NASA VIPER MISSION'S SCIENCE ROLES IN THE MISSION OPERATIONS CENTER. Zara Mirmalek[1,2], Anthony Colaprete[2], Richard Elphic[2], Caleb Fassett[3], Julie Kleinhenz[4], Kathleen Mandt[5], David Lees[2,6], Darlene Lim[2], [1]BAER Institute (mirmalek@baeri.org), Moffett Field, CA, [2]NASA Ames Research Center, Moffett Field, CA, [3]John Hopkins University Applied Physics Laboratory, [4]NASA Johnson Space Center, Houston, TX, [5]NASA Goddard Space Flight Center, [6]KBR, Inc.

Introduction: The NASA VIPER (Volatiles Investigating Polar Exploration Rover) mission defined science roles in on-console positions in a Mission Operations Center, supporting real-time remote science on the Moon.

As the first NASA mission utilizing a tele-operated robot on the Moon, VIPER required the development of dedicated operations spaces for mission systems, payload commanding, and science operations at the NASA Ames Research Center (ARC). It brought an opportunity to define and organize some of the mission roles in the three mission operations workspaces at ARC: Mission Operations Center (MOC), Payload Operations Command Center (POCC), Mission Science Center (MSC). VIPER's Science Operations team developed science team roles and placement of some of these roles within the MOC, on the basis of research on the communication and interaction needs specific to conducting remote science with a tele-operated robot and instruments near the lunar South Pole [1, 2, 3, 4, 5, 6].

Assessing the Need for Science Roles in VIPER's MOC: From late fall 2019 to early fall 2020 a science operations work system was designed to enable the VIPER Science Team (VST) to conduct lunar science in cooperation with mission systems operations [1, 7]. Attention was given to drawing out organizational conditions within which the work system would need to operate. Foremost among these conditions were structural technologies, e.g., robot, maps, instruments, time, data architecture, software, and cultural aspects, e.g., workgroup size, language, hierarchy, meeting behavior norms, verbal and non-verbal signals indicating affirmation, question, and transgression. Fundamentally the work system needed to support scientists' investigation process of questioning, requesting, collecting, analyzing, discussing and presenting but also support adjusting their process to operate within specific time and space limitations in a space mission.

Accounting for the temporal parameters. All VIPER mission personnel share some temporal parameters including the nominal duration of the mission (~ 100 Earth-days), low-latency communication with the remotely operated robot (~ less than 10 seconds round trip), rover's speed (centimeters per second), goal distance (20 km), data transmission speed, and Earth's movement below the lunar horizon for the robot that occurs every-two-weeks (and lasts two-weeks). These are some of the fundamental temporal factors that shape VIPER mission operations choices on "how, when, who, and with what tools".

The specific activity of interactive lunar rover remote operations [8] includes waypoint commanding, which is pivotal to real-time operations. As the rover is driven along the planned traverse, seeking to arrive at locations designated as science stations where the drilling activities will occur [6], the rover driver sends a new command typically every ~ 2-8 meters .

Rover drive team and science team. The rover's Drive Team includes four roles: 1) Driver, 2) Co-Driver (Co-D), 3) Navigation (Nav), 4) Real-time Science (RTSci). Their roles were positioned side-by-side at a long workstation, all facing their set of monitors and several large wall monitors, see Figure 1. The Driver is flanked by RTSci on their left and Co-D on their right. The Drive Team roles and task development built on VIPER team members explicit and implicit knowledge from previous research conducting remote robot operations in analog environments [9, 10].



Figure 1: Five console positions in one of two rows in the MOC. The roles on-console are as follows, starting from left: Science Lead, Real-time Science, Driver, Co-Driver, Navigation (shown here with two persons at one console during a simulation exercise).

