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Developing a remote team training program based on the space flight resource management model

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ABSTRACT

In response to the worldwide COVID-19 outbreak, an increasing number of people have been teleworking. Among the challenges of working away from the office is physical separation, which makes it difficult to collaborate as a team. This study highlights a set of team management capabilities of astronauts who work in extremely remote and team-centric environments—in space and on the ground. This specific operating style for astronauts is referred to as *space-flight resource management* (SFRM). This research examined the team management capabilities of astronauts that completed a training program incorporating SFRM skills in a remote working environment. The program involved an original board game developed as a training tool for NASA's moon base tabletop simulation to foster the experiential learning of SFRM skills. We conducted two training sessions with similar groups of ten students, quantitatively measuring the level of each skill, and then compared the results of the two sessions. We observed that the developed training helped trainees acquire remote team management capabilities, especially in their communication skills, cross-cultural intelligence, and situational awareness. The study showed that in addition to the learning effect, repetitions of such training could enhance remote team management capabilities, which are invaluable in the teleworking environment.

1. Introduction

Teamwork is an integral aspect of American space flight from the earliest days of the space race [1]. To minimize human errors in space flights, the National Aeronautics and Space Administration (NASA) has been developing theories and training on human factors [1–5], including *crew resource management* (CRM), which was originally introduced for the aviation industry [6].

By the 1970s, it was already known that most airline accidents were caused by poor decision making by flight crews [4]. For example, the commanding behavior of captains often prevents copilots from pointing out mistakes or problems. To remedy this, *cockpit resource management* was developed as a way for airline pilots to make accurate decisions using all available human resources in the cockpit [2,4–6]; in the 1980s, it was expanded beyond the cockpit to include all crew resources, including cabin attendants and ground staff. The CRM philosophy was that those in the cockpit were considered the only contributing members of the flight team [4,6]. The philosophy has been further transferred to the shipping industry, and is referred to as the bridge resource management (BRM). This implies that cooperative human relations among system operators play a critical role in maintaining safety.

In the 1990s, NASA experienced several failures in space shuttle missions caused by human factors [7–10]. The NASA space flight training division decided to introduce CRM training to astronauts by employing experienced CRM instructors from the military and civil sectors [11]. Because the training was developed mainly for space missions, NASA referred to this new operating style as *space flight resource management* (SFRM). Since then, NASA has developed various types of SFRM training (e.g., lectures, simulations, and analog missions) for astronauts and ground support staff [11, 12] and its collaborative agencies such as the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) [12–16]. For example, in addition to incremental training for astronauts onboard the ESA's Columbus module [12–14], ESA has conducted life science research at Concordia station that is relevant to physiological and psychological situations for long-duration spaceflights [15]. ESA also developed human behavior and performance (HBP) training for both astronauts and flight controllers [15,16]. Because of the significant communication delays between the crews in space and their ground support [14–16], astronauts should be prepared to handle unexpected events on their own in space missions such as flights to the moon or Mars [5, 14]. Enhancing crew autonomy is considered the principal goal in SFRM training [13, 17].

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A variety of analogue trainings have been developed by ISS partner agencies incorporating SFRM [18–29]. The most frequent training is NASA Extreme Environment Mission Operations (NASA NEEMO), which is conducted for up to three weeks in seawater [18]. It delegates groups of astronauts, engineers, and scientists to live in an undersea research facility known as Aquarius [18]. ESA has also developed similar analogue trainings for astronauts known as Cooperative Adventure for Valuing and Exercising human behavior and performance Skills (CAVES) [19]. In contrast to the NASA NEEMO [18], the CAVES is conducted in natural caves that also provide space-relevant conditions such as isolation from the outside world, confinement, minimal privacy, and limited resources for living [19–23]. The PANGEA course is also designed by ESA to provide astronauts with fundamental geology knowledge [24–27]. It is expected to be beneficial for astronauts working together with planetary scientists and engineers in future space missions [24]. The most challenging analogue training is the MARS-500 conducted by Russia, ESA, and China, in preparation for the long-duration spaceflight to Mars [28]. It confined crew members for more than 500 days to arrive, orbit, and return from Mars to Earth and examined the impact on the crew members' physical and psychological states of fatigue, stress, well-being, and good spirit [29]. By completing these difficult analogue trainings in a team in extreme environments such as undersea, natural caves, and the Antarctica [18–29], astronauts are trained to work safely and effectively in multicultural teams for successful space missions.

Different researchers have provided different definitions of the SFRM. Jenkins-Todd et al. defined SFRM as a successful human error-management training program [2]. Pruyn and Sterling defined it as "the exercise of skills designed to improve the ability of personnel to minimize the occurrence and effects of errors by establishing habit patterns that are reinforced by team-centered self-critique" [4]. All agree that managing human error is the primary purpose of SFRM training [2,4]; however, NASA presently emphasizes on imparting general skills, such as creative problem-solving to cope with complex, distant, uncertain, and long-duration space missions [5]. Furthermore, because human errors can occur anywhere and at any time, it would be valuable for the managerial skillsets designed for astronauts to be tailored for application in remote team management. SFRM training was designed to be practical and skill-based rather than task-based to prepare NASA team members for uncertain situations [2,5]. Research in many other high-risk industries has shown that effective teamwork in uncertain environments can build resilience in the face of challenges [5]. Hence, we believe that the essence of SFRM skills is applicable to remote team management, provided the training is appropriately tailored to non-astronaut applications. Therefore, we developed tailored training for general users by analyzing the essence of SFRM.

The purpose of this research was to examine whether team management capabilities in a remote working environment could be improved through a training program incorporating SFRM. We highlighted eight essential SFRM skills in the developed training program: communication, cultural intelligence, teamwork, situational awareness, decision-making, team care, leadership and followership, and conflict management [3]. Playing games can teach management skills while maximizing students' enjoyment [30]; therefore, we developed an original board game as a training tool that would provide experiential team learning of SFRM skills.

The remainder of this paper is organized as follows. Section 2 discusses previous literature related to the SFRM skills model and remote management training. Section 3 presents an overview of the training and the original developed board game as a training tool based on NASA's moon base tabletop simulation for teaching experiential team learning. Section 4 shows the results of the training and discusses the improved skills among the same two groups of five people after two series of experimental training sessions in a month. Section 5 discusses the effectiveness of the training in improving SFRM skills, as measured and quantified using SFRM evaluation metrics. Finally, Section 6 presents conclusions based on the research outcomes and discusses the study's limitations.

