Teamwork Training Needs Analysis for Long-Duration Exploration Missions

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Executive Summary

As part of NASA's ongoing effort to enhance the teamwork training curriculum for long-duration exploration mission (LDEM) teams, we conducted a comprehensive training needs analysis (TNA) dedicated to identifying critical needs and gaps in the agency's existing curriculum and to providing general nonprescriptive recommendations for effectively and efficiently addressing these needs/gaps. Several complementary investigative methods were employed throughout this TNA, including interviews with 13 subject matter experts (SMEs), archival analysis of interview data previously collected from 12 astronauts with long-duration space flight experience, a review of recent LDEM astronaut job analysis findings, the analysis of existing NASA teamwork training materials, a review of the relevant scientific literatures, and rigorous content mapping of the data resulting from each of these activities. As a result of these efforts, 17 critical teamwork training needs/gaps were identified and 23 recommendations for addressing them were formulated. These needs/gaps and recommendations clustered into 7 broad categories, including needs/gaps and recommendations related to the: 1) content of the teamwork training, 2) consistency of the teamwork training content, 3) methods used to develop teamwork competencies, 4) amount of teamwork training provided, 5) timing of teamwork training, 6) types of participants who receive teamwork training, and the 7) methodologies used to evaluate NASA's current teamwork training programs. Table 1 provides a summary of these findings along with several specific examples of ways in which they could be immediately applied to enhance NASA's existing teamwork training curriculum in support of the agency's current and future LDEM efforts (i.e., potential next steps).

TABLE 1. SUMMARY OF FINDINGS AND POTENTIAL NEXT STEPS

CATEGORY	TRAINING NEEDS/GAPS	TRAINING RECOMMENDATIONS	POTENTIAL NEXT STEPS
TRAINING CONTENT	**Need/Gap 1**: Astronaut trainees receive too few opportunities to develop the teamwork knowledge, attitudes, and skills necessary for monitoring and responding effectively to one's own and others' emotions and behaviors that will result from living and working both autonomously and cooperatively within a small diverse group over the course of a long-duration exploration mission (LDEM). **Need/Gap 2**: Both flight controller and astronaut trainees receive too few opportunities to develop the team and multi-team system (MTS)-specific competencies necessary for team and MTS success during LDEMs.	**Recommendation 1**: Incorporate more training into NASA's astronaut teamwork training curriculum that specifically targets teamwork knowledge, attitudes, and skills related to small group living and self-care over extended periods of time in isolated, confined, and extreme environments. **Recommendation 2**: Incorporate more training into NASA's astronaut and flight controller teamwork training curricula that specifically targets team- and MTS-specific competencies.	**Example 1:** Analogue training specifically designed to develop small group living and self-care competencies will need to be designed specifically to include long periods of uneventful/monotonous co-habitation so as to mirror the expected circumstances under which LDEM crews will need to live. **Example 2:** LDEMs are expected to change the nature of the coordination between flight control and flight crews (e.g., greater crew autonomy). As such, simulation-based training designed to target MTS-specific competencies for LDEMs will need to be scripted to mirror these expected changes.
TRAINING CONSISTENCY	**Need/Gap 3**: NASA's astronaut and flight controller teamwork-related training activities tend not to be explicitly linked to one another so, across activities, a) the teamwork concepts introduced often differ and b) the specific terminology and definitions used to introduce the same teamwork concepts often vary. **Need/Gap 4**: The availability and content of each specific astronaut and flight controller teamwork-related training activity within NASA's teamwork curriculum tends to vary across team/MTS members so they are unlikely to receive teamwork training that is equivalent.	**Recommendation 3:** Ensure that all astronaut and flight controller team/MTS members are provided with opportunities to participate in the same or maximally equivalent teamwork-related training activities. **Recommendation 4:** Select and employ a single high-level teamwork competency model across a) all NASA astronaut and flight controller teamwork-related training activities and b) all astronaut and flight controller team/MTS members. **Recommendation 5:** When discussing a particular teamwork concept in either NASA's astronaut or flight controller training, refer to a) previous teamwork-related training activities that addressed the same concept and b) future teamwork-related training activities that will address the same concept. **Recommendation 6:** When NASA astronaut and flight controller teamwork-related training activities are intended to address only a subset of	**Example 3:** LDEM training cycles are lengthy. Thus, in order to create consistency with respect to team competencies trained from start to finish, it is critical to specify a standard LDEM teamwork model as soon as possible such as the Expeditionary Skills/Crew Office Team Skills model. Delays in accomplishing will have long-term ripple effects in terms of training inconsistencies. **Example 4:** LDEM task training is spread out over a long period of time. As a result, new task-related curriculum must be developed over time to keep up with technology and mission changes. To ensure consistency, specifications/ criteria for the development of new LDEM task and team training should explicitly direct training developers to link their curriculum back to and reference competencies within the standard teamwork model chosen, e.g.,

		the competencies in the overall model, make this explicit to trainees.	the Spaceflight Resource Management (SFRM) model.
TRAINING METHODS	**Need/Gap 5:** Online training methods are currently underutilized within NASA in the development of astronaut and flight controller trainees' teamwork competencies.	**Recommendation 7:** Incorporate the use of online training methods into NASA's astronaut and flight controller teamwork training curricula to a) prepare individuals to participate in in-person training activities, b) provide "just-in-time" and "booster/refresher" in between in-person training activities and during missions, and to c) provide opportunities for team/MTS members to train together remotely.	**Example 5:** Create an online training architecture that can be used to deliver online training of various types throughout the training pipeline. This will allow LDEM crew members and flight controllers to become familiar with a single system that they access repeatedly over time.
AMOUNT OF TRAINING	**Need/Gap 6:** Too little time is provided to astronaut trainees in NASA's teamwork-related classroom-based training to practice and receive performance feedback on the teamwork competencies they receive instruction on. **Need/Gap 7:** NASA astronaut and flight controller trainees are provided with too few transportable teamwork-related training materials (e.g., job aids, training guides) to refer to and use in the context of other training activities and/or missions. **Need/Gap 8:** Too few opportunities to receive mentoring and/or coaching are provided to astronaut and flight controller trainees throughout NASA's teamwork training pipeline. **Need/Gap 9:** Most NASA astronaut and flight controller trainees receive too few opportunities to participate in moderate-length simulations most suitable for developing critical teamwork knowledge, attitudes and skills associated with small group living and self-care (most critical for astronauts), as well as team/MTS specific competencies (critical for both astronauts and flight controllers).	**Recommendation 8:** Extend NASA's existing classroom-based teamwork-related courses for astronauts to allow additional time for practice and feedback. **Recommendation 9:** Incorporate more teamwork-specific training content into NASA astronaut and flight controller trainees' technical training and on-the-job performance periods through the use of training guides and job aids. **Recommendation 10:** Provide more mentoring and/or coaching to NASA astronaut and flight controller trainees throughout the training pipeline to provide regular and frequent learning and development opportunities tailored to their individual needs. **Recommendation 11:** Provide more regular opportunities for NASA astronaut and flight controller trainees to participate in moderate-length (e.g., 3-7 days) simulation- and/or analogue- based training most suitable for developing critical teamwork knowledge, attitudes and skills associated with small group living and self-care (most critical for astronauts), as well as team/MTS specific competencies (critical for both astronauts and flight controllers).	**Example 6:** Develop low fidelity team tasks that can be used efficiently to provide opportunities to practice team competencies trained throughout the LDEM training pipeline. **Example 7:** Training guides and job aids that reference a common teamwork competency model could be used to support consistency throughout the LDEM pipeline. **Example 8:** Create an online mentoring system to support continued remote interaction between LDEM crew members during periods of time in their training pipeline when they are geographically distributed.

TIMING OF TRAINING	**Need/Gap 10:** NASA's astronaut teamwork-related training activities are not strategically timed/spaced to maximize training effectiveness, in terms of a) promoting the development of more advanced competencies overtime, b) minimizing competency decay, and c) promoting transfer of training.	**Recommendation 12:** Provide teamwork training to astronauts in regular frequent intervals throughout NASA's astronaut training pipeline with opportunities for instruction, practice, assessment, and feedback in-between. **Recommendation 13:** Strategically sequence NASA astronaut teamwork-related training activities to move from basic to more advanced content and methods. **Recommendation 14:** Provide booster/refresher and just-in-time teamwork training tools/activities to astronauts as needed throughout NASA's astronaut training pipeline. **Recommendation 15:** Provide more teamwork training to astronauts during the "unassigned" and "mission" phases of NASA's astronaut training pipeline.	**Example 9:** Create curriculum shells that aid training developers in creating task/mission-specific training throughout the LDEM pipeline that consistently maps to a standard teamwork competency model. **Example 10:** Create an authoring tool that will assist crew members in developing their own just-in-time training that facilitates mission-specific learning during an LDEM.
TRAINING PARTICIPANTS	**Need/Gap 11:** Few NASA teamwork-related training activities allow for astronaut/flight controller team members to participate in targeted teamwork training as an intact team, limiting learning opportunities regarding individual differences impacting teamwork. **Need/Gap 12:** Few NASA teamwork-related training activities include participation by astronaut/flight controller trainees from both the U.S. and international partner agencies, limiting learning opportunities regarding cross-cultural factors impacting teamwork. **Need/Gap 13:** Few NASA teamwork-related training activities allow for astronaut/flight controller trainees to participate in targeted teamwork training with members of different units within the MTS, limiting learning opportunities	**Recommendation 16:** Increase the number of NASA-provided opportunities for astronaut/flight controller team members to participate in teamwork-related training together as an intact team. **Recommendation 17:** Increase the number of NASA-provided opportunities for teamwork-related training that includes both astronaut/flight controller trainees from the U.S. and from international partner agencies. **Recommendation 18:** Increase the number of NASA-provided opportunities for teamwork-related training that includes astronaut/flight controller trainees from different technical roles/functions and units within an MTS.	**Example 11:** Utilize distance learning technologies to provide opportunities for flight controllers and flight crew members who are geographically distributed to participate collectively in team training during the course of the LDEM pipeline.

	regarding interdependencies across different technical roles/functions.		
TRAINING EVALUATION	**Need/Gap 14:** Current NASA astronaut and flight controller teamwork-related training evaluation methodologies do not regularly include the use of a) quantitative measures, b) objective measures, c) longitudinal data collection, d) multi-source data, or e) assessments of outcomes other than trainee reactions, such as assessments of the specific team-related knowledge, attitudes, and skills targeted by training. **Need/Gap 15:** Trainee performance assessments conducted by instructors and peers as part of NASA's astronaut and flight controller teamwork-related training activities are not regularly utilized to evaluate training effectiveness. **Need/Gap 16:** Instructors and peers who assess trainee performance as part of NASA's astronaut and flight controller teamwork-related training activities are not typically provided with rater training. **Need/Gap 17:** Currently, NASA astronaut and flight controller teamwork-related training evaluation data is not collected, stored, analyzed, and/or utilized in a standardized manner.	**Recommendation 19:** Incorporate the use of measures which assess training outcomes beyond trainee reactions (i.e., learning, behavior, results) into NASA's astronaut and flight controller teamwork-related training evaluation methodologies. **Recommendation 20:** Incorporate the use of objective measures of targeted training outcomes into NASA's astronaut and flight controller teamwork-related training evaluation methodologies. **Recommendation 21:** Incorporate longitudinal designs into NASA's astronaut and flight controller teamwork-related training evaluation methodologies to a) track trainees' change on teamwork competencies over the course of their careers and to b) track changes in training effectiveness over time. **Recommendation 22:** Incorporate the use of valid and reliable quantitative ratings of trainees' teamwork competencies into NASA's astronaut and flight controller teamwork-related training evaluation methodologies by a) providing standardized rater training to those responsible for assessing trainees' teamwork competencies and b) utilizing multiple raters when assessing trainees' teamwork competencies so that the reliability of those ratings can be assessed. **Recommendation 23:** Consistently store and utilize NASA astronaut and flight controller teamwork-related training evaluation data in a central repository so that the data can be readily accessed and used to assess trends and norms related to trainees' mastery levels and the impact of curriculum changes over time.	**Example 12:** Specify regular intervals of time during the LDEM training pipeline in which crew members will be repeatedly assessed with respect to competencies within the standard teamwork model. **Example 13:** Develop and require standardized rater training for all instructors involved in training and assessment throughout the LDEM so that behavioral ratings collected over time will be reliable. **Example 14:** Develop a standardized teamwork knowledge/mental model-based assessment (e.g., card sorting task) that can be used to track changes and monitor the need for refresher training over the course of the LDEM pipeline.