While only one role (Driver) is responsible for sending driving commands, assessing the lunar terrain to inform actual traverse decisioning is a multi-role activity [8]. These assessments need to be communicated to the Driver within the timeframe that

supports their ability to process and apply the input (cognitively and operationally). The timeframes for this activity can vary from seconds to minutes. Expectations for response time are sometimes unspoken and sometimes included in the question or asked for in response to a question. The physical proximity between RTSci and Driver, and Driver and Co-D, is underpinned by the need to communicate verbally and non-verbally with shared content (e.g., digital content on displays) and metacommunication (e.g., context signals) [11, 12].

VIPER Science roles in the MOC and in the MSC: Correspondingly, the RTSci role is the only science role with the responsibility and capability (e.g., communication protocol, console includes view-only version of rover operations software) to communicate responses, questions, and recommendations to the Driver and Co-D.

The scientist in the RTSci role needs to draw not only from their own knowledge but also from that of their co-investigators, the on-console science team seated in the MSC, in an adjacent building within ARC's Multi-Mission Operations Center. A single person cannot be responsible for representing all their team's knowledge. They can be responsible for communicating a decision, but how that decision is drawn together is open for design. For this reason, the role of Science Lead (SciLead) was established and positioned in the console to the left of the RTSci console. RTSci is thus enabled to maintain attention and participation with the Drive team without risk of losing contact with their science team counterparts.



Figure 2: Twelve assigned console positions in the MSC. The console to the left of the projector screen is for the role of MSC Lead.

The SciLead role is responsible for communicating knowledge between the science team in the MSC and the Drive team in the MOC and for communicating to the MSC context information that is present in the MOC, which does not come across data displays or voice comms. SciLead maintains responsibility for participating in tasks in the MOC and in the MSC. SciLead has two primary science roles with which they pair – RTSci and MSC Lead (in addition to the mission team roles to which they must be immediately responsive, e.g., Flight Director).

Although the MSC Lead is physically located in the MSC, this role's responsibilities are in both the MSC and MOC. RTSci and SciLead rely on the MSC Lead to communicate the science team's assessments, questions, concerns. To expedite these communications, science operations required the development of an architecture to deliver simultaneous receipt and display of telemetry, e.g., instrument (MSolo, NIRVSS, NSS, TRIDENT) and camera data, plus software, e.g. OpenMCT, for all science roles.

Communication work practices for the RTSci and SciLead roles were developed during integrated mission simulations (2021 – 2024) that included the Drive Team and the Science team in the MSC. The pressure of needing to be responsive to colleagues and keep apace of their activity deadlines provided a work environment in which to practice selecting speech and communication media (e.g., via voice communication, digital text, map annotation), to learn gestural signals, to devise and test tools to aid in sharing knowledge status and information needs.

Some of these work practices were interpersonal. For example, persons in the SciLead and RTSci roles learned one another's communication habits and preferences for signaling for attention, interrupting, requesting or receiving communication with the MSC. Some practices required new tools. For example, they developed a representation, "Science Traverse Objectives Table", providing a high-level account on the science focus shared by the team in the MSC and in the MOC for each shift. The expected traverse is parsed with information such as science objectives, hypothesis, instrument use, and actual outcomes are noted in real-time.

References: [1] Z. Mirmalek et al. (2021) *LPSC 52*, Abstract #1734. [2] D. Lim et al. (2024) *LPSC 55*, Abstract #1646. [3] D. Andrews (2020) *ELS*. [4] A. Colaprete et al. (2023) *LPSC 54,* Abstract #2910. [5] R. Beyer et al. (2022) *LPSC 53*, Abstract #2479. [6] M. Shirley et al. (2022) *LPSC 53* Abstract #2874[7] Z. Mirmalek et al (2024) *LEAG* Abstract #5058. [8] T. Fong (2024) *NTRS* 20240010930. [9] T. Fong et al. (2010) *Acta Astro., 69*, 1176-1188. [10] J. Heldmann et al. (2016) *Adv. in Space Research, 58*, 545-559. [11] G. Bateson (1972) *Steps to an Ecology of Mind*. [12] E. Rogers and T. Steinfatt (1998) *Intercultural Communication*.