMillan, Director of SpaceWERX. The goal of this panel was to bring together experts to discuss how government, academia, and industry can work together to foster innovation. A number of topics were covered, including the role of academia in bringing early stage innovation that can close knowledge gaps as well as how Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs can provide early-stage innovation funds to lower barriers of entry for small businesses. Mr. Lindenfeld shared the perspective of a company that has worked with NASA since 2017 on developing a cryogenic controller through the SBIR program that is now planned for a flight demonstration on the lunar surface. Dr. Abbud-Madrid stressed the importance of **casting a broad net** when looking **for innovation**, including the **international community, academia, and small and large companies**. Lt. Col. McMillan described how SpaceWERX, the Space Force arm of AFWERX, seeks to leverage the innovation going on outside the DOD and allow companies to drive innovation. Addressing several questions from the audience, the group discussed the timeframe for sustainability on the lunar surface, and all anticipated some form of **continued presence being achievable by the late 2020s**. When discussing the skills needed to build this future, all agreed again that the field is wide open for students and those companies looking to contribute. They also stressed the importance of students having **hands-on experience with practical applications**.

On day two, the flight demonstrations panel featured a series of speakers, including Dr. Danette Allen, Jason Schuler, and Dan Andrews of NASA, Dan Hendrickson of Astrobotic, and Matthew Atwell of Intuitive Machines. Dr. Allen kicked off the panel talking about the history of AI and the digital ecosystem, and how it has changed over the last ten years. Jason Schuler described the ISRU Pilot Excavator and the partnership between KSC, JSC, JPL, and Astrobotic to develop the excavator for demonstration on a CLPS mission. Dan Andrews then summarized the VIPER mission to investigate volatiles at the south pole of the Moon. Following the NASA presentations, Dan Hendrickson spoke about Astrobotic's cuberover and its capabilities and potential use cases. Finally, Matthew Atwell described the Deployable Hopper that Intuitive Machines and ASU are working on, that will be delivered to the lunar surface by a Nova-C lander. The community had a number of technical questions for each of the presenters, suggesting a **great deal of interest in these demonstrations**. Several questions surrounded **data availability** between stakeholders, specifically whether a NASA-developed resource map would be shared with companies, and whether commercially obtained data sets would be shared publicly.

The final panel of the meeting focused on the big picture for autonomy and robotics. The panelists, AJ Gemer, of Lunar Outpost, Dr. Hazel Edwards, Chair and Professor at Howard University, and Dr. Stephen Hart of TRAClabs, each offered diverse perspectives on the challenges for autonomy and robotics on the Moon. From the commercial

viewpoint, Mr. Gemer shared their experience with developing robotic solutions for the Moon. Dr. Edwards spoke about her work with the Habitats Optimized for Missions of Exploration (HOME) Space Technology Research Institute. As an architecture professor, she works to bridge communications gaps between space engineers and architecture students working on optimal designs for habitats. Dr. Hart detailed the adaptation of Robotic Operating Systems (ROS) to space. The panel provided advice to students or newcomers to the field interested in robotics, suggesting they keep up with the space industry news, seek out projects and internships that provide hands-on experience, and prioritize math. They also discussed how the government can help foster growth, stressing networking and SBIR programs as being valueable, as well as suggesting that requiring **standardization** is important as well as **providing access to** as many **data sets** as possible (but science and technical/environmetnal monitoring data).

KEY FINDINGS

- The investor community desires a return on investment on a shorter time horizon than many lunar surface technology elements are likely to provide. When possible, companies should consider alternative uses, on Earth's surface or near-Earth orbit, for technology that they hope to have privately funded. For companies seeking private investors, it is important to demonstrate flexibility and growth potential, and that they understand their customer(s).
- It is recognized that to build a sustained presence on the lunar surface by the end of the decade, innovation will need to come from academia, large and small companies, and in collaboration with the international community. Continued communication between government agencies and these stakeholders is critical to ensure that they can mature the technology required.
- Standardization, open-source resources, and open sharing of data between members in the community will be extremely important to make the best use of finite resources.
- The community recognizes that building a diverse workforce is critical to innovation, and many stress that the best way to ensure that students are prepared is to provide hands-on experience through academic programs and internships.