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1.0   Background

1.1   Purpose and Scope

The success of future long-duration exploration missions (LDEMs) will be determined largely by the extent to which mission-critical personnel possess and effectively exercise essential teamwork competencies throughout the entire mission lifecycle (e.g., Galarza & Holland, 1999; Hysong, Galarza, & Holland, 2007; Noe, Dachner, Saxton, & Keeton, 2011). To ensure that such personnel develop and exercise these necessary teamwork competencies prior to and over the full course of future LDEMs, it is essential that a teamwork training curriculum be developed and put into place at NASA that is both 1) comprehensive, in that it targets all teamwork competencies critical for mission success and 2) structured around empirically-based best practices for enhancing teamwork training effectiveness.

In response to this demand, the current teamwork-oriented training needs analysis (TNA) was initiated to 1) identify the teamwork training needs (i.e., essential teamwork-related competencies) of future LDEM crews, 2) identify critical gaps within NASA's current and future teamwork training curriculum (i.e., gaps in the competencies targeted and in the training practices utilized) that threaten to impact the success of future LDEMs, and to 3) identify a broad set of practical nonprescriptive recommendations for enhancing the effectiveness of NASA's teamwork training curriculum in order to increase the probability of future LDEM success.

1.2   Scope of Work

To fulfill the stated purpose of this investigation, a variety of research methods were employed to conduct a comprehensive TNA focused on LDEM teamwork training needs. TNAs traditionally consist of three parts (McGehee & Thayer, 1961). The first part involves an analysis of the tasks performed by trainees on-the-job (e.g., task interdependency) in order to determine which competencies are necessary for successful job performance. The second involves an analysis of trainee characteristics that have the potential to influence the effectiveness of different types of training strategies (e.g., prior experience, personality, culture, motivation) as well as trainee characteristics that create additional training needs (e.g., competency deficiencies). The third and final part involves an analysis of the organizational context in which training occurs in order to identify which training strategies and competencies are most required and supported by the trainees' work environment.

In keeping with the traditional TNA approach, the current TNA involved the analysis of LDEM task, person, and organizational characteristics related to LDEM teamwork training needs. In addition, the current TNA included the examination of existing job analysis findings which offered additional information concerning LDEM teamwork training needs in the form of several teamwork-related competencies deemed important for LDEM crew performance through the analysis. This TNA was even further expanded to include the collection and analysis of information regarding NASA's teamwork training curriculum as well as information regarding empirically-supported best practices for teamwork training. This crucial expansion allowed for the identification of critical gaps in the agency's teamwork training curriculum along with the formulation of several general evidence-based recommendations for addressing these gaps.

To gather and analyze the information included in the current TNA, several complementary investigative methods were employed simultaneously. Each of these methods and their contributions to this effort are described in detail below.

2.0   Method

2.1   Interviews

Between the months of October 2015 and January 2016, a series of semi-structured telephone interviews were conducted with a diverse group of 13 subject matter experts (SMEs) experienced in the assessment, training, and /or development of astronauts and/or flight controllers within NASA and

its partner space agencies. Each interview lasted 30 to 90 minutes. SMEs interviewed included both NASA personnel and personnel from organizations contracted by NASA to provide teamwork training services. Interviewees included training designers and administrators, instructors, and an astronaut trainee, as well as several individuals who occupy alternative roles within Behavioral Health and Performance (BHP) Operations, Flight Operations Directorate (FOD), the NASA Astronaut Office, and other organizations within NASA.

The SMEs interviewed were asked to report their knowledge of and experience with the development, implementation, and evaluation of NASA's previous, current, and future teamwork training efforts and/or their experience assessing LDEM training needs. SMEs with experience developing, delivering, and/or evaluating specific teamwork-related training courses/activities we asked to provide detailed information regarding those courses/activities with which they were most familiar. Specifically, they were asked to report on the nature of the trainers/instructors and trainees/participants involved, the developmental history and future of the courses/activities, the course/activity learning objectives, methods, and relative position within the teamwork training curriculum, as well as the methods used to evaluate the courses/activities, the results from any prior evaluation efforts, and the general strengths and weaknesses of the courses/activities. SMEs were also asked to report their knowledge of LDEM training needs, their general perceptions of the overall teamwork training curriculum, its strengths and weaknesses, and their suggestions for enhancing its effectiveness.

Detailed summaries of each interviewee's responses were recorded in writing. A content analysis of these records was then conducted to extract and code information pertinent to the current investigation. This included information regarding LDEM training needs, information regarding task, person, and organizational characteristics related to those training needs, as well as information regarding the past, present, and future of NASA's teamwork training curriculum.

2.2 Analysis of Archival Interview Data

As part of a recently completed team TNA (Smith-Jentsch, et al., 2015), semi-structured in-person interviews were conducted with 12 NASA astronauts possessing long-duration mission experience. These 30-90 minute interviews were conducted at Johnson Space Center (JSC) in Houston, Texas during the months of February and June of 2010. During the interviews, astronauts were asked to report their prior experiences with long-duration missions. Specifically, they were asked to describe their experiences with team coordination, communication, cohesion, performance, leadership, and stress during such missions. In addition, they were asked to describe characteristics of the individuals, the tasks, and of the physical, social, and organizational environments encountered during long-duration missions.

As part of the prior investigation, each interview was recorded and fully transcribed. The resulting transcripts were collected and reviewed as part of the current TNA. Content analysis techniques were utilized to extract information relevant to the current investigation, including information regarding LDEM training needs, information regarding task, person, and organizational characteristics related to those training needs, as well as information regarding the past, present, and future of NASA's teamwork training curriculum.

Although the recently completed team TNA captured a substantial amount of information relevant to the current TNA, it is important to note that these two investigations were not duplicative but were, instead, designed to complement and build upon one another. Specifically, the current TNA supplements the prior one in three significant ways. First, while the prior TNA was focused mainly on identifying the teamwork training needs of LDEM astronauts/flight crews, the current investigation has an expanded scope to include the identification of LDEM flight controllers'/mission control teams' teamwork training needs as well. Second, while the prior TNA was largely focused on identifying the specific teamwork-related competencies necessary for successful LDEMs (as well as specific training

strategies suitable for developing those competencies and LDEM task/person/organizational characteristics likely to impact teamwork training needs) the current investigation has an expanded focus to include more in-depth analysis of NASA's current/planned teamwork training curriculum, the identification of critical gaps within it, as well as the identification of recommendations for addressing those gaps. Finally, because the data collection periods for the two investigations were more than five years apart, the current TNA was designed to capture critical updates related to LDEM teamwork training needs, including recent changes in NASA's teamwork training curriculum, recently developed plans for future development of that curriculum, new information regarding relevant LDEM task, person, and organizational characteristics, as well as recent findings from the relevant scientific literature.

2.3   Analysis of Recent Job Analysis Findings

As a result of a recent astronaut job analysis conducted by NASA (Barrett, Holland, & Vessey, 2015), 18 behavioral competencies were identified as being critical for future exploration mission success. These competencies were formulated and validated using a rigorous methodology involving the work of an expert panel and the completion of a series of 90 minute interviews with 26 SMEs. In addition, the extent to which each of the competencies are critical for performance and the extent to which each of the competencies should be present at the time of hire was assessed through the analysis of data collected via a web-based survey.

As part of the current TNA, findings and conclusions from this recent job analysis were reviewed and analyzed in order to determine 1) the extent to which each of the 18 competencies are teamwork-related (based on the known definitions and descriptors associated with each competency) and 2) which of the competencies require the most development throughout the LDEM training pipeline (based on information regarding the importance of each competency and regarding whether each competency should be present at the time of hire).

2.4   Analysis of Training Content/Materials

Materials from several existing NASA training courses/activities that target teamwork-related competencies were collected as part of the current TNA. These materials included documents describing the training content and methods, training materials presented and/or distributed to trainees, and training evaluation tools. An extensive review and analysis of this material's content was conducted to determine the extent to which each course/activity met the critical training needs and adhered to the teamwork training best practices identified through this TNA. Specifically, the materials were reviewed for information regarding each training program's content and its consistency with other elements of NASA's teamwork training curriculum, the amount/length and timing of the training, the training methods utilized, the trainees targeted, and the methods used to evaluate the effectiveness of the training.

2.5   Review of the Scientific Literature

An extensive review of the scientific literature on teams, multi-team systems (MTSs), and personnel training and development was conducted in order to identify a set of empirically-supported best practices for developing teamwork competencies. Review of the literature was also conducted to identify the team performance outcomes most commonly associated with each of these best practices.

2.6   Content Mapping

The information obtained through this TNA regarding critical LDEM teamwork training needs and the task, person, and organizational characteristics impacting them was systematically mapped to the information obtained regarding NASA's teamwork training curriculum and the best practices for teamwork training. Through this process, critical gaps in the teamwork training curriculum were identified along with several viable solutions for addressing these gaps.

3.0   Findings and Recommendations

3.1   Overview

The methods employed by this TNA resulted in the collection, analysis and interpretation of a significant amount of information pertinent to NASA's prior, current, and future teamwork training needs and efforts. Several types of information were gathered and utilized. These included:

I.   General information regarding the broad task, person, and organizational characteristics most critical in determining teamwork training needs within the NASA organization. A summary of these characteristics is provided in Table 2.

II.   Information regarding which teamwork-related competencies are most essential for LDEM crew success and require the most development throughout the LDEM training pipeline because they are not expected to be present at the time of hire. The teamwork-related competencies that were identified as being most critical and that are most in need of development through teamwork training are summarized in Table 3.

III.   Detailed information regarding several specific NASA courses and learning activities (prior, current, and future) geared toward developing teamwork competencies among astronauts and flight controllers. A summary of the most critical course/activity-specific information is provided in Table 4.

IV.   Information regarding empirically-supported strategies for effectively training teamwork competencies gathered from the relevant scientific literatures. A summary of the most relevant best practices extracted from the literature is provided in Table 5.