2. Literature review

2.1. SFRM and skill models

Apart from recognizing the importance of teamwork in the success of space flights, there have been few scientific studies on SFRM. Landon et al. [1] found three reasons for this scarcity: (1) case sample scarcity, because few astronauts have undergone long-duration missions; (2) model mismatches, with single management models applied to different cultural backgrounds; and (3) noncooperation, because busy astronauts have been reluctant to contribute to teamwork research. However, several SFRM models have been developed based mainly on practical SFRM exercises at NASA and its collaborative agencies [4,31].

Pruyn and Sterling [4] and Foster [31] divided the SFRM model into six performance elements, as shown in Fig. 1: command, leadership, communication, workload management, situational awareness, and decision-making. *Command* is "the exercise of official authority to achieve a mission' [4]. It is normally regarded as the right to exercise authority over crew or team members [31]. *Leadership* is the set of "techniques employed to accomplish tasks" [31]. These two skills are similar, with one significant difference: *leadership* can be provided by any team member at any time, whereas *command* is assigned to a single team member [4]. Hence, it is possible to replace a leader during a long-duration mission. The replaceability of leadership is an outstanding characteristic of SFRM. These two skills are the foundation elements in the model and are placed at the bottom of the pyramid (Fig. 1) because teamwork must be based on a solid foundation of command and leadership [4].

At the center of the pyramid model (Fig. 1), there are three elements: communication, workload management, and situational awareness. *Communication* is "the act of exchanging information, ideas, and thoughts in an accurate and timely manner, such that the message is clearly received and understood' [31]. It can involve dialog in any form among team members but should not be a monolog [4]. Poor communication among project members sometimes leads to space mission failures. For example, NASA's Mars Climate Orbiter (MCO) failed in 1999 owing to the miscalculation of the spacecraft trajectory by ground software, which was originally caused by a lack of communication between the navigation team and spacecraft operations team [32]. This implies that cross-communication between different functionalities in one project is critical for the success of space missions.

Workload management is the process of evenly distributing the team members' activities by planning, prioritizing, and appropriately assigning tasks [4]. Effective workload management prevents team members from being overloaded or underused [4]. These two performance ele-

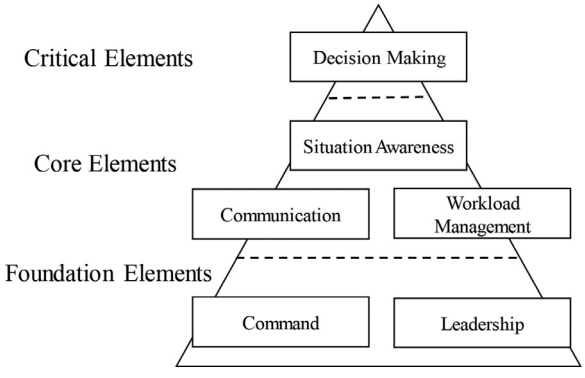

Fig. 1. Original SFRM model [4]

Fig. 2. ISS SFRM model [3]

ments are placed at the same level to imply interdependency [4]. For example, overloaded team members may think they are too busy to communicate with other members. However, when they do not communicate sufficiently, they cease to function as a team, increasing the likelihood of workload deviations. *Situational awareness* is the continuous ability of a team member to accurately perceive the relationship between themselves and their surroundings [31]. This refers to not only being in touch with the reality of a situation but also having the foresight to anticipate future needs [4]. This element is on top of *communication* and *workload management* because, without good communication and workload management, situational awareness cannot be exercised and shared among team members.

The decision-making process is at the top of the pyramid (Fig. 1). *Decision making* is "the method of determining and implementing the best course of action and critiquing the outcome" [31]. The quality of decisions is always dependent on the deciders' appropriate perception of reality; hence, this element is placed above situational awareness [4]. The hierarchical structure shown in Fig. 1 describes how each performance element interacts with the others.

In the 2000s, the original SFRM model was modified to address challenges unique to the International Space Station (ISS) mission. The ISS SFRM, known as the Stop-Think-Act-Review (STAR) model, includes these new skill elements (Fig. 2): cross-cultural intelligence, teamwork, team care, followership, and conflict management. The star shape—points radiating from a common core—provides a visual reminder that the eight skills are interrelated and equally important [3,4,11].

Cross-cultural intelligence and *conflict management* are two skill elements newly added to the ISS SFRM. Both are necessary, especially for ISS mission operations. The model is likely to be modified according to future space missions [33,34]. Crew autonomy is particularly important for long missions [34]. *Cross-cultural intelligence* refers to the ability to understand that team members' cultures (nationalities, professions, heritage, etc.) can influence expectations, behaviors, perceptions, and other factors in the workplace [35]. Cultural awareness is critical given the diversity of astronauts and others aboard the ISS. This is because many inhabitants' missions require that they share close quarters with people of many cultures for as long as half a year. *Conflict management* is "the way individuals and teams identify and manage differences in opinion, perception, technical knowledge, personalities, etc., to complete a task or mission" [35]. General space shuttle missions last approximately two weeks, whereas ISS missions can last up to six months with the same crew members. Conflicts among astronauts during routine operations must be managed. The STAR SFRM model requires an updated skill set appropriate for the ISS mission requirements and beyond.

The STAR model does not include *workload management* and *command* elements found in the original SFRM model. Instead, it adds skills similar to *teamwork* and *team care*. *Teamwork* is "how individuals cooperate with each other to achieve a shared goal, including accepting accountability and responsibility for actions" [35]. *Team care* is "how healthy the person or team is, at a psychological level. This can be influenced by various personal factors" [35]. *Leadership* remains in the ISS SFRM model; however, it is combined with *followership*. *Followership* refers to responding to a "leader's direction while assessing individual and team behavior elements and providing input to best support the leader to reach the common goal" [35]. Because *leadership* and *followership* are conjoined, they share the same points in the STAR model.

Some studies [36, 37] found that team performance, such as communication, is negatively affected by the geographical distance between the leader and followers, such as remote work. To increase the efficiency of communication in remote situations, various previous studies addressed the application of classical traditional methods, such as the theory of leadership and project management, to improve leadership in teams and projects in remote communication.

For example, Kevin [38] tested whether the transformational leadership theory [39] could be applied to remote communication between leaders and their followers in the context of e-mail messages to improve team performance. In this experiment, team performance was measured using the NASA exercise [40]. Specifically, emails with charismatic, intellectually stimulating, neutral, or transformational messages were used to communicate during the exercise. The results showed that team performance was improved by emails with effective style messages. Bickle [41] examined a method for building leadership in remote environments based on the path-goal theory [42]. In this method, the goal of an activity and the path to achieving it are clearly defined to achieve mastery of a specific leadership policy (directive, supportive, participative, achievement-oriented). However, these studies [38–42] focused only on the construction of specific leadership skills in remote environments and did not aim to improve the overall necessary skills in remote environmental activities, such as decision making or conflict management. We also found the limitation that the model was only expected to improve the leadership skills of those who took on the leadership role.