Community Sessions

As a hybrid meeting, community presentations at the Fall Meeting were handled as a plenary lightning talk session, where presentations selected by the technical committee based on contributed abstracts could be shared either in the main meeting room or via zoom, followed by a poster session at Bowie State and a parallel session on Gathertown.

LIGHTNING TALKS

A subset of the poster presentations were presented in the form of short (~2 minute) lightning talks. These talks were intended to provide a quick overview of some of the work that would be presented in more detail in the poster sessions. Lightning talks primarily focused on autonomy and robotics, but included a broad range of topics, including the need for a resouces prospecting campaign, radiation hardening of electronics, and the benefit of open soure and open standards for collecticve invention. All of the lightning talks are available online for viewing through the event page (direct link: https://www.youtube.com/watch?v=m_9QrtyVm7I).

POSTERS AND GATHERTOWN ENVIRONMENT

Posters were hosted both in person and online using the GatherTown environment. GatherTown allows individuals to log in and walk around a virtual conference hall as an avatar (similar to a low-resolution video game), interacting

with people within a small radius of them. Posters that were presented in GatherTown as well as some of those that were presented in-person are also posted on the LSIC Meeting website, and will remain available for reference.

Breakout Sessions

For our first hybrid meeting, we opted to keep virtual and in-person breakout sessions separated, rather than mixing the two attendance modes together. For sessions that are discussion-heavy, we expected that without heavy moderation, any in-person interactions would dominate and those online would be less likely to be heard or feel included. There were seven parallel breakout sessions, three in person and four fully virtual, each discussing the same topics. The breakout sessions were presented with the scenario given in NASA's Break the Ice Challenge, which assumes a location around a permanently shadowed region (PSR) near the lunar South Pole with a NASA Power Plant, NASA Power Distribution, and a NASA Water Extraction Plant in place, and asked to explore, from a systems perspective, what the robotic and autonomy needs and concerns would be for establishing, operating, and maintaining those infrastructure elements.

Each of the in-person breakout sessions was held in room with a white board for brainstorming as a group, and those online were facilitated with a zoom session with a dedicated page or series of pages in Confluence for participants to add comments in writing (https://lsic-wiki.jhuapl.edu/display/2020FM/Virtual+Breakout+Sessions). These spaces were also used to capture notes, so that participants could reference these during and after the meeting. Each of the seven breakout groups proceeded through the afternoon independently, but there were a number of topics that most, if not all, of the groups raised.

ESTABLISHING INFRASTRUCTURE ON THE LUNAR SURFACE

Almost every breakout group spent a great deal of time in the first hour discussing the need for a **robust resource prospecting campaign** before any infrastructure would be established. Groups identified that this function, especially for the case of exploring resources in the permanently shadowed regions (PSRs) would require developments in robotics and would benefit greatly from some level of autonomous operations. This campaign would need to include both orbital and **surface exploration**, the latter of which **could be leveraged** to install first-order **infrastructure elements such as markers or beacons for positioning**.

Every breakout group highlighted the **importance of establishing interoperability standards**. For example, **power charging and connecting** needs to be standardized, and specific standards should be specified by NASA or NASA in collaboration with international partners. Similarly, interfaces for any refueling would need to be standardized. Several industry members noted that the way payloads standards are being defined by CLPS (fully community-driven) is not ideal; they felt that more direction from NASA would be beneficial for smaller companies, in particular. Beyond interface standards, some groups also highlighted the need to **standardize procedures for testing, verifying and validating autonomous systems**, to establish trusted autonomy.

Many of the breakout groups highlighted the importance of establishing infrastructure and standards for **communication and positioning knowledge**. One group suggested that other infrastructure elements, such as the **VSAT arrays, could be used to host communications**, or, as mentioned above, beacons or markers could be deployed routinely with precursor missions to aid positioning. Secure communications will be critical not only for communicating with autonomous systems, but also for anomaly detection.