Upon extensive content review, mapping, and analysis of the information collected as part of the current TNA, several critical teamwork training needs and gaps were identified. These specific needs/gaps followed several broad themes, including needs/gaps related to the: 1) content of the teamwork training, 2) consistency of the teamwork training content, 3) methods used to develop teamwork competencies, 4) amount of teamwork training provided, 5) timing of teamwork training, 6) types of participants who receive teamwork training, and the 7) methodologies used to evaluate NASA's current teamwork training programs. Based upon the nature of these needs/gaps and upon information gathered regarding relevant task, person, and organizational characteristics as well as known information regarding best practices for teamwork training, several broad nonprescriptive recommendations for revising and augmenting NASA's teamwork training curriculum were formulated. These needs/gaps and general recommendations and the rationale for each are organized according to theme and presented below.

TABLE 2. SUMMARY OF KEY TASK, PERSON, AND ORGANIZATIONAL CHARACTERISTICS IMPACTING LDEM TEAMWORK TRAINING NEEDS

Task Characteristics	1. The amount and pace of team members' workload varies over the course of a mission, with team members experiencing long periods of relatively low workload (particularly flight crew members). 2. The level of team member interdependence required by tasks varies over the course of a mission, with teams experiencing long periods of low interdependence (particularly flight crew members). 3. Flight crew members must live and work together in isolated, confined, and extreme environments for extended periods of time.
Person Characteristics	1. Teams are composed of individuals with diverse cognitive, affective, and behavioral tendencies. 2. Teams are composed of individuals from multiple cultures. 3. Trainees have varying baseline levels of teamwork competencies and different baseline views of the nature of teamwork. 4. At least at the beginning of the training pipeline, trainees' typically possess a relatively low level of teamwork expertise. 5. Trainees typically show relatively high levels of interest and engagement in teamwork training courses/activities.
Organizational Characteristics	1. Individual team members work within both a team and a larger multi-team system (MTS). 2. The LDEM training pipeline is necessarily long and includes a large amount of content. 3. Throughout the training pipeline, the emphasis is placed on training technical content and formally evaluating, documenting, and making selection/placement decisions based on technical performance. There is a reluctance to require a large amount of teamwork training and to formally evaluate, document, and make selection/placement decisions based on teamwork performance. 4. There are several immutable factors (e.g., extensive technical training requirements, scheduling constraints), which significantly limit the amount of time team members can spend in teamwork training over the course of the training pipeline, particularly after they have been assigned to a mission (particularly flight crew members). 5. There are several immutable factors (e.g., distribution of team members across several nations, diversity of technical training requirements, travel and scheduling constraints), which significantly limit the amount of time team members can train together in-person as an intact team once assigned to a mission (particularly flight crew members).

Note. All information reported in this table represents the results of the investigators' content analysis and coding of information obtained through the collection of interview data.

TABLE 3. SUMMARY OF COMPETENCIES IDENTIFIED THROUGH LDEM ASTRONAUT JOB ANALYSIS

COMPETENCY	RELATIVE PROPORTION OF EXPLICIT TEAMWORK ELEMENTS	RELATIVE IMPORTANCE FOR LDEM	RELATIVE EXPECTATION OF PRESENCE AT HIRE
Adaptability	LOW	MODERATE	HIGH
Autonomous Worker	LOW	MODERATE	LOW
Communication	HIGH	MOD. LOW	HIGH
Confidence	LOW	MOD. LOW	HIGH
Emotional Independence	LOW	MOD. LOW	HIGH
Emotion Management	MODERATE	MOD. LOW	HIGH
Family Self-Sufficiency	LOW	VERY LOW	LOW
Judgment	MODERATE	MOD. HIGH	HIGH
Learner/Teacher	HIGH	MOD. LOW	LOW
Motivation	LOW	MODERATE	HIGH
Operations Orientation	LOW	MOD. LOW	LOW
Self-care	LOW	VERY HIGH	LOW
Situational Followership	HIGH	MOD. LOW	LOW
Situational Leadership	HIGH	MOD. LOW	LOW
Small Group Living	HIGH	VERY HIGH	LOW
Sociability	HIGH	MOD. LOW	HIGH
Teamwork	HIGH	MOD. HIGH	HIGH
Technical Inclination	LOW	MOD. HIGH	HIGH

Note. All information reported in this table represents the results of the investigators' content analysis and coding of information obtained through the collection of interview data.
MOD. = MODERATELY

TABLE 4. SUMMARY OF EXISTING TEAMWORK-RELATED TRAINING ACTIVITIES

ACTIVITY	TEAMWORK CONTENT	CONSISTENCY	METHODS	AMOUNT	TIMING	PARTICIPANTS	EVALUATION
Stress Management Course	No formal teamwork competency model or content is utilized although the content is discussed in the context of novel high-stress astronaut team situations. Emphasis is on general knowledge of astronaut role/job, associated stressors, expectations for behavior, and standards for conduct necessary for adapting to the role. Focus is on adaptation to novel high-stress situations.	No explicit ties to other teamwork-related training although similar concepts are introduced elsewhere, typically using different terminology/definitions Topics discussed across participants differ depending on what issues arise so content varies substantially with little explicit standardization. The instructors/instruction style remains consistent.	Classroom-based presentation and discussion with significant proportion of time spent on question and answer. Supported by BHP Operations in partnership with the NASA Astronaut Office.	1.5 hours.	ASCAN phase.	Only astronauts, typically all U.S. with only some international partners occasionally included (e.g., Japan, Canada).	Written reactions from participants are gathered and reviewed.
Conflict Management Course	No formal teamwork model is utilized but content includes knowledge and skills related to identifying sources of conflict and managing conflict in all domains of life (e.g., work, family), including some focus on team and multi-team system (MTS) conflict. Emphasis is on insight- and communication-based strategies. No standard conflict management model is utilized.	No explicit ties to other teamwork-related training although similar concepts are introduced elsewhere and concepts from other training (e.g., cross-cultural training) may arise through discussion, typically using different terminology/definitions. Topics discussed across participants differ only slightly depending on what issues arise so content varies somewhat although there is explicit standardization	Pre-reading assignments and classroom-based lecture and discussion with significant proportion of time spent on role-plays, debriefs, and case studies. Self-assessment, action-plan development, and post-training resources (written materials). Supported by BHP Operations in partnership with	1.5 hours.	ASCAN phase.	Only astronauts, typically all U.S. with only some international partners occasionally included.	Reactions from participants are gathered and reviewed.

Course	Content/Model	Ties to Other Training	Methods	Duration	Timing/Phase	Participants	Evaluation
	and the instructors/instruction style remains consistent.		the NASA Astronaut Office.				
Cross-Cultural Course	No formal teamwork model utilized, but focus is on general knowledge of cultural values, work, styles, and attitudes as they related to differences in teamwork styles. Content in 7 different cultures.	No explicit ties to other teamwork-related training although participants do go on to receive some cultural orientation when training in other countries and cross-cultural issues do tend to arise through discussion in other training (e.g., conflict management training). Topics discussed across participants differ slightly depending on what issues arise so content varies some although there is explicit standardization and the instructors/instruction style remains fairly consistent.	Classroom-based lecture and discussion with small proportion of time spent debriefing critical incidents. Supporting by BHP Operations and developed and led by a 3rd party vendor specializing in this subject matter.	2 days/17 hours.	ASCAN phase for astronauts. Varied timing for non-astronaut personnel.	Always homogeneous in terms of technical role (e.g., only ASCANs or only flight surgeons/support personnel, managers, science teams), typically all U.S. with only some international partners occasionally included.	Verbal and written reactions from participants are gathered and reviewed.
Spaceflight Resource Management (SFRM) Courses **(a) ASCAN version** **(b) Flight controller operator boot camp version**	The content varies based on version but generally includes knowledge and skills related to Spaceflight Resource Management competencies. Emphasis is placed on situation awareness, decision making, communication, teamwork, leadership/followership, team care, technical	No explicit ties to most other teamwork-related training although flight controller participants are provided with a placard with SFRM-related content on it during the flight controller certification training simulations and similar concepts are introduced elsewhere,	Methods vary across versions but include different combinations of classroom-based presentation, video demonstration/case studies, and discussion (2 ½ - 3hrs each), a practicum (3hrs), and 2 spaced practice and feedback activities	Amount varies across versions but may be up to 20-30 hours spread across several days over an 8-9 week period.	(a) ASCAN phase. (b) Operator certification phase (boot camp). (c) Specialist certification phase.	(a) Only astronauts, typically all U.S., ad-hoc teams. (b, c) Only flight controllers, all U.S., ad-hoc teams.	Written and verbal open-ended/qualitative reactions from participants are gathered and reviewed for each module. In the flight controller operator version participants are given a series of knowledge tests and in all versions instructors make qualitative ratings of individual

(c) Flight controller specialist version	conflict management, and cross-cultural issues competencies.	typically using different terminology/definitions. Across versions there is significant variation in both the content and methods. Within each version, topics discussed across participants differ depending on what issues arise so content varies some but there is substantial explicit standardization of the content and formal trainer training is provided to instructors so the instructors/instruction style remains fairly consistent.	(one at the beginning of the course and one at the end) involving low-fidelity Moon Base simulations (1hr each) along with team planning activities (2hrs each) and prebriefs (1/2hr each) and team/individual debriefs (1 ½ hrs each). Flight controller trainees also receive a placard with SFRM-related content on it during their certification training simulations. Developed and delivered by the Flight Operations Directorate (FOD).				participants' performance on teamwork-related competencies but that information is primarily used to provide participants with feedback, no formal rater training is provided to instructors, and the data is not collected or analyzed in a standardized fashion.
NOLS Courses **(a) Expedition outdoor team-building and supervised leadership course** **(b) Advanced expeditionary skills field training** (*course is not run regularly for ISS crews*	Knowledge and skills related to several different teamwork models, including NASA's Expeditionary/Crew Skills competency model, a group decision-making model adapted by NOLS (Tannenbaum & Schmidt, 1973), the Thomas-Kilmann conflict management model (Kilmann & Thomas, 1977), as well	Only has explicit ties to expeditionary training. Both training activities introduce concepts from the ECOS competency model. Similar concepts are introduced elsewhere. However, typically using different terminology/definitions. Topics discussed across participants and administrations differ depending on what issues arise during some training exercises	NOLS presentation which only includes technical content (1/2 day) plus multiple experiential day-long learning activities which include team/individual planning, practice, reflection, peer assessment, and debriefing/feedback and mentoring.	12 days/40 hours each. Astronauts complete the basic course once but the advanced course may be taken multiple times depending on the number of missions a participant is assigned to.	(a) ASCAN phase for astronauts and varied timing for Flight Directors. (b) Assigned phase for astronauts and varied timing for Flight Directors.	(a) Primarily astronauts with a single Flight Director often included, typically all U.S. but international partners have been included in the past, ad-hoc teams. (b) Primarily astronauts assigned to a mission with a single Flight	Written reactions from participants are gathered and reviewed. Formal qualitative ratings of individual participants' performance on teamwork-related competencies are made by instructors. Peer ratings are also made. All ratings are given to participants as performance feedback. Formal

but was for shuttle crews)	as others. Emphasis is placed on self-care, cross-cultural competence, communication, teamwork/collaboration, leadership, conflict, situational awareness, and decision-making/problem solving.	(i.e., competencies on which participants performed poorly are discussed most) so content varies with little explicit standardization. There is substantial standardization in the content of the exercises. Instructors receive trainer training but they do have discretion to utilize different models of teamwork when necessary so the instructors/instruction style may not remain consistent.		Flight Directors may take each course multiple times.		Director often included, typically all U.S. but international partners have been included in the past, intact teams.	rater training is not provided to instructors or peer raters and the data is not collected or analyzed in a standardized fashion.
Expeditionary /Crew Office Skills Training (*new course being piloted*)	Knowledge and skills related to NASA's Expeditionary/Crew Office Skills competency model. Emphasis is on communication, leadership/followership, self-care/self-management, team care, teamwork and group living.	Only has explicit ties to the NOLS course (version a) since they are run in conjunction. They both introduce concepts from the ECOS competency model. Similar concepts are introduced elsewhere, however, typically using different terminology/definitions. Topics discussed across participants differ depending on what issues arise during simulations/exercises so content varies some. Some explicit standardization of content exists but	A sequence of spaced experiential learning activities involving team simulations/exercises and team/individual debriefing/feedback and mentoring. Also includes NASA BHP prebriefings (1-4 hours each) and debriefings (2-4 hours each) surrounding these events (18 hours total). Briefings are associated with a geology trip (40 hours), an extended team simulation in a confined environment (Space Week; 4 days;	Nearly 200 hours spread over several days/weeks throughout the ASCAN training phase (including the time spent in the NOLS course, version a).	ASCAN phase.	Only astronauts, typically all U.S., ad-hoc teams.	Reactions from participants are gathered and reviewed.