Research has also been conducted on the applicability of traditional theories of project management techniques in remote environments. For example, Lee-Kelly [43] conducted a case study on the application of project management techniques to the online performance of a group of working adults in a bank. Rooij [44] conducted an online case study on the use of project management techniques in remote education for graduate students. The study found that the adoption of the PMBOK© [45] for distance education facilitated communication among students. However, these studies were unable to confirm that the adoption of project management techniques led to improved outcomes of activities or improved overall project experience. The study [44] also argued that more insight into the factors contributing to improved online project-based learning outcomes is needed, based on interdisciplinary findings such as leadership.

Compared to previous performance training studies in remote environments [36–45], SFRM in remote environments is expected to achieve the following. First, effective interdisciplinary skills for team and task management, such as leadership and project management techniques, can be comprehensively developed even in remote environments. Second, SFRM can provide comprehensive skills to all participants without depending on their specific roles in the training because the exchangeability of leadership is an excellent feature of SFRM. In previous research [41], the only person that took on the role of a leader could acquire specific leadership skills; however, this can be overcome in SFRM.

2.2. Remote work management and training

Many studies have pointed to the effective use of information and communication devices in telework that assumes teamwork at a distance [46–48]. Sasaki [49] stated that the use of situational information and communication devices is effective for promoting teleworking. Additionally, Pérez et al. [50] found that the introduction of information-sharing software using the internet was effective for facilitating teamwork. However, although these studies have shown the need for information visualization and sharing in teleworking environments, they have not provided specific ideas for enhancing the individuals' ability to work as part of remote teams. Teleworks should not only be able to use information and communication devices, but also remotely manage teams [51].

In remote team management, the concept of shared leadership, in which all members of the team share leadership, has received considerable attention [52,53]. Kishishita and Kawakita [54] found that shared leadership works well in group work aimed at innovation emergence with high uncertainty. When performing tasks with high uncertainty, team members' abilities and information should be shared in ways that maximize the performance of the team and achieve its goals [53]. Reliable and robust communication technology is critical for virtual support teams [46–48]. However, remote teamwork is highly uncertain. It often requires leaders and followers to work on an equal footing, with the leadership role shifting as the task at hand changes [3,55]. This is one reason why unshared remote leadership is not a major factor in teamwork in remote environments [46]. In addition to telecommuting and virtual technology, remote teamwork requires that members improve their individual skills and abilities.

Focusing on remote team management, Tabata [56] developed a training program to improve teamwork skills and tested it with college students, using a scale that measured individual teamwork skills by component. The students answered a questionnaire survey on the five components of social skills and teamwork competence before and after the training. The results showed a significant increase in scores after the training was implemented, confirming that the training led to skill improvement. In a follow-up study, Tabata [57] sought to determine whether the effectiveness of training persisted over time. The same college students completed a self-report questionnaire survey nine months after the end of the training in the first study [56]. The results showed that the skills had improved, although it was not clear whether the improvement in skills over time was because of the training or added practice and experience because the survey was not conducted immediately after the training.

Telecommuting and virtual work have become increasingly popular [47], even before the COVID-19 pandemic. One collaborative work environment that often involves remote team management is the development of information systems. Matsuzawa [58] developed a training program to enhance project management skills in developing an information system where remote teamwork is inevitable. System engineers with no project management experience were recruited to measure training effectiveness. The results showed that the training fostered the interpersonal skills (problem-finding, problem-solving, and coordination) required for project managers; additionally, working in teams with students improved their communication and risk management skills. However, the qualitative evaluation performed by a third party did not allow for quantitative skill measurement, thus, it did not assess whether the subjects' skills were entrenched. In contrast, the present study measured the effects of team skill improvement and retention.

Some studies have quantitatively measured the effects of skill improvement. Surveying the leadership of academic researchers on the impact of leadership behavior on their teams using the Multifactor Leadership Questionnaire (MLQ), Cetin [59] confirmed that leaders' actions that articulate a commitment to goals and a shared vision increase follower motivation. The study concluded that leaders who respect the differences between followers are effective team managers. Additionally, Hamada and Shoji [60] noted that when followers accept and direct their leaders, their self-efficacy increases. Nishinobo [61] pointed out that the interaction between followership and leadership can have negative effects, depending on the combination of the respective behaviors. Although these studies suggest skills for remote managers, they do not mention specific ways to teach these skills. In contrast, the present study developed training programs and provided tools to improve team management skills.

One study that served as the premise for the training developed in the present work examined telework training applied to SFRM: Higashimoto [51] extracted SFRM skills elements based on previous research and showed that SFRM skills acquisition was effective for both experienced and inexperienced teleworkers. However, the validation was done through a single experiment, hence, we were unable to confirm the behavioral changes and educational effects of the subjects after the experiment. The present study has the advantage of using multiple experiments and measuring both skill improvement and retention.

2.3. Originality of the research

Our review of the literature on the development of SFRM and the development of remote team management capabilities showed that telework, which is based on the premise of remote teamwork, requires the leveraged use of information and communication devices and a deep understanding of companies toward teleworking. We found a few examples of measures aimed at specific skill development. In developing our methodology, we hypothesized that the lack of development programs for remote team management capabilities inhibited the effectiveness of teleworking. Therefore, we designed the study with these three unique features: (1) we adopted the SFRM model, with its astronaut skill set, to develop effective training for non-astronauts; (2) we measured the effectiveness of using SFRM skills to develop remote management skills by repeating multiple experiments; and (3) we developed a new quantitative measure of skill level improvement and skill retention.

3. Methodology

3.1. Design of the training

We developed a board game to provide experiential learning of SFRM skills based on NASA's moon base tabletop simulation [62]. Fig. 3 shows an overview of the developed board game. We designed the game for a team of five people to play in less than an hour and a half. The number of players assumes the minimum unit of a team-centric work environment. NASA's original game requires at least one day for the entire training [62]. However, we intentionally reduced the duration of the game to an hour and a half to facilitate the introduction of training to any organization beyond the space sector.