For all of the early large infrastructure, groups felt that NASA or other space agencies needed to play the largest role, as industry does not see a return on investment for such elements in the near term.

OPERATING INFRASTRUCTURE ON THE LUNAR SURFACE

A number of the topics arose regarding **open access to data, standards, and technology**. Many groups raised the issue that once there are ongoing operations on the Moon, there is likely to be a plethora of **environmental monitoring data** produced. These data **would be extremely valuable for future technology development**, but, if collected by private companies, might not be shared unless required by NASA. Open standards would be preferred over being forced to use a sole provider for the case of power sources and distribution. Similarly, **defined material and equipment standards** should be developed to convey lessons learned as operations build up on the Moon. Given the scope of this effort, collective research and innovation would benefit all.

Another common thread was the desire to **narrow down what robotics or autonomous functions absolutely need to be tested on the lunar surface**, versus what could be tested on Earth, so that the former could be prioritized for flight demonstrations. Some of the technology gaps for surface operation identified included navigation sensors, actuators for long-duration, difficult work in a dusty environment, surface communications, positioning, power distribution, and high-performance computing suitable for long-duration surface use. Central to many of these is the question of what radiation hardened electronics are available, as well as thermal management techniques.

Many of the groups debated the **use cases for full autonomy vs. telerobotics**. Some of the groups favored humans in the loop for most complex applications, but discussed issues like PSR navigation as possible areas where autonomy might be preferred. It was suggested that **CLPS could be used to test the limits for autonomous operations**. The issue of 'traffic management' along any prepared routes or conflicts when elements attempted to charge at power stations were discussed in several groups.

MAINTAINING INFRASTRUCTURE ON THE LUNAR SURFACE

The final hour of the day focused on how autonomy and robotics could benefit the off-nominal cases for infrastructure operation, including maintenance, fault analysis, etc. Many of the groups began by discussing the types of potential dangers for infrastructure, including lunar dust, moonquakes, micrometeorites, charging, and radiation.

Many groups raised the point that it is much easier to work with material that is already both on the Moon and in a usable form (e.g. metal) than it is to either bring repair parts or create from local materials. Thus, **recycling and repurposement** will be key. This can be facilitated by building in redundancy as well as **standardization of key parts**, so that especially in the case of life-critical breakdowns, materials from other systems might be available.

A robotic application suggested in at least one group was whether there would be a place for something like 'AAA for space' that could respond to issues. Again, **standardization and multitool functionality** would be key (like a surface-based version of On-orbit Servicing, Assembly, and Manufacturing (OSAM)). Several groups identified that there may be a number of analogous operational environments on Earth, from deep sea, to orbital, to Arctic or Antarctic bases, that could provide insight and recommendations.

