GUIDING PRINCIPLES TO OPTIMIZE REAL-TIME SCIENTIFIC PRODUCTIVTY DURING ARTEMIS CREWED MISSIONS TO THE MOON. J. L. Heldmann[1] D. S. S. Lim[1], D. Newman[2], J. Shaw[2], A. Colaprete[1], R. C. Elphic[1], D. Lees[3], K. Zacny[4], J. Coyan[5], Z. Mirmalek[1,6], A. Sehlke[1,6] A. Wagner[7]. [1]NASA Ames Research Center, Division of Space Sciences & Astrobiology, Planetary Systems Branch, Moffett Field, CA, [2]Massachusetts Institute of Technology (MIT), Cambridge, MA, [3]NASA Ames Research Center, Intelligent Robotics Group, Moffett Field, CA, [4]Honeybee Robotics, Pasadena, CA, [5]USGS, Spokane, WA, [6]BAER Institute, Moffett Field, CA, [7]US Army, Cold Regions Research and Engineering Laboratory, Fairbanks, AK.

Introduction: NASA's Artemis crewed missions to the lunar polar region will offer unprecedented opportunities to conduct high priority lunar science to further our understanding of the Moon's history and evolution as well as address key science questions relevant to broader Solar System science. Artemis offers the ability to capitalize on the unique skills and capabilities of on-site human beings to maximize scientific productivity while on the lunar surface. To optimize scientific return during crewed EVA (extravehicular activity), we present several guiding principles that should be implemented at the earliest stages of the Artemis program.

Mission Organization Philosophy: The integration of scientific EVA activities by astronauts will undoubtedly require coordination amongst multiple Artemis program areas including, but not limited to, the astronaut team, Artemis Science Center on Earth, flight operations, ground data systems, EVA tool development teams, sampling and curation groups, software engineering, communications and navigation, spacesuit development, human landed systems, etc. The Artemis program must embrace the overarching philosophy that "Science enables Exploration and Exploration enables Science". To this end, Science *must* be integrated with each facet supporting lunar surface science operations at the earliest opportunity. Architecture and/or other programmatic decisions in one area often have significant, and at times unrecognized, impacts to other program areas, including Science. Decisions must be made within the Artemis program with Science considerations brought to bear from the earliest stage possible, in parallel with the requirements of other stakeholders, to mitigate against inadvertent negative impacts to the scientific output of the missions.

Crew Training: Artemis crew must be trained in field geology at the earliest opportunity. A significant portion of the EVA work will be dedicated to addressing numerous high priority lunar science questions, and a strong background in lunar science as well as field science and operations will increase the robustness of astronaut decision-making in the field and ultimately increase the scientific return of the mission. Crew must be trained in the scientific background and rationale, field science operations, and post-mission data analysis (including sample return analyses). The crew should also be fluent in technology advances in automation and data in order to optimize productivity on the lunar surface.

Artemis Science Center Ground Data Systems & Visualization: An Artemis Science Center will be located on Earth and have the ability to follow the lunar EVAs and provide scientific support in near real-time. The Science Center will have the ability to synthesize vast amounts of data more rapidly than the astronauts on the Moon due to the number of personnel in the Science Center, extensive career training of the scientists, dedicated data analysis time, and more capable analysis tools. However, in order to add value to EVA execution (including real-time EVA support as well as planning for subsequent EVAs based on previous data collected), the Artemis Science Center must be equipped with sufficient knowledge through return of appropriate types and volumes of data from the lunar surface. The Science Center must have adequate situational awareness to understand the context of the EVA operations, and have ancillary data (e.g., astronaut observations, science instrument data, etc.) returned to Earth and displayed and available in meaningful ways for rapid synthesis and understanding to support both tactical and strategic operations. Advanced tools such as the use of augmented reality and/or virtual reality (AR/VR) should also be considered for meeting the visualization and capability needs of the Science Center. EVA timeline planning and scheduling tools must also be accessible to the Science Center in order to accurately follow astronaut timeline activities as well as have the appropriate information to suggest revised astronaut timelines if/when changes to the field plan are warranted based on scientific knowledge learned on the ground.