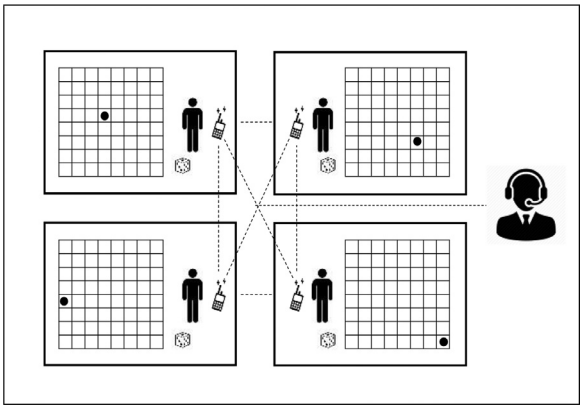

Fig. 3. Overview of the training setup

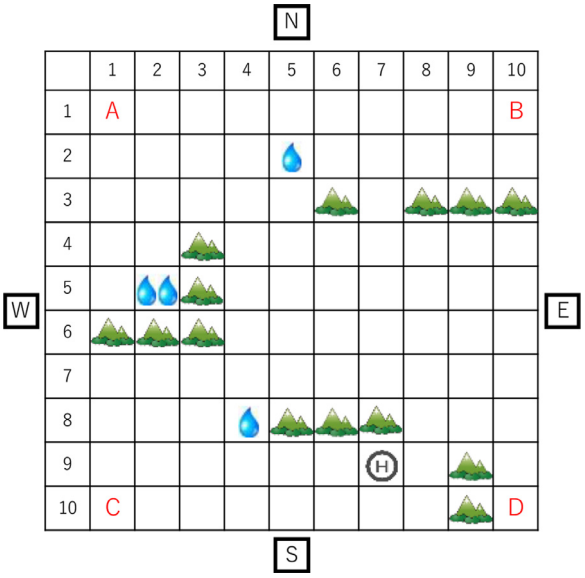

Fig. 4. Typical game board from the training

In our game, one player is assigned the role of a remote director who manages a team from a distance. Although everyone on a teleworking team requires some level of remote management skills, those calling the shots require the highest level [63]. We physically separated our remote director and the other four players by placing each of the five players in an isolated room (Fig. 3). The team had to accomplish an assigned mission with limited time, resources, and communication—we allowed only walkie-talkies for verbal communication—in our simulated teleworking environment. Tokunaga et al. [64] showed that if remote teams have sufficient communication connectivity, they can successfully accomplish complex tasks as if they were working in proximity, even when visual communication is required. However, our training intentionally eliminated these visual signals. We used dice to simulate the uncertainty in decision-making. Our configuration was almost identical to that used in NASA's moon base simulation for astronauts and ISS flight director training [63].

In our training, all participants had a simple mission: to reach a goal as a team in 10 minutes. We gave each participant a walkie-talkie, dice, and a game map. Fig. 4 shows one of the game maps used in the training. The maps used a 10×10 matrix for each round; their configuration varied according to the level of training. The sign of a heliport (H) on the map (Fig. 4) is the goal that every player is expected to reach by the end of each round. Each cell of the matrix represents a potential location for any player, and the players move or stay according to the team's decision. The decisions must be made through group discussions among the players, followed by the final decision of the leader. For the training to be specific to remote team management, we allowed the players to communicate only by walkie-talkie. Prohibiting face-to-face communication can make group-oriented decision-making more difficult. The sign of a mountain on the map (Fig. 4) denotes a barrier that no player can cross; it curtails players' movements. The sign of water denotes the locations where a player can access drinking water, which they need for movement; each player can carry a limited quantity of water at a time.

We gave each player the same visual game map (Fig. 4); however, the maps of the five players showed different initial conditions. For example, we gave Player A 10 L of drinking water in the beginning, and gave Player B only five. This implies that Player B is more likely to need additional drinking water during the mission to achieve the goal. The differences in the initial conditions were intended to influence each player's situational awareness and, in turn, their decision-making. Time management and situational awareness are important features for the successful management of a critical situation [48]. The starting position of each of the non-leader players are at one of the four corners on the map, but their positions are unknown to each other. Thus, they have to communicate their location information based on both their initial and ongoing situational awareness. The ideal approach for facilitating distributed teamwork depends on the costs, resources, and capabilities of the available technical infrastructure [65]. We designed the game settings so that the players could learn and exercise the SFRM skills to accomplish the mission.

3.2. Training operation

The entire training was conducted in the following 16 steps (Table 1), with two rounds of the game in one training session. Because this is team management training, most of the steps must be implemented by all members of a team. However, we designed several steps for the designated leader. Table 1 shows the relationship between the 16 steps and the roles associated with each step. For example, because the remote director is the only one with a global picture of the game, Step 5 (information sharing with team members) and Step 6 (role allocation) are associated only with the leaders. During the interruption and recovery of communication (Steps 9 and 10), the non-leader players have to cope with the emergency situation of losing connection with the remote director. Because this is a training, a non-playing instructor initially facilitates the beginning of each round; however, the remote director is expected to control the game when it commences. The instructor provided participants with game-result reviews (Step 12) and feedback (Step 14) at the end of each round.

The sequential training process is as follows. After all five participants introduced themselves (Step 1), one volunteer became the team leader (Step 2). For the game, we assumed that the leader would volunteer to be the remote director and exert leadership skills throughout the game. Leaders are likely to emerge within a group over time [47]. In case there is no such volunteer, however, we used dice to designate the leader from the participants. Each player then moves to a separate room to start the game (Step 3). The initial conditions were written on a game map. Players must ensure that they understand their information (Step 4). Because we give each player different information, it is important for them to spend some time sharing it with each other for everyone to understand the team's situation (Step 5). The presence of shared mental models is a significant factor influencing the performance of remote teamwork [66].

Next, the leader allocates roles to individual players, as necessary (Step 6). Because of the nature of the remote environment, the leader is required to play a coordinating role in ensuring effective collaboration and communication among team members [46]. If the selected leader cannot start the board game, then the followers are expected to support the leader. The players need to make an initial decision regarding their routes to the goal, considering not only their individual situations but also those of their team members, given the time and resource constraints (Step 7). Situational awareness is important in team-centric decisions. We used dice to provide uncertainty. For example, a player who rolls five on the dice is allowed to move five cells in any direction. However, barrier mountains limit the players' freedom. The need for water is another constraint for players. When they run short of water, players need to move to the water supply or to one of the teammates to share supplies (Step 8). Teamwork through situational awareness and communication is the key to success in this training.

In the middle of the training, we introduce a sudden interruption of communication; the leader's walkie-talkie is shut off (Step 9). The communication emergency causes confusion in the team, as the players must cope with a leaderless situation. Traore et al. [38] reported that mission activities must be coordinated according to the team's situational awareness in emergency situations. After the non-leader players reach a decision about their next moves, communication with the leader is restored, with full walkie-talkie recovery (Step 10). The sudden return of the absent leader sometimes brings about a bout of confusion, especially

Table 1
Training steps and roles in lead

	Training Steps (Step 1 through 16)	Roles in the Training All	Remote Director	Other Players	Instructor
1.	Self-introduction				X
2.	Leader volunteers (or is chosen) for the first round	X			
3.	Member isolation in five separate rooms	X			
4.	Self-information confirmation	X			
5.	Information sharing with team members		X		
6.	Role allocation		X		
7.	Decision made on a route to the goal	X			
8.	Water supply and exchange	X			
9.	Interruption of communication with leader			X	
10.	Recovery of communication with leader			X	
11.	Information re-sharing		X		
12.	First-round result review				X
13.	Team discussion	X			
14.	Feedback from instructor				X
15.	Second-round operation (repeat Steps 2–14)	X			
16.	Close of training: member appraisals				X

if a new leader has been established from among the other members. Team dynamics are also changed. The original leader does not know the situation during the interruption; therefore, information re-sharing is important (Step 11). Ten minutes later, the first round was completed, and the results were reviewed by the training instructor (Step 12).