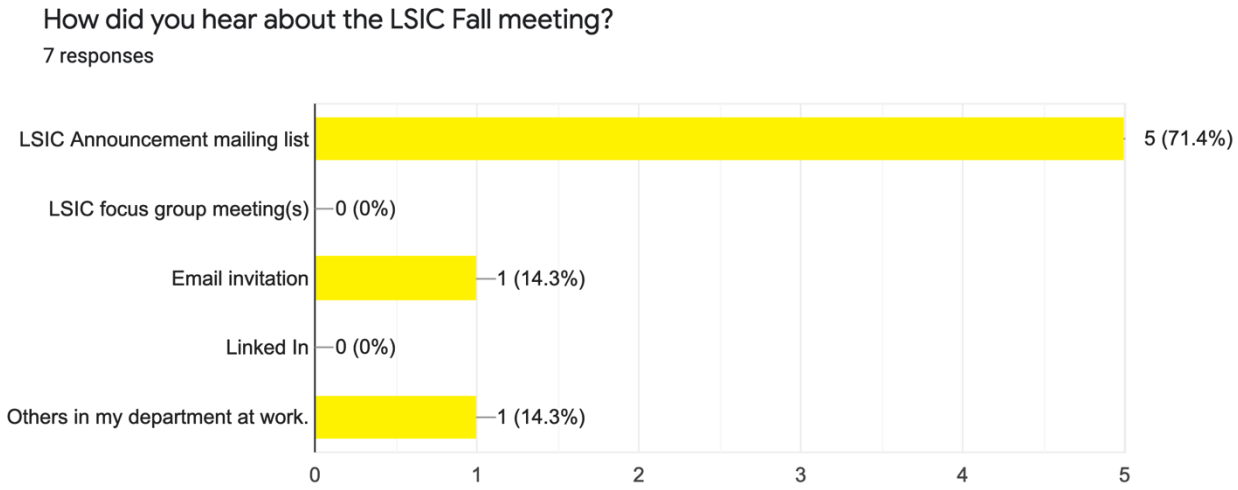
Although none of the groups focused on how to deal with malicious acts, they recognized that there might be unintentional cases where a **malfunction** of one company or government's technology **prohibits another from functioning**, for instance by breaking down at a charging station. Also, the question was raised of how to handle any broken down equipment that a company or government either could not or did not care to recover, for instance if a tethered rover were to become lodged in a PSR. If another company or government was able to recover it, what would be the legal process, or, specifically, how is **salvage law** treated in space.

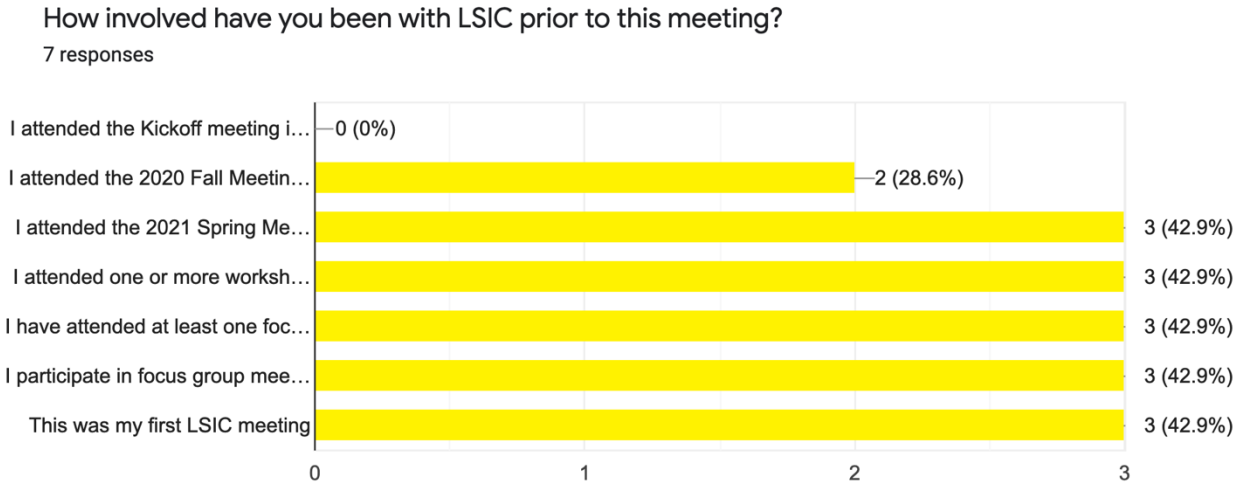
- An understanding of the resources available and their extractability is critical, and currently lacking. A resource prospecting campaign for water ice reduces risk and focuses the direction of technology development to build towards a sustained presence on the Moon.
- Some of the most critical technology gaps for autonomous operations on a Lunar base are free space optical communications and radiation hardened computer hardware. Government needs to prioritize investment in communications and position, navigation, and timing (PNT) as well as ensuring standards for these are developed.
- Standardization remains a critical aspect of all stages of lunar infractructure development and operation. Although larger companies with the capacity to build and maintain complex infrastructure might benefit from closed standards, smaller companies strongly advocated for open sharing of standards as well as monitoring data that would help the community, as a whole, to improve their technology. At some point, NASA or other funding agencies would need to require that either a specific interface standard is used or that it at least be open, and not proprietary.
- Continued understanding about what functionality can be tested on Earth vs. what has to be tested on the Moon should be used to help NASA prioritize what is demonstrated on future CLPS missions.
- Recycling and repurposement of material will be key to maintaining infrastructure, but there are legal ramifications that need to be understood for both this and for other aspects of operation on the lunar surface.