	mentors used do not receive training so styles may differ.		e.g., HERA module), and the NOLS training course (version a; 40 hours).				
Other Analogue-Based Training (e.g., NEEMO/CAVES/Antarctic lunar habitat)	No formal teamwork competency model is typically utilized but training targets various teamwork-related competencies such as information exchange, situational awareness, team decision-making, supporting behavior, emotion management, self-care and small group living, as well as others.	No explicit ties to other teamwork-related training although similar concepts are introduced elsewhere, typically using different terminology/definitions. Training is not mandatory so receipt of the content is inconsistent across trainees. Further, the amount of teamwork content included varies across administrations. Content of the activities and topics discussed during pre/debriefs vary across participants depending on the nature of the exercises and what issues arise. There is some explicit standardization in the content of the activities, however. Although instructors may receive similar training the instructors/instruction style does not necessarily remain consistent.	Experiential learning activities involving practice in high-fidelity space analogues (e.g., isolated, confined, extreme environments; undersea, subterranean, Antarctic) and team prebriefs and debriefs (multiple days/weeks).	Not mandatory, opportunities to participate are limited. Amount varies since length of activities vary and trainees may participate multiple times, but activities each take place over several consecutive days/weeks.	Unassigned Phase for astronauts.	Participants vary based on analogue, ad-hoc teams.	Evaluation practices vary across activities and administrations depending on their content. No formal evaluation of teamwork training elements has been known to be regularly conducted although other evaluation efforts may be (e.g., evaluation of participants' technical skills).
Military Leadership Reactions Course	No formal teamwork competency model is known to be used but focus is placed on	No explicit ties to other teamwork-related training although similar concepts are introduced	Experiential learning activities involving team exercises/obstacles	Not mandatory, opportunities	Unassigned phase.	Primarily astronauts with a single Flight Director	No formal evaluation of teamwork training elements has been

	knowledge and skills related to various aspects of teamwork. Emphasis on leadership/followership, information exchange, communication delivery, team decision-making/problem solving, and supporting behavior.	elsewhere, typically using different terminology/definitions. Training is not mandatory so receipt of the content is inconsistent across trainees. The topics discussed during pre/debriefs vary across participants depending on what issues arise so content varies somewhat. There is explicit standardization in the content of the activities. However, although instructors may receive similar training the instructors/instruction style does not necessarily remain consistent.	and team prebriefs and debriefs. Developed and led by the U.S. Military.	to participate are limited. 3 days/ 1 week.		sometimes included, typically all U.S. However, some international partners may be included, ad-hoc teams.	known to be conducted by NASA.
Routine Operations/ Emergency Simulations	No formal teamwork competency model is utilized but training targets various teamwork-related skills such as information exchange, situational awareness, team decision-making, and supporting behavior.	No explicit ties to other teamwork-related training although similar concepts are introduced elsewhere, typically using different terminology/definitions. Content varies across participants depending on the nature of the simulations and what issues arise during pre/debriefs. There is some explicit standardization in the content of the	Practice and feedback activities involving high-fidelity simulations (e.g., in ISS mock-up) and team prebriefs and debriefs (full-day).	Several hours over 4-6 days spread across several months/years throughout the astronaut training pipeline.	Assigned phase for astronauts. Varied timing for flight controllers.	Sometimes only astronauts and sometimes a mix of astronauts and flight controllers/CAP COMs, U.S. and international partners, intact teams assigned to a mission (with CAPCOMs substituting for absent members).	No formal evaluation of teamwork training elements is conducted. Instructors make notes on participants' performance to use during debriefs but no formal rater training is provided to instructors and that data is not collected or analyzed in a standardized fashion.

	simulations, however. Although instructors all receive similar training the instructors/instruction style does not necessarily remain consistent.						
NASA Flight Controller Certification Training Simulations (mini-sims & integrated sims)	Knowledge and skills related to FCPC competencies with some content related to the SFRM content. Emphasis is placed on teamwork generally, as well as other teamwork-related competencies such as problem recognition and resolution, conflict management, communication.	No explicit ties to most other teamwork-related training although participants are provided with a placard with SFRM-related content on it and similar concepts are introduced elsewhere (including SFRM training), typically using different terminology/definitions. Content of the simulations and pre/debriefs varies across participants depending on what their strengths/weaknesses are and on what issues arise so there is little explicit standardization. Although instructors all receive similar training the instructors/instruction style does not necessarily remain consistent.	Series of practice and feedback activities involving high-fidelity mini- and integrated simulations along with team prebriefs and team/individual debriefs. Flight controllers also receive a placard with SFRM-related content.	Several days spread over several weeks. Amount varies across trainees based on the time and number of simulations it takes them to certify.	Operator and specialist certification phases for flight controllers. Varied timing for astronauts.	Typically only flight controllers although astronauts are sometimes included, typically all U.S. although some international partners have been included in the past (e.g., Japan), ad-hoc teams.	No formal evaluation of teamwork training elements is regularly conducted, although an evaluation study targeting a portion of the teamwork content has been conducted in the past. Formal quantitative ratings of individual participants are made by instructors using the FCPC which include global/broad teamwork elements. Some formal rater training is provided to instructors but ratings are still inconsistent. Ratings are used to provide feedback to participants and to track performance toward certification but the data is not analyzed in a standardized fashion.
T-38 High-Performance Jet Instrument	Knowledge and skills related to Crew Resource Management principles with a focus	No explicit ties to other teamwork-related training although many participants are	Classroom-based presentation and video case studies (1-2 hours) paired	4 hours per year.	Once annually throughout	Only astronauts/pilots, typically all	Verbal reactions from participants are gathered and reviewed and instructors make

Refresher Training	on particular areas of teamwork such as situational awareness, decision making, supporting behavior, information exchange, and communication delivery.	familiar with the content through previous pilot training, particularly training provided by the U.S. Navy. Content varies across participants depending on the nature of the exercises and what issues arise during pre/debriefs with little explicit standardization. Instructors participate in and observe the course several times but do not receive other formal trainer training so the instructors/instruction style may not remain consistent.	with simulations, real flight exercises, and team prebriefs and debriefs (1-2 hours).		training pipeline.	U.S., ad-hoc teams.	notes on participants' performance to use during debriefs but no formal rater training is provided to instructors and that data is not collected or analyzed in a standardized fashion.
Other Simulation-Based Technical Skills Training (e.g., EVA, Robotics)	No formal teamwork competency model is typically utilized but training targets various teamwork-related skills such as information exchange, situational awareness, team decision-making, and supporting behavior.	No explicit ties to other teamwork-related training although similar concepts are introduced elsewhere, typically using different terminology/definitions. Content varies across participants depending on the nature of the exercises and what issues arise during the pre/debriefs, although there is some explicit standardization in the nature of the exercises. Although instructors all possess similar	Series of practice and feedback activities involving high-fidelity simulations along with team/individual prebriefs and debriefs.	Varies depending on requirements but involves several hours each year.	Periodically (quarterly, biannually) throughout the training pipeline.	Participants vary depending on the type of training, may be ad-hoc or intact teams.	No formal evaluation of teamwork training elements is conducted. Instructors make formal ratings of participants' overall performance to use during debriefs but teamwork elements are not rated separately. No formal rater training is provided to instructors. Ratings are used to provide feedback to participants and to track technical competency but that

training the instructors/instruction style does not necessarily remain consistent.		data is not collected or analyzed in a standardized fashion.

Note. All information reported in this table represents the results of the investigators' content analysis and coding of information obtained through the collection of interview data and written/electronic training materials.

ASCAN = Astronaut Candidate (a period of approximately two years during which newly-hired astronauts undergo intensive soft and technical skills training until graduation to full Astronaut), BHP = Behavioral Health and Performance, CAPCOM = Capsule Communication, CAVES = Cooperative Adventure for Valuing and Exercising Human Behaviour and Performance Skills, ECOS = Expeditionary / Crew Office Skills, EVA = Extravehicular Activity, ISS = International Space Station, SFRM = Spaceflight Resource Management, FCPC = Flight Controller Performance Criteria, HERA = Human Exploration Research Analog, NASA = National Aeronautics and Space Administration, NOLS = National Outdoor Leadership School

TABLE 5. SUMMARY OF TEAMWORK TRAINING BEST PRACTICES

CATEGORY	BEST PRACTICE
Content	Utilize job analysis findings to determine teamwork training content so that trained content is linked to and will enhance team members' job performance (Baker, Salas, & Canon-Bowers, 1998; Brannick, Salas, & Prince, 1997; Burke, 2005; Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995b; Tannenbaum & Yukl, 1992).
	Target all action, transition, and interpersonal processes as well as emergent states that are critical for team performance so that training targets all competencies empirically-linked to and will enhance team performance outcomes (Cannon-Bowers et al., 1995b; Hollenbeck, DeRue, & Guzzo, 2004; Salas, DiazGranados, Klein et al., 2008; Smith-Jentsch, Salas, & Brannick, 2001).
	Target teamwork competencies that are applicable to a particular team/task as well as competencies that are transportable across several teams/tasks so that team members develop both the team/task-specific and the team/task-generic competencies necessary for optimal performance over time and across circumstances (Cannon-Bowers & Salas, 1997; Cannon-Bowers et al., 1995a; Smith-Jentsch, Zeisig, Acton, & McPherson, 1998)
	Target individual, team, and multi-team system (MTS) competencies so that training enhances performance outcomes at all relevant levels of analysis (DeChurch, 2003; Mathieu, Marks, & Zaccaro, 2001; Tesluk, Mathieu, Zaccaro, & Marks, 1997).
Consistency	Repeatedly and consistently utilize the same models of teamwork throughout training so that a coherent and strong mental model of teamwork is developed among trainees which guides individual performance (Salas, Burke, Bowers, & Wilson, 2001; Smith-Jentsch, Campbell, Milanovich, & Reynolds, 2001; Smith-Jentsch, Cannon-Bowers, Tannenbaum, & Salas, 2008; Smith-Jentsch, Mathieu, & Kraiger, 2005; Smith-Jentsch et al., 1998).
	Ensure that all team members are exposed to the same teamwork training content so that a consistent view of teamwork is shared by all trainees which guides team performance (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Smith-Jentsch et al., 2001; Smith-Jentsch et al., 2008).
Methods	Utilize evidence-based teamwork training methods whose effectiveness has been empirically-supported so that the probability of training effectiveness is maximized (Aguinis & Kraiger, 2009; Arthur, Bennett, Edens, & Bell, 2003; Salas, DiazGranados, Weaver, & King, 2008; Salas et al., 2012; Weaver, Dy, & Rosen, 2014).
	When possible, utilize a variety of teamwork training methods so that the probability of training effectiveness is maximized for all trainees, regardless of their individual learning styles/preferences, so that trainees' learning is enhanced through repeated and varied exposure to the training content, and so that trainees' ability to transfer the training content to novel situations is enhanced (Blickensderfer, Cannon-Bowers, & Salas, 1998; Fanning & Gaba, 2007; Salas & Cannon-Bowers, 1997; Salas, Cooke, & Rosen, 2008).
	Strategically match the teamwork training methods used to the task, person, and organizational characteristics as well as the competencies being trained/training needs so that the probability of training effectiveness and efficiency/utility is maximized (Brannick et al., 1997; Kozlowski, Gully, Nason, & Smith, 1999; LePine, Piccolo, Jackson, Mathieu, & Saul, 2008; Salas & Cannon-Bowers, 1997; Serfaty, Entin, & Jonson, 1998).