Debriefing is highly significant in SFRM training [3,35]. Hence, the game dedicates a certain amount of time to team discussions after each round. The players discuss the results (mission failure or success) and countermeasures for the next round, if necessary (Step 13). After the discussion, the instructor provides the team with the necessary feedback for improving their SFRM skills, using a rubric matrix as a guideline for generating recommendations for the players. The next round starts with another game map (usually a more difficult configuration). The players move to the same separate rooms as before to start implementing the same steps (Step 15). Finally, the instructor provides as much feedback as possible regarding the success or failure of the remote team management and appraises the level of teamwork (Step 16). It usually takes less than an hour and a half to complete all 16 steps.

3.3. Evaluation of training

We expected that all or a part of the SFRM skills–communication, cross-cultural intelligence, teamwork, situational awareness, decision-making, team care, leadership, followership, and conflict management would be improved by the training. Out of the eight skills defined in the ISS SFRM model (Fig. 2), we treated *leadership* and *followership* as independent skills because they are different from each other by definition. The improvement of the nine skills was examined by the difference between the quantified score of each skill.

The definitions of the nine skills are presented in Table 2. For example, *communication skills* are the ability to express ideas in a way that can be easily and clearly understood by others. *Situational awareness* refers to understanding what is going on with the team and its current situation and gaining a mutual understanding between you and the team. These definitions provide clarity of understanding for both the participants and instructors about the training, which assures the objectiveness of the skill assessment.

We further divided each SFRM skill into the expected behaviors of each player during training (Table A.1 in the Appendix). For example, *communication skills* include four expected behaviors: (1) speak without omitting subjects, predicates, objects, etc.; (2) start with the conclusion, then describe the process that led to that conclusion; (3) have conversations on the same level (check the page of the material before starting a conversation); and (4) make sure that everyone on the team understands what you and the others are saying. The concrete expressions of the expected behaviors enable a more precise evaluation of each skill level. We used a five-point Likert scale to quantify the skill levels (4 = very applicable; 3 = somewhat applicable; 2 = neither; 1 = somewhat inapplicable; 0 = not applicable at all). We treated the average of every skill behavior as the score of that skill, and the average of all the participants' scores as the skill score for a round. For every round, we performed an evaluation using SFRM skill metrics (Table 2 and Table A.1). If the average score was more than two, the skill was positively evaluated. Conversely, if the average score was less than 2, the skill was negatively evaluated.

4. Results

4.1. Verification of the training

To cover all remote management capabilities in a single training, all SFRM skills must be incorporated systematically into the operational process. We verified the training design by checking that each SFRM skill element was included in at least one of the steps throughout the game. Table 3 shows the relationship between the eight SFRM skill elements (columns) and 16 training steps (rows). An *X* indicates that skill is required in the step. For example, Step 3 (dividing the members into separate rooms) requires communication skills because each player is located in an isolated room to prevent direct communication among the players. The systematic relationship between the skills and steps was validated through thorough discussions with a team of an astronaut trainer and an ISS Japan Experimental Module (JEM) flight director at the Japan Aerospace Exploration Agency (JAXA). A face-to-face interview with JAXA employees was conducted on July 13, 2019, to review SFRM skill definitions (Table 2), questionnaires for SFRM skill evaluation (Table A.1), and confirming the appropriate inclusion of SFRM skills in the training process (Table 3). In this way, we successfully incorporated all SFRM skills into the game design to provide comprehensive training of remote team management capabilities.

4.2. Demonstration of training

We conducted two training sessions with the same ten participants one month apart: Session 1 was held on November 6, 2019, and Session 2 was held on December 6, 2019, at the university's Biwako-Kusatsu campus. A repeat session was used to measure the skill improvement after the first training session. The subjects maintained the same roles for all the trials because changing roles forced them to learn more in less time but broadened the subject's understanding of the other roles.

The participants were ten students, all males aged 20–24 years, recruited from the College of Information Science and Technology and the Graduate School of Information Science and Technology at Ritsumeikan

Table 2
SFRM skill metrics for assessment (definition of each skill)

SFRM Skill Element	Definition
Communication	Ability to express ideas in a way that can be easily and clearly understood by the other person. During the process, try to reduce or eliminate miscommunication with other parties.
Cross-cultural intelligence	Understanding the differences in individual characteristics and thinking. Consideration of the impact of those characteristics on behavior. Ability to build trust by deeply understanding others, what they are thinking, and how they want to act.
Teamwork	The collective work of individuals to achieve shared goals. Acting in a way that maximizes mission outcomes in every situation.
Situational awareness	Understanding what is going on within the team and the team's current situation to achieve a mutual understanding between an individual and the team.
Decision-making	The cognitive processes to determine a series of behaviors, including the assessment of choices and risks. Evaluation of multiple options and risks, taking appropriate action, and determining plans of action.
Team care	Keeping individuals and the team healthy and preventing anyone from getting into a negative situation. Looking for causes and remedies for negative situations. Affected by multiple human factors (e.g., stress, fatigue, boredom, training, illness).
Leadership	Guiding the team/individuals towards a common goal and bringing the team together. Enriching followers according to the task to motivate them and increase their sense of responsibility.
Followership	Creating an environment that encourages follower autonomy (but not rogue behavior). Sharing roles flexibly as appropriate to a situation. Evaluating individual and team behaviors as directed by the leader and providing the best possible support for the team to achieve common goals.
Conflict management	Identifying and managing differences in team/individual opinions, perceptions, expertise, and personality. Respecting individual opinions to the extent that the mission is achievable and affirming the consensus of the team. Making choices that are beneficial to the team.