APPENDIX 1 – MEETING FEEDBACK

The responses to the post-meeting survey for the Fall Meeting were limited, despite multiple attempts to encourage participation. Results are presented here, but

Background Information





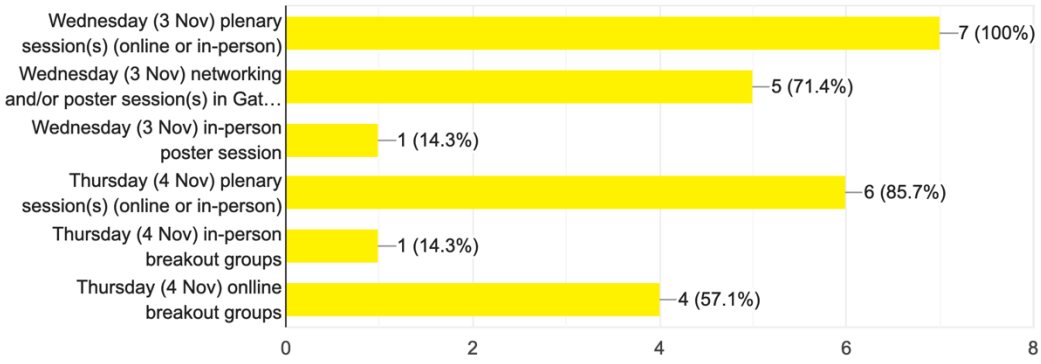
Attendance

How did you attend the 2021 LSIC Spring Meeting?

7 responses

What parts of this meeting did you attend?

7 responses

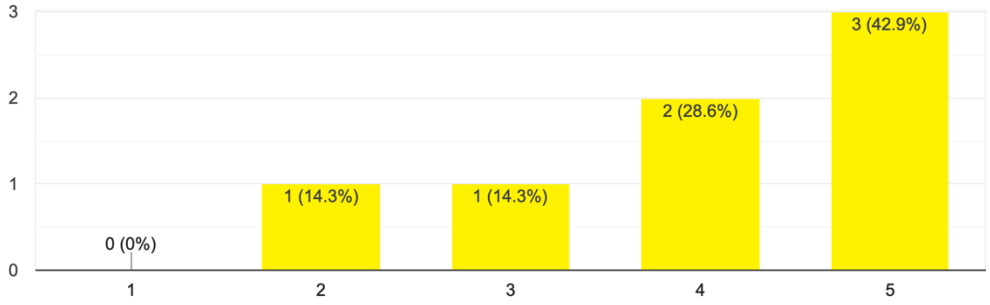


Tools Feedback

How was your user experience with the following tools used during the meeting? (1=poor, 5=excellent)