Amount	Make determinations about the amount of teamwork training required based on task, person, and organizational characteristics as well as nature and magnitude of the training needs so that all critical competencies are sufficiently developed, minimizing competency deficiencies (Delise, Allen Gorman, Brooks, Rentsch, & Steele-Johnson, 2010; Salas, DiazGranados, Klein et al., 2008; Salas, Tannenbaum, Kraiger, & Smith-Jentsch, 2012).
Timing	Provide intermittent opportunities for teamwork training, practice, and feedback so that the probability of trainee learning is maximized (Arthur, Day, Bennett, & Portrey, 2013; Harrison, Mohammed, McGrath, Florey, & Vanderstoep, 2003; Smith-Jentsch et al., 2015).
	Incorporate incremental increases in difficulty/complexity of the teamwork training content over time so that the probability of trainee learning is maximized (Stocker, Burmester, & Allen, 2014; Volpe, Cannon-Bowers, Salas, & Spector, 1996).
	Limit the amount of time that passes between teamwork training and on-the-job performance so that the probability of competency decay is minimized (Arthur et al., 2013; Mathieu, Tannenbaum, Donsbach, & Alliger, 2014).
Participants	Include all members of a team or multi-team system (MTS) in group teamwork training activities so that the same view of teamwork is shared by all team/MTS members and so that team/MTS members have opportunities to gain familiarity with one another and to develop team-specific competencies, all which serve to enhance team/MTS performance (Dierdorff & Ellington, 2012; Kozlowski, Grand, Baard, & Pearce, 2015; West et al., 2015).
	Increase trainee motivation to develop and utilize teamwork competencies (e.g., through adjustments to the organizational environment) so that the probability for training effectiveness is maximized via increased trainee engagement (Ellington & Dierdorff, 2013; Kjellin, Hedman, Escher, & Felländer-Tsai, 2014; Salas, 2015; Stocker et al., 2014).
Evaluation	Collect a variety of teamwork training evaluation data to include data regarding each meaningful training element and outcome, both quantitative and qualitative data, longitudinal data, and data from multiple sources, including objective sources when possible, so that maximally valid assessments of training effectiveness can be made based on a collection of relevant information regarding all critical training elements and outcomes (Cannon-Bowers, Salas, & Milham, 2003; LePine et al., 2008; Rosen, Schiebel, Salas, Wu, Silvestri, & King, 2012; Sierra & Smith-Jentsch, 2012a).
	When human raters are used to evaluate trainees/training outcomes, provide training to raters to maximize the extent to which their ratings are both valid and reliable so that accurate assessments of training effectiveness can be made based on the resulting data (Gorman & Rentsch, 2009).
	Utilize evaluation data to inform the design, development, and implementation of future training so that evidence-based improvements can be made to enhance the probability of training effectiveness (Cannon-Bowers et al., 2003; Salas et al., 2012).

3.2 Training Content

3.2.1 Training Needs/Gaps

Combined, the existing teamwork-related training activities in NASA's current teamwork training curriculum target a wide variety of teamwork knowledge, attitudes, and skills, including the majority of the teamwork-related competency elements recently identified through job analysis as being important for LDEM performance. Results of our interviews suggested, however, that the specific teamwork components being targeted in many of the teamwork-related training activities were loosely defined, unclear, or in a constant state of flux. Moreover, it was often unclear whether the targeted objectives were attitudinal, knowledge-based, or skill-based. With respect to both flight controller and astronaut simulation-based team training in particular, it was often unclear the degree to which "teamwork" competencies relative to "taskwork" competencies (e.g., technical skills) received emphasis. Finally, with respect to the astronaut curriculum specifically, our interviewees combined with the materials from several teamwork-related training activities revealed gaps related to the training of team- and task-generic knowledge, attitudes, and skills associated with living and working both autonomously and cooperatively within a small group of diverse individuals for extended periods of time while in an isolated, confined, and extreme environment. These elements of teamwork involve things such as being able to monitor and respond appropriately to one's own and others' emotions and behaviors (e.g., boredom, frustration) that may result from extended periods of reduced workload and low levels of interdependent work, rapid and unexpected shifts in workload/interdependence, and exposure to chronic life and work stressors unique to LDEM teams and tasks. In addition, this TNA revealed that, with respect to both the flight controller and the astronaut curricula, few training activities are dedicated to developing the team/MTS-specific competencies (i.e., competencies associated with a particular group of interdependent individuals/teams) that support team and MTS performance (e.g., cohesion, collective efficacy). Based on this, we have identified the following training needs/gaps.

> ***Need/Gap 1:*** *Astronaut trainees receive too few opportunities to develop the teamwork knowledge, attitudes, and skills necessary for monitoring and responding effectively to one's own and others' emotions and behaviors that will result from living and working both autonomously and cooperatively within a small diverse group over the course of an LDEM.*

> ***Need/Gap 2:*** *Both flight controller and astronaut trainees receive too few opportunities to develop the team/MTS-specific competencies necessary for team and MTS success during LDEMs.*

3.2.2 Training Recommendations

In order to ensure that NASA's astronaut and flight controller teamwork training curricula sufficiently develop all teamwork competencies identified as being important for individual, team, and MTS performance during LDEMs, it is critical that the specific objectives covered in each training activity are clearly spelled out and agreed upon by the stakeholders involved (i.e., developers, instructors, managers). Further, going forward, special emphasis should be placed on strengthening training that targets those competencies that are 1) expected to be most critical for performance and 2) not expected to be present prior to training (i.e., at the time of selection/hire). Results of the recent astronaut job analysis conducted by NASA (Barrett et al., 2015) suggest that, for future LDEMs, teamwork elements associated with the "small group living" competency meet these two criteria best, supporting our conclusion that the absence of small group living-specific training is a significant need/gap within the existing astronaut teamwork training curriculum. While it does not include a large number of explicit teamwork-related elements, another competency resulting from the job analysis that meets both criteria is the "self-care" competency. We believe that self-care will play a key role in implicitly supporting teamwork performance during LDEM, primarily because it will allow flight crew

members to maintain a sufficient level of emotional, cognitive, and behavioral independence/autonomy over time. This should result in team members placing fewer demands on their teammates which should, in turn, minimize unproductive negative interpersonal team and MTS processes and maximize the resources available for productive teamwork processes to occur (Sierra & Smith-Jentsch, 2012b). Moreover, findings from the scientific literature suggest that team/MTS-specific competencies such as team cohesion, collective efficacy, and shared knowledge about teammates' unique characteristics and expertise are significant predictors of effective team and MTS performance (e.g., Mathieu, Kukenberger, D'Innocenzo, & Reilly, 2015; Smith-Jentsch, Kraiger, Cannon-Bowers, & Salas, 2009; Stajkovic, Lee, & Nyberg, 2009). As such, a scarcity of training that targets these team/MTS-specific competencies among both flight controllers and astronauts is likely to result in suboptimal team and MTS performance over the course of future LDEMs. Considering all of this, we offer the following recommendations:

> ***Recommendation 1:*** *Incorporate more training into NASA's astronaut teamwork training curriculum that specifically targets teamwork knowledge, attitudes, and skills related to small group living and self-care over extended periods of time in isolated, confined, and extreme environments.*

> ***Recommendation 2:*** *Incorporate more training into NASA's astronaut and flight controller teamwork training curricula that specifically targets team- and MTS-specific competencies.*

3.3   Training Consistency

3.3.1   Training Needs/Gaps

This TNA revealed that the teamwork terminology and definitions introduced to both astronaut and flight controller trainees are currently quite variable both across and within NASA's existing teamwork training activities. The majority of these differences do not appear to be intentional. Rather, it appears that, in most cases, explicit efforts were not made to ensure consistency. In fact, most of our interviewees reported that differences likely existed but were unsure as to the specific nature of those differences. In addition to this, our TNA revealed that the availability of some of the non-mandatory teamwork-related training activities within NASA's teamwork training curriculum is inconsistent across team/MTS members, for both astronaut and flight controller trainees. Thus, the following training needs/gaps were identified:

> ***Need/Gap 3****: NASA's astronaut and flight controller teamwork-related training activities tend not to be explicitly linked to one another so, across activities, a) the teamwork concepts introduced often differ and b) the specific terminology and definitions used to introduce the same teamwork concepts often vary.*

> ***Need/Gap 4****: The availability and content of each specific astronaut and flight controller teamwork-related training activity within NASA's teamwork curriculum tends to vary across team/MTS members so they are unlikely to receive teamwork training that is equivalent.*

3.3.2   Training Recommendations

Inconsistencies with respect to the manner in which teamwork concepts are labeled and defined within the NASA teamwork training curriculum may be confusing to individual astronaut and flight controller trainees as they participate in teamwork training over the course of their careers. This may be particularly true when the same terms are used to mean different things or when different terms are used to label what appears to be largely the same concept. For example, there are two teamwork-oriented models: Spaceflight Resource Management (SFRM) model and the Expeditionary/Crew Office Skills (ECOS) model. The SFRM model targets teamwork behaviors while performing a team

task, while the ECOS model targets teamwork during task performance as well as living together as a team. Both models incorporate elements of leadership/followership and communication among other teamwork factors, but the specific behaviors have nuanced differences and do not absolutely overlap. Validation and mapping of the two models to enhance consistency across the models is warranted.