Table 3
Inclusion of SFRM skills in the training process

	Training Steps (Step 1 through 16)															
SFRM Skill Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Communication	X		X	X	X			X	X	X	X	X	X	X	X	X
Cross-cultural intelligence	X											X	X	X	X	X
Teamwork			X				X	X	X	X			X		X	
Situational awareness				X	X		X	X	X	X	X			X		
Decision-making		X				X	X		X	X					X	
Team care				X		X		X					X	X	X	X
Leadership		X				X				X			X		X	
Followership									X	X			X		X	
Conflict management					X				X	X	X	X		X	X	

Table 4
Game results of the training (Groups A and B in Session 1 and Session 2)

	Session 1 (November 6, 2019)				Session 2 (December 6, 2019)			
	Group A		Group B		Group A		Group B	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
# of players achieving goal	0	3	0	2	3	4	3	3
Time left (sec.)	0	0	0	0	0	240	0	0

University in Kyoto, Japan. None of the participants had any prior remote work experience.

In each session, the ten participants were divided into two groups: group A and group B. Each participant was provided with a walkie-talkie as a communication tool. In each session, five minutes after the instructor explained the rules, the game began (two rounds of Steps 1–15). At the end of Round 2, the instructor concluded the entire training (Step 16 in Table 1).

Table 4 shows the game results for groups A and B. It presents the number of players who reached the goal within the time limit and the time left after all players reached the goal. In session 1, neither group reached the goal within the time limit (10 min) in the first round. Although some players in each group reached the goal in the second round, neither group accomplished the entire mission as a team. In contrast, in the first round of Session 2, some players in each group reached the goal, although neither group accomplished the goal as a team. However, in the second round of Session 2, Group A accomplished the entire mission with 240 s remaining, whereas Group B still did not accomplish the entire mission in time. Thus, only one out of the four trials achieved complete team success. This confirmed that the game settings were properly adjusted for novice players who needed to learn SFRM skills.

4.3. Skill measurement results

At the end of each round in each session, the instructor asked the participants to evaluate their behaviors throughout the game using the self-assessment method of the SFRM skill metrics presented in Table 3. We distributed the paper-based questionnaire to each participant, asking them to answer each question using a 5-step Likert scale to quantify their level of achievement for each skill. Table 5 presents the average scores of the ten participants for each skill in each round. Because this was designed as a training program for team management capabilities, we believe that computing the average team scores produced a more appropriate indicator than evaluating individual scores.

5. Discussion

5.1. Skill improvement between rounds

First, we examined the participants' round-to-round skill improvement by computing the average scores of the nine skills of Rounds 1 and 2 in each session and comparing the difference between the two rounds. Table 6 shows the average scores of the nine skills and their standard

Table 5
Skill measurement results

	Session 1 (n = 10)		Session 2 (n = 10)	
	Round 1	Round 2	Round 1	Round 2
Communication	2.23	2.23	2.68	2.98
Cross-cultural intelligence	1.75	2.50	2.50	2.75
Teamwork	2.78	3.05	2.95	3.28
Situational awareness	2.38	2.70	3.13	3.08
Decision-making	2.30	2.63	2.65	2.98
Team care	2.65	2.70	2.98	2.95
Leadership	2.40	2.70	2.48	2.70
Followership	2.78	3.13	2.93	3.10
Conflict management	2.93	2.80	2.85	2.90

deviations. We conducted a one-sided *t-test* to examine whether there was a significant improvement from round 1 to round 2. We compared the skills according to each round because the game map configurations for each were different. Table 6 also presents the average score of Sessions 1 and 2, providing a more stable measurement of the improvement between the two rounds, independent of the game map configurations used. The asterisks *, **, and *** indicate that the difference between Rounds 1 and 2 was statistically significant at the 10%, 5%, and 1% levels, respectively.

In the first training session (Session 1), the average score of Round 1 was 2.46, and that of Round 2 was 2.71 (Table 6). The 0.25 difference was statistically significant at the 1% level ($p = 0.009$). In the second training (Session 2), the average score of Round 1 was 2.79, and that of Round 2 was 2.97 (Table 6). The 0.18 difference was statistically significant at the 1% level ($p = 0.004$). Finally, the average score of Round 1 in the two sessions was 2.63, and that of Round 2 was 2.84 (Table 6). The 0.21 difference was statistically significant at the 1% level ($p = 0.002$). These results clearly indicate a statistically significant degree of overall improvement in the nine skills from rounds 1 to 2. From this, we can infer that the ten participants improved their remote team management capabilities during Round 1 and then applied the improved skills in Round 2. Therefore, we concluded that including multiple rounds of training had a positive impact on remote team management capabilities. The results support previous studies [67,68] that have shown the need for repetition of training to improve new skills and the need to identify and improve training problems between training sessions.

5.2. Skill improvement between sessions

Subsequently, we looked for improvements in the participants' skills between the first and second sessions, held one month apart. Table 7 shows the average score of the nine skills for each round and its standard deviation. It also shows the average of the Round 1 and Round 2 scores to provide a more stable measurement for the two rounds. We conducted a one-sided *t-test* to examine whether there was a significant improvement in the skills from the first session to the second one month later. We expected to see some improvements owing to the settlement of the skills. The asterisks *, **, and *** indicate that the difference between Sessions 1 and 2 was statistically significant at the 10%, 5%, and 1% levels, respectively.

The average score of Round 1 in Session 1 was 2.46, and that in Session 2 was 2.79 (Table 7). The 0.33 difference was statistically significant at the 1% level ($p = 0.004$). The average score of Round 2 in Session 1 was 2.71, and that in Session 2 was 2.97 (Table 7). The 0.26 difference was statistically significant at the 1% level ($p = 0.005$). Finally, the average of the Round 1 and Round 2 scores in Session 1 was 2.59, and that in Session 2 was 2.88 (Table 7). The 0.29 difference was statistically significant at the 1% level ($p = 0.002$). These results indicate that there was an improvement in the nine skills on average, with a statistically significant improvement between Sessions 1 and 2. From this, we can infer that the remote team management capabilities were retained during the one-month interval between sessions, and the skills were properly applied in Session 2. We concluded that training was likely to be beneficial for those without prior remote work experience.

Furthermore, we found that there was improvement both from the first session to the second (0.29) and improvement from the first round to the second (0.21). The round-to-round improvement was associated with the learning effect of repeating the same game under the same rules in one day. We assumed the strength of the learning effect to be as much as 0.21, because that was the average of the round-to-round improvement. Session-to-session improvement was associated with skill settlement because of the one-month interval. The results showed that the improvement between rounds was larger than the improvement between sessions, with a difference of 0.08. This implies that the skill settlement effect is larger than the learning effect in this training. Although we cannot ignore the impact of the learning effect, we believe that the nine skills were instilled in the participants through the repetition of the training.