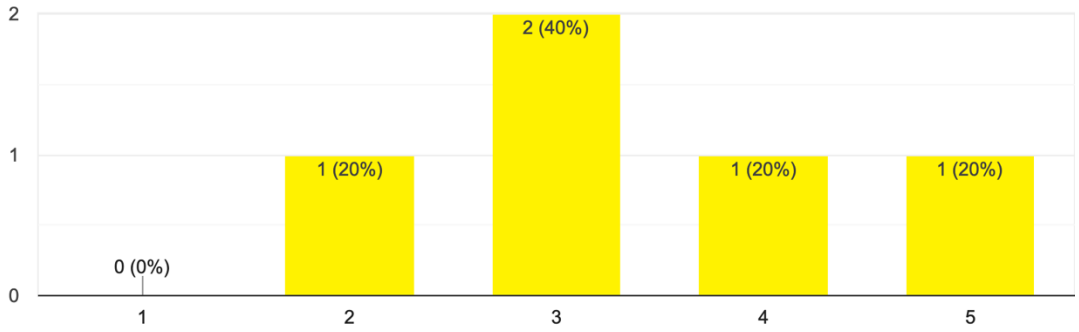
Zoom

7 responses



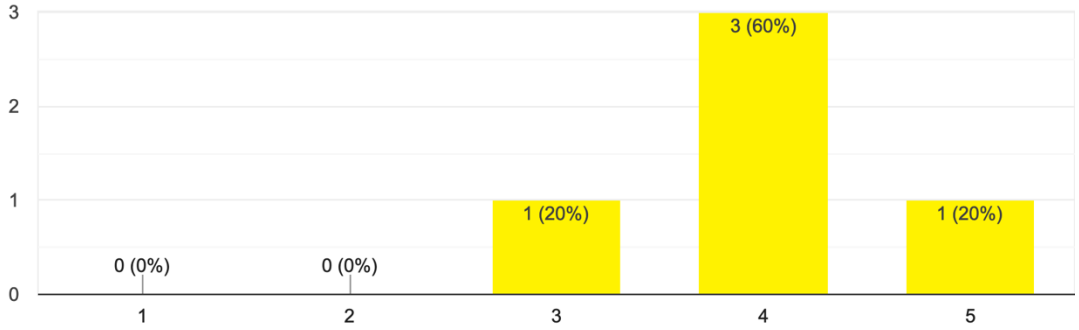
Slido

5 responses



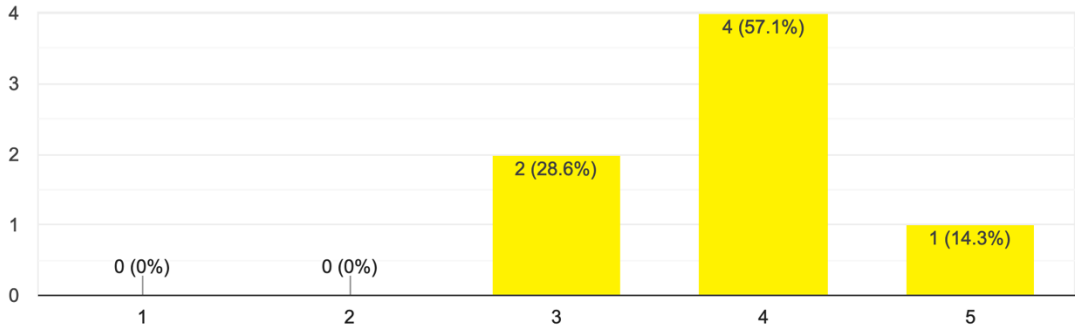
GatherTown

5 responses



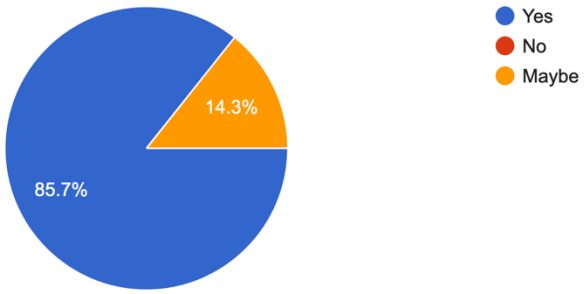
Confluence

7 responses



Do you plan to continue to use Confluence to interact with the community?