Conversely, when trainees are exposed to a consistent set of teamwork concepts over time, this reinforces their knowledge and skills and fosters a sense of familiarity and confidence with the material (Smith-Jentsch et al., 2001). Further, consistency in the introduction of teamwork-related terms and definitions across team/MTS members throughout the training pipeline will help astronaut and flight controller team/MTS members who have never trained or worked together before to communicate effectively with one another and to build a sense of collective efficacy more quickly (Smith-Jentsch et al., 2008). Moreover, consistency across different technical roles/functions and space agencies should also facilitate the effectiveness and efficiency of large-scale MTS training and performance activities within NASA's teamwork training curriculum (Smith-Jentsch et al., 2001). Considering this, we offer the following recommendations:

> ***Recommendation 3:*** *Ensure that all astronaut and flight controller team/MTS members are provided with opportunities to participate in the same or maximally equivalent teamwork-related training activities.*

> ***Recommendation 4:*** *Select and employ a single high-level teamwork competency model across a) all NASA astronaut and flight controller teamwork-related training activities and b) all astronaut and flight controller team/MTS members.*

> ***Recommendation 5:*** *When discussing a particular teamwork concept in either NASA astronaut or flight controller training, refer to a) previous teamwork-related training activities that addressed the same concept and b) future teamwork-related training activities that will address the same concept.*

> ***Recommendation 6:*** *When NASA's astronaut and flight controller teamwork-related training activities are intended to address only a subset of the competencies in the overall model, make this explicit to trainees.*

3.4   Training Methods

3.4.1   Training Needs/Gaps

This TNA revealed that NASA's astronaut and flight controller teamwork-related training currently takes place largely in the context of simulation-based training activities which involve a series of practice scenarios preceded by planning and prebrief sessions and followed by team/individual debrief and feedback sessions. The existing curriculum also includes a small number of classroom-based courses (e.g., conflict management training, cross- cultural training, SFRM modules) which primarily employ a combination of presentation/lecture, discussion, and case study methods, with a relatively small amount of time spent on practice/role play and a with relatively few transportable training materials (e.g., job aids/training guides). In addition, the curriculum includes a small number of experiential analogue-based training activities (e.g., NOLS courses, Space Week) which also include practice scenarios flanked by planning/prebrief and feedback/debrief sessions. Finally, primarily in conjunction with the simulation- and analogue-based training, trainees are presented with very few opportunities to receive activity-specific mentoring and coaching from senior personnel. Currently, there appears to be little or no use of online training methods to develop either astronauts or flight controller trainees' teamwork competencies within NASA. Thus, we have identified the following training need/gap:

> ***Need/Gap 5:*** *Online training methods are currently underutilized within NASA in the development of astronaut and flight controller trainees' teamwork competencies.*

3.4.2 Training Recommendations

Use of online training methodologies prior to, during, and between in-person teamwork training activities and LDEMs has the potential to yield a number of benefits. First, supplemental online training may serve to strengthen the effectiveness and efficiency of simulation-based, analogue, and classroom-based training. Specifically, online instruction can be used to enable team members to become familiar with teamwork concepts and with one another prior to a simulation, analogue, or classroom-based learning experience so they will be able to make the most of that experience. Practice and feedback could even be incorporated by presenting case studies online followed by opportunities for team members to discuss those cases in an electronic format.

Use of online training may also be an effective and efficient way to help prevent or slow the decay of teamwork-related competencies over time when the use of in-person teamwork training is not possible due to time/scheduling limitations. Online training can be an effective method of refreshing and even boosting knowledge, skills, and attitudes gained in previously completed training during the long period's in-between in-person training activities prior to a mission as well as during missions. Online training may also be useful in facilitating the adaptive transfer of trained teamwork competencies. Specifically, self-paced online instruction could be used to facilitate adaptive transfer by allowing individuals to reflect on lessons learned in the context of a current mission. Such training could incorporate guided reflection, goal setting, and even electronic communication with an instructor or with fellow trainees to discuss impediments to transfer. When applied to specific performance challenges, it can serve as an effective and efficient method of just-in-time training.

Finally, incorporation of online training into the teamwork training curriculum would provide additional opportunities for team/MTS members to participate in training together even during periods when they are not co-located. Online instruction is a particularly effective and efficient way of transmitting consistent standardized knowledge about teamwork concepts to trainees who are physically distributed and even multi-cultural (Smith-Jentsch et al., 2001). As such, we offer the following recommendation:

> **Recommendation 7:** *Incorporate the use of online training methods into NASA's astronaut and flight controller teamwork training curricula to a) prepare individuals to participate in in-person training activities, b) provide "just-in-time" and "booster/refresher" in between in-person training activities and during missions, and to c) provide opportunities for team/MTS members to train together remotely.*

3.5   Amount of Training

3.5.1   Training Needs/Gaps

Working in concert, the teamwork-related training activities within NASA's astronaut and flight controller teamwork training curricula do appear to address a significant portion of LDEM teamwork training needs. Certain training activities, however, are provided in very small amounts and with some degree of inconsistency, making the amount received by some insufficient. For example, while astronaut trainees are provided with classroom-based instruction targeting several important teamwork-related concepts (e.g., stress management, conflict management, cross-cultural issues) during the astronaut candidate (ASCAN) training phase, many of these classroom-based training activities are of very short duration (e.g., 1.5 hours) so trainees do not have sufficient time to practice and receive performance feedback on the teamwork competencies targeted by those activities. It is also the case that both astronaut and flight controller trainees tend to receive very few transportable teamwork training materials (e.g., job aids, training guides) for later reference and use within the context of other training activities and/or missions. In addition, although mentoring/coaching is provided to both astronaut and flight controller trainees some extent, trainees still do not receive very much throughout the training pipeline. Moreover, many astronaut and flight controller trainees receive

few opportunities to participate in moderate-length simulation- and analogue-based training most suitable for developing critical teamwork competencies including knowledge, attitudes, and skills associated with small group living and self-care (most critical for LDEM astronaut trainees), and various team/MTS-specific competencies (critical for both LDEM astronaut and flight controller trainees). This is partly due to the fact that only some trainees are provided with opportunities to participate in a number of the existing simulation and analogue-based training activities (e.g., NEEMO/CAVES/Antarctic Lunar Habitat). As such, we have identified the following training needs/gaps:

> ***Need/Gap 6:*** *Too little time is provided to astronaut trainees in NASA's teamwork-related classroom-based training to practice and receive performance feedback on the teamwork competencies they receive instruction on.*

> ***Need/Gap 7:*** *NASA astronaut and flight controller trainees are provided with too few transportable teamwork-related training materials (e.g., job aids, training guides) to refer to and use in the context of other training activities and/or missions.*

> ***Need/Gap 8:*** *Too few opportunities to receive mentoring and/or coaching are provided to astronaut and flight controller trainees throughout NASA's teamwork training pipeline.*

> ***Need/Gap 9:*** *Most NASA astronaut and flight controller trainees receive too few opportunities to participate in moderate-length simulations most suitable for developing critical teamwork knowledge, attitudes and skills associated with small group living and self-care (most critical for astronauts), as well as team/MTS specific competencies (critical for both astronauts and flight controllers).*

3.5.2   Training Recommendations

Providing all astronaut and flight controller trainees with a sufficient amount of teamwork training is critical for ensuring effective individual, team, and MTS performance over the course of future LDEMs. There are several ways in which an adequate amount of training can be consistently supplied to both training groups. These include extending the duration of existing training activities, ensuring that all trainees are provided with opportunities to participate in training activities that are currently non-mandatory, leveraging existing technical training and on-the-job performance periods (e.g., time during missions) to a greater degree by incorporating additional teamwork-specific content (in the form of transportable teamwork-specific training materials that trainees are instructed to utilize during technical training activities and throughout missions), and incorporating additional teamwork-specific training activities into the existing curriculum. When contemplating such curriculum augmentation, is particularly important to consider both the feasibility and the potential return-on-investment of each possible addition. This TNA revealed that several specific augmentations to NASA's existing astronaut and flight controller teamwork training curricula are likely to be both feasible and efficient. Specifically, by providing astronaut trainees with more time to practice and receive performance feedback on teamwork competencies during existing teamwork-related training activities, enhanced learning and transfer outcomes are likely to result (Smith-Jentsch, Salas, & Baker, 1996). According to interviewees, adding such practice and feedback may only require extending a couple of the existing activities by as little as 30 minutes, suggesting that this could be a high return-on-investment augmentation. Further, providing both astronaut and flight controller trainees with transportable teamwork training tools such as job aids and debriefing guides (Smith-Jentsch et al., 1998) to use in the context of their regular technical training and on-the-job performance (e.g., during missions) would require little time and few resources, yet such an augmentation also has the potential to significantly enhance training outcomes by significantly increasing the amount of teamwork-related training trainees receive. In addition, mentoring and coaching can be useful in addressing the teamwork training needs of individual astronaut and flight controller trainees that cannot be addressed

through other training activities and this can typically be accomplished with little time commitment from both trainees and mentors and on a schedule that suits each of the participants. Finally, moderate-length simulations can target critical teamwork competencies among both astronaut and flight controller trainees that cannot be targeted elsewhere and, because they are relatively brief, they are likely still feasible despite the scheduling constraints persistent throughout the training pipeline. Based on this, we offer the following recommendations:

> ***Recommendation 8:*** *Extend NASA's existing classroom-based teamwork-related courses for astronauts to allow additional time for practice and feedback.*

> ***Recommendation 9:*** *Incorporate more teamwork-specific training content into NASA' astronaut and flight controller trainees' technical training and on-the-job performance periods through the use of training guides and job aids.*

> ***Recommendation 10:*** *Provide more mentoring and/or coaching to NASA astronaut and flight controller trainees throughout the training pipeline to provide regular and frequent learning and development opportunities tailored to their individual needs.*
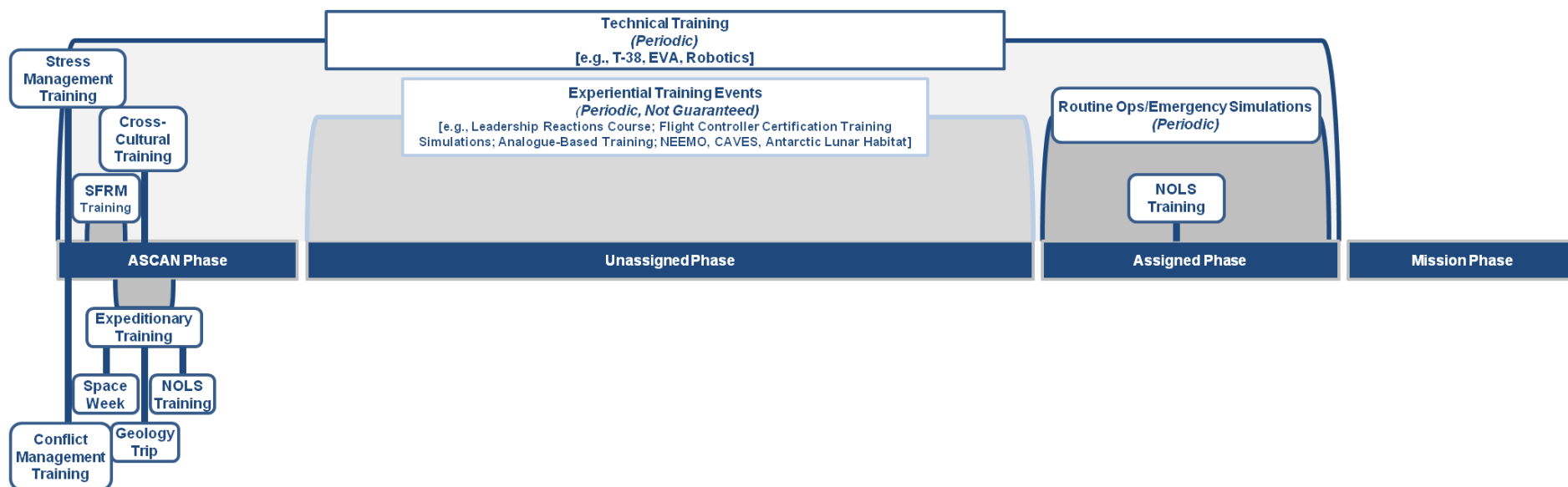
> ***Recommendation 11:*** *Provide more regular opportunities for NASA astronaut and flight controller trainees to participate in moderate-length (e.g., 3-7 days) simulation- and/or analogue- based training most suitable for developing critical teamwork knowledge, attitudes and skills associated with small group living and self-care (most critical for astronauts), as well as team/MTS specific competencies (critical for both astronauts and flight controllers).*