5.3. Individual skill improvement

Finally, we evaluated the improvements in the participants' individual skills throughout the training. Fig. 5 shows the distribution of the average improvement in each skill. The horizontal axis represents session-to-session skill improvement, which we computed by subtracting the average score of Session 1 from that of Session 2; the larger the difference, the greater the skill improvement. We deduced that this was a skill-instilling effect because the sessions are conducted at one-month intervals. The vertical axis represents the round-to-round skill improvement, which we computed by subtracting the average score of Round 1 from that of Round 2; the larger the difference, the greater the skill improvement. We deduced that it was a learning effect of the skill because the rounds were repeated on the same day. Thus, Fig. 5 describes the relationship between the settlement and learning effects of each skill.

We divided Fig. 5 into four quadrants to categorize the four skill categories according to the results. The first category is positioned at the top right, where both session-to-session improvement and round-to-round improvement were relatively high. *Cross-cultural intelligence* is in this category. Exploring the relationship between team culture and team management is an important aspect of understanding how the workplace is perceived at both the team and individual levels [69]. The skills in the first quadrant represent those that the participants could learn quickly (within a single day of training) and could be retained after the training. This skill at the top right quadrant implies that the developed training was successful in improving the participants' cross-cultural skills.

Table 6
Total skill improvement (comparison of Rounds 1 and 2)

		Round 1		Round 2		One-sided *t* test		
		Mean	sd.	mean	sd.	*t*-value	*p*-value	sig.
Average of nine skills	Session 1	2.46	0.36	2.71	0.27	-2.949	0.009	***
	Session 2	2.79	0.23	2.97	0.18	-3.550	0.004	***
	average of Sessions 1 and 2	2.63	0.27	2.84	0.20	-3.844	0.002	***

Notes: * $p < .1$, ** $p < .05$, *** $p < .01$

Table 7
Total skill improvement (comparison of Sessions 1 and 2)

		Session 1		Session 2		one-sided *t* test		
		Mean	sd.	mean	sd.	*t*-value	*p*-value	sig.
average of nine skills	Round 1	2.46	0.36	2.79	0.23	-3.441	0.004	***
	Round 2	2.71	0.27	2.97	0.18	-3.245	0.005	***
	average of Rounds 1 and 2	2.59	0.29	2.88	0.19	-3.806	0.002	***

Notes: * p < .1, ** p < .05, *** p <.01

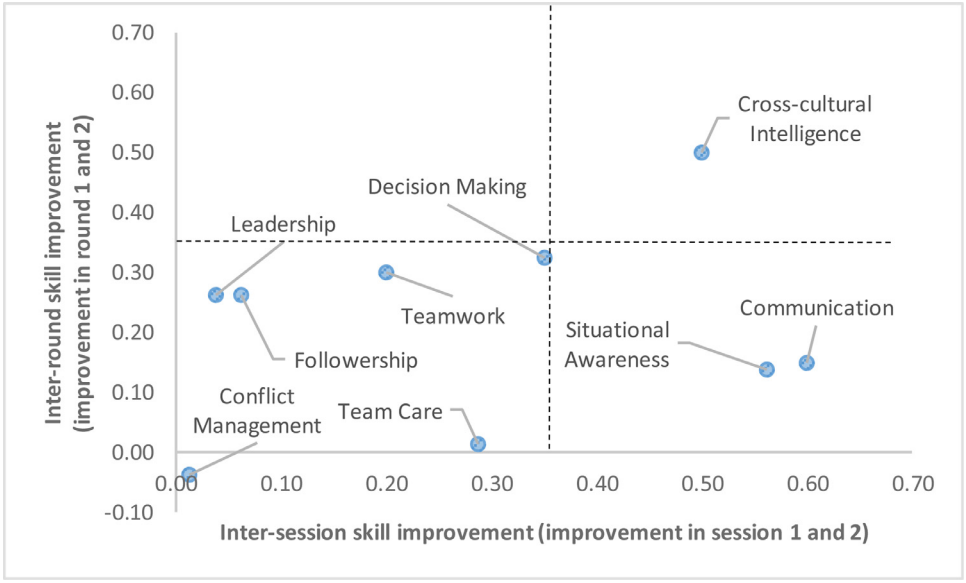

Fig. 5. Individual skill improvement (average, improvement)

The second category is positioned at the bottom right, where the session-to-session improvement is high, but the round-to-round improvement is low. *Communication* and *situational awareness* fell into this category. Husin et al. [70] found that *communication* was the biggest challenge in team management. Situational awareness, a cognitive process that determines behaviors such as the assessment of choices and risks, is considered to be a difficult skill to teach quickly; however, the participants in our study successfully improved this skill within the one-day training because the training was repeated. *Communication* and *situational awareness* are two core skills that are critical for teams working remotely [4,51,55]. We inferred that the repetition of the game made the developed training effective by enhancing these essential remote team management capabilities.

The third category is positioned at the top left, where the round-to-round improvement is high, but the session-to-session improvement is low. Fig. 5 shows that there were no SFRM skills that fit this category. Skills in this category are those that could be learned in a day, but would be easily lost after training. We deduce that the repetition of the training did not affect the acquisition of skills that would fit in this category.

The last category was positioned at the bottom left, where both the session-to-session improvement and round-to-round improvement were relatively low. The other six SFRM skills (i.e., decision-making, teamwork, team care, leadership, followership, and conflict management) were categorized (Fig. 5). The skills in this fourth category were those considered difficult to learn within a day of training and difficult to sustain through repeat training. Table 8 presents the average scores for each skill and their standard deviations. We conducted a one-sided *t-test* to examine whether there was a significant improvement in the skills from the first session to the second after one month. We calculated the mean value as the average of the Round 1 and Round 2 scores in each session, as this provided a stable measurement. The asterisks *, **, and *** indicate that the difference between Sessions 1 and 2 was statistically significant at the 10%, 5%, and 1% levels, respectively. Although there was some improvement in all the nine skills, only three had statistically significant changes: *communication, cross-cultural intelligence*, and *situational awareness*. This implies that some revisions in the training program will be required to improve the development of remote management capabilities. The analysis was based only on a sample size of ten participants, and it is unknown whether increasing the sample size or the number of training rounds or sessions could change the number of statistically significant improvements for the various skills.

The results of SFRM in remote environments to improve communication skills are consistent with the results of previous studies that have shown that proper project management in remote environments can improve the quality of communication among teams. For instance, Rooij [44] reported that the amount of communication among students increased when PMBOK© was introduced to remote education. Lee-Kelly [43] also confirmed that proper project management instructions can lead to reduced frustration and improved communication quality in teams, even in remote situations. Hence, SFRM is as effective as traditional project management methods in promoting proper task management and improving team communication, which in turn improves team activities in remote environments.

However, the lack of improvement in specific skills between rounds and sessions may be because SFRM is a training program that aims to improve overall skills rather than specific skills. For example, in a previous study on improving leadership in remote environments [38], it was confirmed that the introduction of the transformational leadership theory could improve team performance. However, it should be noted that this previous study was a training program that focused on leadership and followership, and not on improving other overall skills in the execution of the entire project. We can conclude that the SFRM content should be further developed using the findings on the improvement of these skills.