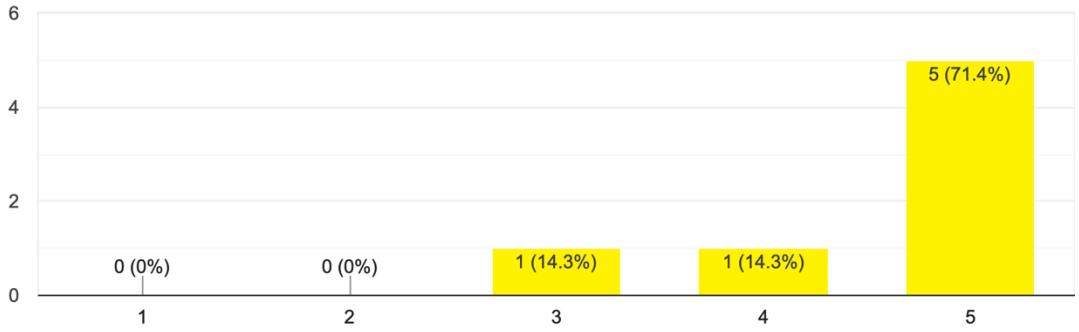
7 responses



Session Feedback

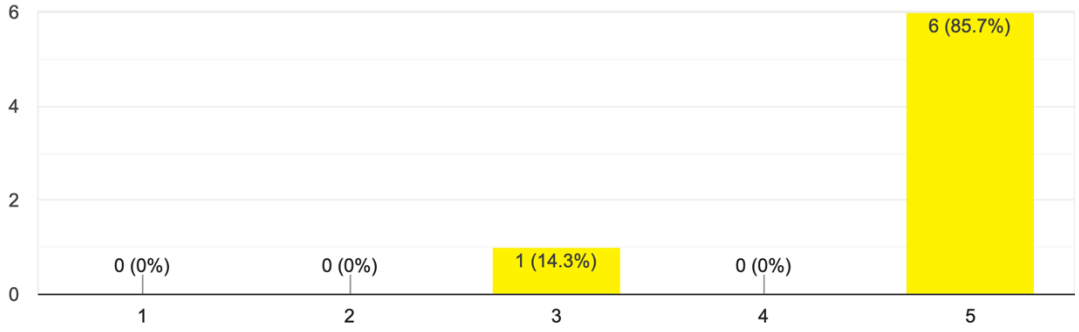
How would you rate the overall content of the plenary sessions?

7 responses



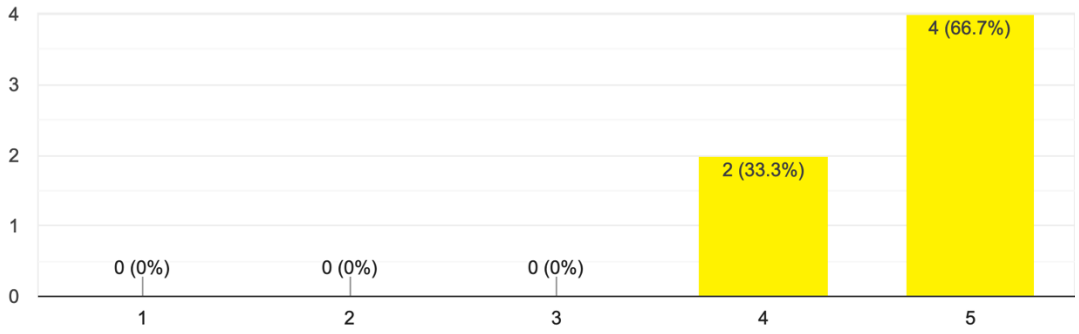
How would you rate the overall content of the panel presentations?

7 responses



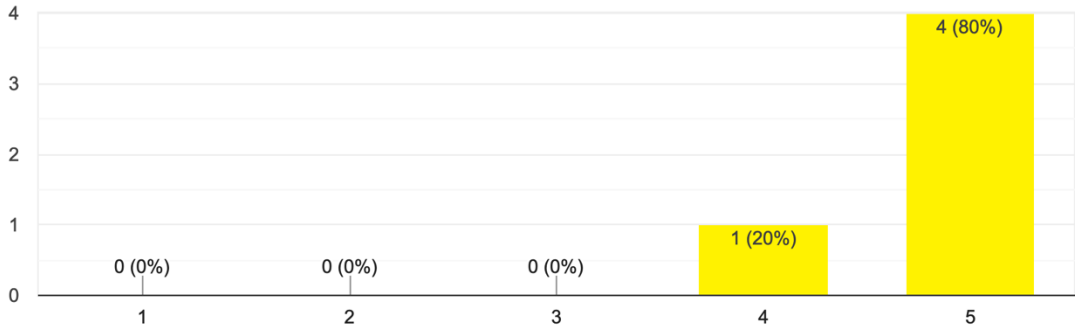
How would you rate the overall content of the breakout sessions?