3.6   Timing of Training

3.6.1   Training Needs/Gaps

The current TNA revealed that NASA's existing astronaut teamwork training pipeline is heavily front-loaded. Specifically, astronaut trainees receive substantial portion of their teamwork training within the first year after beginning training as an ASCAN. Primarily due to time and workload limitations and scheduling constraints, many astronaut trainees receive very little teamwork training during the unassigned phase of the training pipeline (i.e., times when they are not assigned to a specific mission) would could last as long as 5-10 years. This is in part due to the fact that the available teamwork training opportunities (e.g., analogue-based training opportunities such as NEEMO/CAVES) are not provided to all trainees. Although the amount of guaranteed teamwork training increases slightly once astronaut trainees are assigned to a mission, a relatively little amount of teamwork training is provided during the assigned phase of the training pipeline (i.e., times when astronauts are assigned to a specific mission but still in training) as well. In addition, it appears that no formal teamwork training is currently being provided to astronauts during the mission phase of the pipeline. To illustrate the relative timing of the teamwork-related training activities within the current astronaut teamwork training curriculum, a graphical depiction of the existing astronaut teamwork training pipeline is provided in Figure 1. Upon examination of the information collected through this TNA the following training need/gap was identified:

> ***Need/Gap 10:*** *NASA's astronaut teamwork-related training activities are not strategically timed/spaced to maximize training effectiveness, in terms of a) promoting the development of more advanced competencies overtime, b) minimizing competency decay, and c) promoting transfer of training.*

Technical Training
(Periodic)
[e.g., T-38, EVA, Robotics]

Stress
Management
Training

Cross-
Cultural
Training

SFRM
Training

Experiential Training Events
(Periodic, Not Guaranteed)
[e.g., Leadership Reactions Course; Flight Controller Certification Training
Simulations; Analogue-Based Training; NEEMO, CAVES, Antarctic Lunar Habitat]

Routine Ops/Emergency Simulations
(Periodic)

NOLS
Training

ASCAN Phase

Unassigned Phase

Assigned Phase

Mission Phase

Expeditionary
Training

Space
Week

NOLS
Training

Conflict
Management
Training

Geology
Trip

Note. Astronauts may cycle through the unassigned, assigned, and mission phases multiple times over the course of their tenure, depending on how many missions they are assigned to.

Figure 1. Existing Astronaut Teamwork Training Pipeline
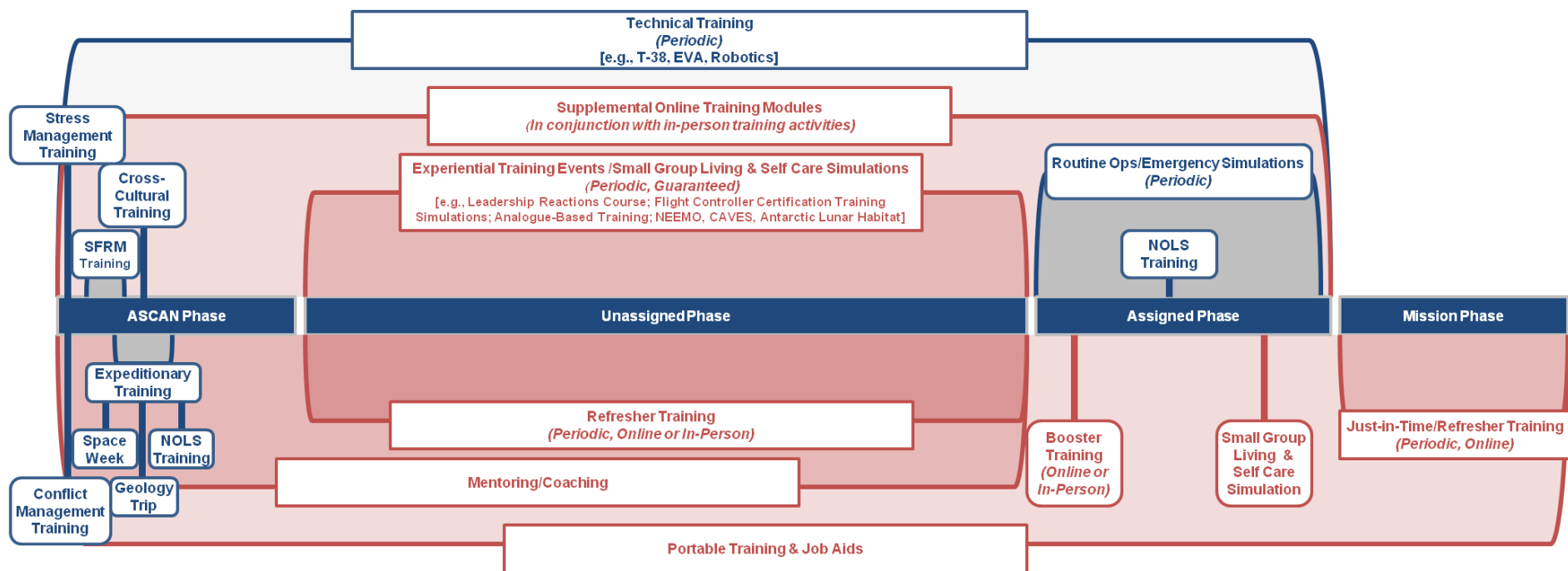
3.6.2 Training Recommendations

In order to promote the development of advanced teamwork knowledge, attitudes, and skills, to minimize the amount and rate of teamwork competency decay amongst astronaut trainees overtime, and to promote training transfer, it is important to strategically align the timing of NASA's teamwork-related training activities with those goals. In particular, it is important that astronaut trainees are provided with regular and frequent teamwork training opportunities throughout the training pipeline and that those activities build upon one another sequentially (i.e., moving from basic to advanced content/methods). Regular cycles of increasingly advanced instruction, practice, assessment, and feedback are ideal for promoting competency development and transfer among astronaut trainees. It is also of critical importance that astronaut trainees do not experienced extended periods of time without receiving any teamwork training. In periods when the provision of regular extensive teamwork training is not possible (e.g., during an LDEM), astronaut trainees should be provided with some form of refresher training to prevent significant competency decay. In times immediately preceding performance episodes with high teamwork demands, astronaut trainees should also be provided with booster training to ensure that sufficient levels of critical teamwork competencies are restored. Finally, in times when astronaut trainees encounter a specific teamwork performance-related challenge, providing them with just-in-time training should be employed to assist them in transferring what they learned in training while on the job. One way to ensure that astronaut teamwork training is delivered regularly, frequently, at the proper time, and in proper sequence is to utilize a variety of on-demand training methodologies in conjunction with existing in-person training activities. Given the significant time/schedule constraints astronaut trainees encounter throughout the training pipeline, the most suitable methods would likely involves the use of mentoring/coaching, online training, and job aids/training guides. Considering all of this, we offer the following recommendations (a graphical depiction of a potential augmented astronaut teamwork training pipeline is provided in Figure 2).

> **Recommendation 12:** *Provide teamwork training to astronauts in regular frequent intervals throughout NASA's astronaut training pipeline with opportunities for instruction, practice, assessment, and feedback in-between.*

> **Recommendation 13:** *Strategically sequence NASA astronaut teamwork-related training activities to move from basic to more advanced content and methods.*

> **Recommendation 14:** *Provide booster/refresher and just-in-time teamwork training tools/activities to astronauts as needed throughout NASA's astronaut training pipeline.*

> **Recommendation 15:** *Provide more teamwork training to astronauts during the "unassigned" and "mission" phases of NASA's astronaut training pipeline.*

Figure 2. Potential Augmented Astronaut Teamwork Training Pipeline

The figure shows the astronaut teamwork training pipeline across four phases: ASCAN Phase, Unassigned Phase, Assigned Phase, and Mission Phase.

Technical Training
(Periodic)
[e.g., T-38, EVA, Robotics]

Supplemental Online Training Modules
(In conjunction with in-person training activities)

Experiential Training Events /Small Group Living & Self Care Simulations
(Periodic, Guaranteed)
[e.g., Leadership Reactions Course; Flight Controller Certification Training Simulations; Analogue-Based Training; NEEMO, CAVES, Antarctic Lunar Habitat]

Routine Ops/Emergency Simulations
(Periodic)

Stress Management Training

Cross-Cultural Training

SFRM Training

NOLS Training

ASCAN Phase | Unassigned Phase | Assigned Phase | Mission Phase

Expeditionary Training

Space Week

NOLS Training

Conflict Management Training

Geology Trip

Refresher Training
(Periodic, Online or In-Person)

Booster Training
(Online or In-Person)

Small Group Living & Self Care Simulation

Just-in-Time/Refresher Training
(Periodic, Online)

Mentoring/Coaching

Portable Training & Job Aids

Note. Potential augmentations to the existing astronaut teamwork training pipeline are noted in shades of red. Astronauts may cycle through the unassigned, assigned, and mission phases multiple times over the course of their tenure, depending on how many missions they are assigned to.