Artemis Science Center Organization: The Artemis Science Center must be organized with a structure that is optimized for supporting real-time operations during EVA as well as informing longer-term strategic EVA planning. The Science Center must either include or have access to personnel with expertise regarding each scientific instrument collecting data on the Moon. Leads for both tactical and strategic planning will be important for leading these activities during flight operations. A streamlined communication architecture from the Science Center to the Flight Director (FD) and/or Capsule Communicator (CapCom) positions is critical to ultimately minimize cross-talk and avoid auditory confusion between the Science Center discussions and the astronaut crew. We recommend a dedicated Science Lead console position in direct communication with the FD and/or CapCom who can relay direct findings and recommendations from the Science Center as well as answer science-related questions quickly during operations.

Decision Making Protocols: The Artemis program must clearly delineate responsibilities and protocols regarding decision affecting planned crew EVAs. During (and after) crew surface operations, we will inevitably have new, unanticipated discoveries about the Moon which will likely prompt a change in the a priori EVA plan. Flexibility must be a central tenet by all parties regarding the EVA operations plans to respond to unexpected / interesting data and/or situations as warranted. The ability for Science to recommend changes from the a priori plan must be expected and embraced, e.g., the scheduling timeline would accommodate discussion on emergent planning in the Science Center and with other mission areas. The program must also clearly outline when and where such changes may be permissible, including inputs from the science team on Earth as well as the astronauts on the Moon. Plans should include rapid science decision-making along with flexibility in recognition that future decision making must be dynamic and can incorporate algorithms for in-time learning to be implemented.

Simulations and Analog Testing: Many of the procedures and architectures discussed here will benefit from testing and refinement through mission simulations and analog field testing. We recommend a robust program of mission simulations and analog tests in a rigorous program which should be strategically developed based on the specific information required to optimize the Artemis science activities. Field tests are also beneficial to surface tool development. For example, astronauts should not simply test tools in the field once the tools have been developed, but rather the crew should go to the field *during* development of these tools to provide feedback and iterate on the design and tool functionality. Science, Operations, and Technology work should be conducted in a sequenced program which also will serve as training opportunities for crew and Artemis staff in myriad capacities. Field analog activities should include non-simulated science in order to increase the fidelity and robustness of the work and subsequent findings. We also emphasize that the science team requires dedicated training to effectively participate in real-time mission operations.

Training the Next Generation: Human and robotic exploration of the Moon and beyond must be a sustained effort. The required longevity of such exploration programs highlights the need for training and flight mission experience for early career scientists and engineers in order to provide continuity within the workforce to execute such long-term exploration goals. The Artemis program should intentionally focus on utilizing Artemis activities and missions to train the next generation while simultaneously focusing on diversity, equity, and inclusion to develop a technical workforce capitalizing on the talents of our full society to maximize productivity and innovation.

Conclusions: A transdisciplinary collaborative environment is essential for optimal scientific return for Artemis. All stakeholder groups (scientists, engineers, operations specialists, and astronauts) must be engaged for a deep and sustained collaborative effort. We also suggest a vision for integrated science and technology deployment which is enabled by the collaboration of robotic and human explorers. Such missions would maximize science, develop in-situ technologies, enable data collection and sample return, implement human robotic interactions (HRI) and learning algorithms to assure collaborative, effective protocols, provide for identification and extraction of resources for long-term missions, and utilize visualization technology that provide full immersion in lunar scenarios to demonstrate both significantly enhanced science and operations in real (or-near real time).

The Artemis program represents a monumental opportunity through the planned return of astronauts to the lunar surface. Artemis will explore a lunar polar region, an area never before visited by humans. Such new sites will offer exceptional scientific opportunities to learn and discover new knowledge about our Moon and the Solar System as a whole. In order to optimize the scientific return of the Artemis missions, we suggest an early focus on Artemis management strategies, crew training, Science Center ground data systems and visualization tools, Science Center organization, and decision-making protocols based on scientific inputs throughout the Artemis hierarchy. We also emphasize the importance of training the next generation of planetary scientists and engineers to enable a robust and sustainable program of human and robotic exploration in the Solar System. Many of these details will be best assessed and refined through strategically-planned mission simulations and terrestrial analog field campaigns with non-simulated scientific research activities.