6 responses



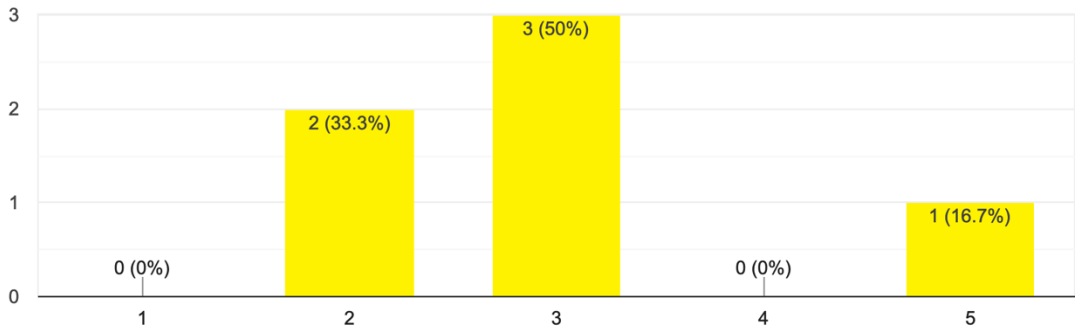
How would you rate the overall content of the poster session?

5 responses



If you participated online, how did your experience compare to a fully virtual meeting?

6 responses



If you participated online, and have specific feedback about what we did well, or what we did poorly to help you stay engaged, please let us know below.

1 response

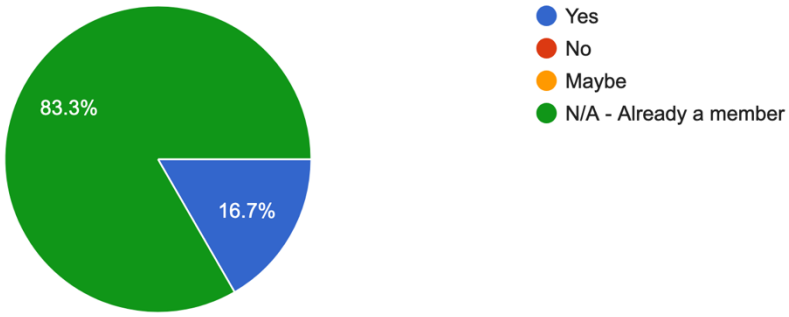
sli.do questions went into an admin queue, and were sometimes not acknowledged/approved/checked in time for the session. Audio/Video challenges at times. Gather.Town was nice (as an experienced user).

Did not receive email with log-in details the first day, but did receive them the second day. Sounds like other virtual attendees also found it more useful to navigate links via the online site/agenda as opposed to the emails. Would be helpful if Zoom/GT/sli.do links were posted on the agenda page, as well.

Other Feedback

If you are not already involved in LSIC, are you interested in joining?

6 responses



Please share any additional feedback with us here:

3 responses

Rachel was DA BOMB at emceeing! :-)

Thanks all for hosting a great event! Appreciated the choice to collaborate with Bowie State and their engaging sessions in the conference schedule. Hope to see more collaborations like this in the future.

I am in Australia, so even in non-covid times virtual attendance is a real boon.

KEY FINDINGS

- This year's survey received a very low response rate, even though it was released within a few days of the meeting. Next meeting, plan to solicit real-time feedback via Slido at the end of the first and second day.
- Of those who responded, the majority heard about the meeting through the LSIC mailing list, though we did gain one from a directed email invitation and one from word of mouth from a colleague.
- All sessions were well received, with most ranked as excellent or great.
- The community appears to be becoming more comfortable with tools such as Gathertown and Confluence, and most indicated that they intended to continue to use Confluence for collaboration after the meeting.