Table 8
Individual skill improvement (Sessions 1 and 2)

		Session 1		Session 2		one-sided *t* test		
		mean	sd.	mean	sd.	*t*-value	*p*-value	sig.
Average of ten participants (n = 10)	Communication	2.23	0.70	2.83	0.53	-3.307	0.005	***
	Cross-cultural intelligence	2.13	0.51	2.63	0.59	-1.813	0.052	*
	Teamwork	2.91	0.35	3.11	0.49	-1.072	0.156	
	Situational awareness	2.54	1.07	3.10	0.43	-2.091	0.033	**
	Decision-making	2.46	0.90	2.81	0.50	-1.242	0.123	
	Team care	2.68	0.69	2.96	0.57	-1.150	0.140	
	Leadership	2.55	0.87	2.59	0.69	-0.166	0.436	
	Followership	2.95	0.67	3.01	0.51	-0.305	0.384	
	Conflict management	2.86	0.91	2.88	0.52	-0.056	0.478	

Notes: * p <. 1, ** p < .05, *** p < .01

6. Conclusion

We developed a training program based on an astronauts' skillset model (SFRM) to enhance remote team management capabilities. We incorporated SFRM skills into our experiential team training program. Most of the previous studies on SFRM have been theoretical introductions of astronaut training and its application [1–6, 11]. However, this study developed a practical training tool for non-astronaut applications by developing an original board game based on NASA's moon base tabletop simulation [62]. Using the SFRM skill metrics as an objective index enabled us to identify and quantitatively compare improvements in the participants' skill levels. This study contributes to the literature in the field of skill evaluation, as it relates to remote team management. We believe that our unique approach contributes to the overall understanding of remote team management and capability development.

We conducted two training sessions one month apart with the same ten participants. They were divided into two teams of five participants and required to collaborate throughout the training to achieve a specified goal within the allotted time. In both training sessions, neither group succeeded in achieving the assigned mission in the first round, but they almost succeeded in the second round. We expected that the teams would fail in the first round but would learn enough to succeed in the next round. The results of the two groups' efforts assured us that the training was properly designed for inexperienced remote teams by producing the expected behaviors from the participants. Our results were identical to those of our previous study with a different set of participants [51]. Thus, we are confident that the game map configuration is suitable for a program that equips novice remote workers with SFRM skills. The evaluation results showed that there were statistically significant improvements in skills from one round to the next and one session to the next. Thus, we concluded that the developed training was effective for teaching remote team management capabilities if there were multiple rounds of the game in a session. We inferred that the learned skills were instilled as a result of the repetition of the same training program at different times. Repetition in training helps the trainees to learn fundamental skills.

All nine skills improved to some degree between the two sessions. However, only three skills improved at a statistically significant level: *communication, cross-cultural intelligence*, and *situational awareness*. According to our observations of the training, the participants successfully improved their cross-cultural skills in a day and retain them after the training, probably because that skill is related more to mindset than technique. Collaboration experiences under time constraints can increase participants' awareness of the importance of recognizing differences among people. In contrast, we found that it was more difficult to improve participants' communication and situational awareness skills within a day. This is probably because these skills are related more to techniques than mindset. According to our results, repeating the same training with intervals may enhance these skills. We believe that increasing the number of training sessions may lead to statistically significant improvements for the other skills; therefore, further research is required to explore this idea. Future studies will determine the impact of the developed training on each skill more precisely.

The effectiveness of the training was partially confirmed by the student experiment, but there were some limitations in the research. The ten students in the experiment were recruited from the College of Information Science and Technology of our university. We agree that their high ICT literacy, as well as their young ages (20-24), may have biased the results. Training non-engineering students with less ICT literacy would result in different conclusions. Furthermore, more practical examinations in the business environment are required. Future studies should examine the effectiveness of training a large number of remote workers in different contexts. One of the barriers of this is that the analog operation of the training is constrained by the participant's physical location. We are now developing an online training platform on which the training can be provided regardless of the participant's location and language. It provides easier access to the SFRM training opportunity and is expected to increase the number of training samples. Furthermore, the configuration of the game map and rules must be improved to include contingent task delivery among astronauts and a flight controller for mission success. We believe that improved training would be a useful tool for business managers to learn successful remote team management under uncertainty.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Nobuaki Minato: Conceptualization, Methodology, Software, Writing – original draft, Supervision, Writing – review & editing. **Yu Ikeda:** Investigation, Data curtion. **Yuki Higashimoto:** Investigation, Data curtion. **Kenji Yamagata:** Validation. **Seiji Kamiyoshi:** Validation.

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Appendix

Table A.1.

Table A.1
SFRM skill metrics for assessment (definition of expected behavior for each skill)

SFRM Skill Element	Expected Behaviors for Each Skill
Communication	Speak without omitting subjects, predicates, objects, etc.
	Start with the conclusion and explain the process that led to that conclusion.
	Have conversations on the same level (check pages of material before starting conversations).
	Make sure everyone on the team understands what you and the others are saying.
Cross-cultural intelligence	Take time to listen to others and understand them before starting the work.
	Talk to everyone on the team to understand their thoughts.
	Let everyone on the team express themselves.
	Find and use the strengths of each team member.
Teamwork	Share the big picture before starting the work.
	Accept help as needed and help others.
	Accept failures and discuss strategies for improvement.
	Ensure that everyone on the team is working toward improvement.
Situational awareness	Gather real-time information on everyone on the team.
	Keep track of the locations and water levels of everyone on the team.
	Unify the perceptions of everyone on the team.
	For unknown situations, pause to confer as a team.
Decision-making	Each individual has their separate priorities for achieving the goal.
	Align individual need vectors to make team unity the priority.
	Manage risks until the mission is accomplished.
	Predict the impact of choices and risks to the goal.
Team care	Express appreciation to other members regularly.
	Consult with all members to identify negative situations.
	Address the causes of each negative situation.
	Promote positive thinking throughout the team.
Leadership	Communicate common goals clearly to all the members.
	Instruct all members to function as a team.
	Assign roles to members to keep the team motivated.
	Tell all members the purpose and reason for each instruction.
Followership	Actively listen to the leader and other members.
	Take initiative by proposing alternative options and offering opinions.
	Respect and follow the decisions of the team once determined.
	Adapt your role as needed in unknown situations.
Conflict management	Listen to the all members' opinions without interrupting.
	Seek input from all members regarding the agenda.
	Write out the merits and demerits of your opinions.
	When there is no consensus, compare every option until the team determines the best solution.

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