Figure 2. Potential Augmented Astronaut Teamwork Training Pipeline

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3.7　Training Participants

3.7.1　Training Needs/Gaps

The current TNA revealed that astronauts and flight controllers who are likely to end up contributing to the same future mission together as team/MTS members have very few opportunities within NASA to train together prior to that mission. It is more common that astronauts and flight controllers taking part in any one of NASA's teamwork-related training activities have no future together as teammates or as members of the same MTS. In addition, and related to this, there are seldom opportunities within NASA for astronauts/cosmonauts and flight controllers from each of the different international partner space agencies to receive team-related training together. In those situations where participants in NASA's teamwork-related training activities are multinational and in intact teams, the focus is typically on technical training rather than on specific teamwork or cross-cultural concepts (e.g., routine operations and emergency simulations). Finally, our interviews also revealed that NASA's existing teamwork-related training activities tend not to mix participants from different technical roles/functions (i.e., astronauts and flight controllers), although there are a few sporadic exceptions. This resulted in the identification of the following training needs/gaps:

> *Need/Gap 11: Few NASA teamwork-related training activities allow for astronaut/flight controller team members to participate in targeted teamwork training as an intact team, limiting learning opportunities regarding individual differences impacting teamwork.*

> *Need/Gap 12: Few NASA teamwork-related training activities include participation by astronaut/flight controller trainees from both the U.S. and international partner agencies, limiting learning opportunities regarding cross-cultural factors impacting teamwork.*

> *Need/Gap 13: Few NASA teamwork-related training activities allow for astronaut/flight controller trainees to participate in targeted teamwork training with members of different units within the MTS, limiting learning opportunities regarding interdependencies across different technical roles/functions.*

3.7.2　Training Recommendations

Developing team-specific competencies such as team cohesion, collective efficacy, and shared knowledge about teammates' unique characteristics and expertise is critical for effective team performance (Mathieu et al., 2015; Smith-Jentsch et al., 2009 Stajkovic et al., 2009). Training for such competencies requires that members of an intact work team or crew participate in a substantial amount of training together. Thus, LDEM astronaut and flight controller teams would likely benefit from being provided with increased opportunities to do so. In addition to being supported by the scientific literature, this opinion was expressed by several of the individuals interviewed as part of this TNA. Multi-cultural differences in expectations regarding team coordination and team leadership/followership have also been noted as important factors influencing team performance (Scott & Wildman, 2015). Therefore, it is critical for team members to be provided with opportunities to foster awareness of and to work toward limiting these differences. For this reason, LDEM astronaut/cosmonaut and flight controller team members from the U.S. and international partner agencies would likely benefit from being provided with increased opportunities to participate in teamwork-related training together. Several of the individuals interviewed as part of this TNA concurred with this conclusion. Finally, shared knowledge of interdependencies between units in an MTS has been found to be linked to performance in prior research (Smith-Jentsch et al., 2005). Trainees can gain perspective about such interdependencies by observing and engaging in targeted discussions with others who hold key roles within their MTS. As such, an increase in NASA's teamwork-related training activities that involve a mix of astronaut and flight controller trainees from different technical roles/functions and organizational units within the LDEM MTS would be beneficial

in helping to enhance several key predictors of team/MTS performance, including members' inter-positional knowledge. Thus, we offer the following recommendations:

>***Recommendation 16:*** *Increase the number of NASA-provided opportunities for astronaut/flight controller team members to participate in teamwork-related training together as an intact team.*

>***Recommendation 17:*** *Increase the number of NASA-provided opportunities for teamwork-related training that includes both astronaut/flight controller trainees from the U.S. and from international partner agencies*

>***Recommendation 18:*** *Increase the number of NASA-provided opportunities for teamwork-related training that includes astronaut/flight controller trainees from different technical roles/functions and units within an MTS.*

3.8   Training Evaluation

3.8.1   Training Needs/Gaps

This TNA revealed that NASA's teamwork-related training activities are typically evaluated via the collection and review of qualitative data regarding astronaut and flight controller trainees' immediate subjective reactions to the training content and methods. This evaluation data does not appear to be collected, stored, analyzed, or utilized in a standardized fashion. This limits the extent to which it can be made useful in contributing to efforts dedicated to monitoring training effectiveness over time and making improvements to NASA's teamwork training curriculum. Although not currently being used to evaluate the effectiveness of NASA's teamwork-related training activities, astronaut and flight controller trainees' mastery of teamwork concepts is often assessed as part of the training process. Mastery of teamwork concepts is not typically assessed using quantitative metrics at NASA. Instead, NASA's trainee assessments typically involve qualitative observations made by instructors and/or peers regarding astronaut and flight controller trainees' strengths and weaknesses. Qualitative feedback is then provided to trainees in narrative form based on these assessments. Quantitative ratings of teamwork competencies are made in some of NASA's astronaut- and flight controller-focused simulation-based training. However, these ratings tend to be global rather than multi-dimensional in nature (e.g., "teamwork" category within Flight Controller Performance Criteria). In these cases, ratings are provided by a single rater only, which does not allow for estimates to be calculated regarding the reliability of those assessments. Further, across the astronaut and flight controller teamwork-related training activities which incorporate an assessment of trainees' mastery, raters are not typically provided with any form of rater training in order to ensure the reliability and validity of those ratings. Thus, as a result of this TNA, the following training needs/gaps were identified:

>***Need/Gap 14:*** *Current NASA astronaut and flight controller teamwork-related training evaluation methodologies do not regularly include the use of a) quantitative measures, b) objective measures, c) longitudinal data collection, d) multi-source data, or e) assessments of outcomes other than trainee reactions, such as assessments of the specific team-related knowledge, attitudes, and skills targeted by training.*

>***Need/Gap 15:*** *Trainee performance assessments conducted by instructors and peers as part of NASA's astronaut and flight controller teamwork-related training activities are not regularly utilized to evaluate training effectiveness.*

>***Need/Gap 16:*** *Instructors and peers who assess trainee performance as part of NASA's astronaut and flight controller teamwork-related training activities are not typically provided with rater training.*

Need/Gap 17: *Currently, NASA astronaut and flight controller teamwork-related training evaluation data is not collected, stored, analyzed, and/or utilized in a standardized manner.*

3.8.2 Training Recommendations

Several factors can impact the effectiveness of training and, in turn, training can have an impact on several outcomes. As such, NASA's teamwork-related training evaluation efforts should involve the collection of diverse data. This includes qualitative and quantitative data, objective and subjective data, data from multiple sources, and data regarding training reactions, learning, behaviors, results in both the short- and the long-term. In addition to ensuring high diversity of the data, it is also important for NASA to ensure high data quality (e.g. reliability and validity). Among other things, this involves providing any human raters with the necessary rater training and using multiple raters in order to monitor and ensure the reliability of the ratings. Finally, it is also important to systematically collect, store, analyze, and utilize data resulting from all of NASA's teamwork-related training evaluation efforts so that it can inform the monitoring and improvement of NASA's astronaut and flight controller teamwork training curricula overtime. With regard to astronaut and flight controller teamwork skills specifically, it is particularly important for NASA to collect, store, and analyze quantitative data regarding trainees' mastery of teamwork competencies upon the conclusion of training, and also ideally prior to the start of training and periodically after they have completed training so that their mastery can be monitored and potentially targeted for intervention over time. Normative data with respect to astronaut and flight controller trainees' mastery in teamwork competencies can also be used to provide individuals with feedback and to inform decisions regarding placement on teams and promotion to leadership roles.

It is important to note that many factors can change the effectiveness of a teamwork-related training activity over time. Such changes include but are not limited to characteristics of the instructors providing training, differences in the pre-training experience levels and technical mastery held by trainees, differences in the tasks performed by training following training, and differences in organizational reward systems (e.g., certification criteria). A central repository of astronaut and flight controller teamwork-related training evaluation data can also be a valuable tool for monitoring and detecting changes in training effectiveness resulting from these factors. As a result of knowledge gained through this TNA, we offer the following recommendations related to teamwork-related training evaluation:

> ***Recommendation 19:*** *Incorporate the use of measures which assess training outcomes beyond trainee reactions (i.e., learning, behavior, results) into NASA's astronaut and flight controller teamwork-related training evaluation methodologies.*

> ***Recommendation 20:*** *Incorporate the use of objective measures of targeted training outcomes into NASA's astronaut and flight controller teamwork-related training evaluation methodologies.*

> ***Recommendation 21:*** *Incorporate longitudinal designs into NASA's astronaut and flight controller teamwork-related training evaluation methodologies to a) track trainees' change on teamwork competencies over the course of their careers and to b) track changes in training effectiveness over time.*

> ***Recommendation 22:*** *Incorporate the use of valid and reliable quantitative ratings of trainees' teamwork competencies into NASA's astronaut and flight controller teamwork-related training evaluation methodologies by a) providing standardized rater training to those responsible for assessing trainees' teamwork competencies and b) utilizing multiple raters when assessing trainees' teamwork competencies so that the reliability of those ratings can be assessed.*

Recommendation 23: *Consistently store and utilize NASA astronaut and flight controller teamwork-related training evaluation data in a central repository so that the data can be readily accessed and used to assess trends and norms related to trainees' mastery levels and the impact of curriculum changes over time.*

4.0   Conclusion

4.1   Summary of Findings

The current TNA was conducted for the purpose of enhancing NASA's teamwork training curriculum in order to facilitate the development of LDEM astronaut and flight controller team members' teamwork competencies and to, ultimately, enhance the probability of future LDEM success. A number of complementary investigative methods were employed through the completion of this TNA which resulted in the discovery of several key findings capable of informing NASA's current and future teamwork training efforts. Specifically, 17 critical needs and gaps pertaining to the agency's current and future teamwork training curriculum were identified. These needs/gaps clustered into 7 broad categories, including needs/gaps related to the: 1) content of the teamwork training, 2) consistency of the teamwork training content, 3) methods used to develop teamwork competencies, 4) amount of teamwork training provided, 5) timing of teamwork training, 6) types of participants who receive teamwork training, and the 7) methodologies used to evaluate NASA's current teamwork training programs.

Overall, findings from this TNA reveal that, although several efforts to enhance the teamwork competencies of astronauts and flight controllers are currently underway and purportedly successful, there are several ways in which the NASA teamwork training curriculum could be enhanced to achieve an even greater probability of future LDEM success. The TNA results suggest that such enhancements should involve the targeting of additional mission-critical competencies and the incorporation of a number of additional teamwork training best practices from the relevant scientific literatures. These suggested enhancements form the basis for the 23 teamwork training recommendations derived from the findings of this TNA.

4.2   Future Directions

It is important to note that the purpose of this TNA was to produce broad, nonprescriptive recommendations for developing NASA's LDEM teamwork training curriculum in the form several general guidelines. It is beyond the scope of this investigation to provide specific proposals regarding precisely how to implement each of these recommendations within the context of preparing for future LDEMs, however. This is the case for several interrelated reasons.

Specifically, the development of recommendations regarding exactly when and how much (for example) of a particular type of teamwork training must be provided to NASA LDEM team trainees in order to enhance the likelihood of mission success would require a significant amount of empirical research, not permitted by the scope of the current TNA. This research would likely need to include a series of controlled experimental studies designed to accurately estimate which training content, timelines, methods, and amounts are most likely to yield the desired LDEM team performance results. Although an effort should be made to conduct additional research of this kind, it must be recognized that the initiation of such a research stream is likely to be challenging given that there are still several critical uncertainties surrounding future LDEMs; with regard to the LDEM training pipeline, the trainees, the future of the NASA organization, and to the missions themselves. These uncertainties are currently in the position to hinder the design and success of rigorous empirical studies, as well as the accurate formulation of specific recommendations. Further, it is important to note that all of the information collected through this TNA represents the current state of the NASA organization, the existing knowledge regarding future LDEM teams, their tasks, their competency needs, and of NASA's teamwork training curriculum, as well as the current state of the scientific literature.

Information collected as part of this effort suggests that significant evolution within each of these arenas is currently underway and will continue well into the future. As such, meaningful changes are expected to take place which will inevitably alter the basis of our conclusions as the age of long-duration exploration grows nearer. This promise of change serves to further preclude the accurate formulation of specific recommendations for implementation at this time.

Despite these challenges, we have identified several ways in which NASA can make immediate progress toward enhancing its existing teamwork training curriculum in preparation for future LDEMs. Outlined in Table 1, each of these potential "next steps" corresponds with and adheres to the general recommendations resulting from the current investigation. It is important to note that the suggestions provided are merely specific examples of ways in which the broader guidelines resulting from this TNA can be immediately applied to support NASA's current and future LDEM efforts. They are not necessarily the best or most practical approaches to implementation. For this reason, their feasibility and utility should be rigorously assessed before they are committed to and all viable alternatives should be sought and considered. This will be particularly important as critical variables become better understood and/or change in the time leading up to future LDEMs.

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