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A Social Cybernetic Analysis of Simulation-Based, Remotely Delivered Medical Skills Training in an Austere Environment: Developing a Test Bed for Spaceflight Medicine

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Abstract— **This paper describes analysis of medical skills training exercises that were conducted at an arctic research station. These were conducted as part of an ongoing effort to establish high fidelity medical simulation test bed capabilities in remote and extreme "space analogue" environments for the purpose studying medical care in spaceflight. The methodological orientation followed by the authors is that of "second order cybernetics," or the science of studying human systems where the observer is involved within the system in question. Analyses presented include the identification of three distinct phases of the training activity, and two distinct levels of work groups – termed "first-order teams" and "second-order teams." Depending on the phase of activity, first-order and second-order teams are identified, each having it own unique structure, composition, communications, goals, and challenges. Several specific teams are highlighted as case examples. Limitations of this approach are discussed, as are potential benefits to ongoing and planned research activity in this area.**

I. Introduction

This paper describes a cybernetic modeling of a skills training program delivered to learners under challenging and unusual conditions. This paper does not focus on the effectiveness of the instructional technique, but rather on the human systems processes involved in delivering this training. In this paper we will focus primarily on the individual and team elements involved in delivering advanced skills training.

Models presented in this paper are based upon an analysis of the teaching of a complex medical procedural skill, endotracheal intubation, with the use of a high-fidelity patient simulator platform. Endotracheal intubation involves inserting a plastic, flexible breathing tube into the trachea of a human patient. This procedure is relatively complex, and requires considerable skill to perform. Endotracheal intubation is typically taught to physicians, paramedics, and other healthcare providers, and is a potentially life-saving maneuver used in emergency situations. While such training is common place in medical schools and post graduate medical residency training programs, this exercise was unusual in that is was conducted at an arctic research station, in the middle of the arctic winter, and in that it was delivered to novice/inexperienced non-medical trainees by an instructor (physician) located thousand kilometers away at a major teaching centre. A brief explanation of why this skill was taught, why it was taught in the manner in which it was, and why the process is being modeled, will help frame this analysis.

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II. Background

A. Challenge of Providing Medical Support in Spaceflight

A major problem facing human spaceflight is the provision of medical care to astronauts while they are aloft. The volume-confined and mass-limited nature of spacecraft, limitations of skill sets posed by a small crew size, and the need to be self sufficient without direct support from ground-based medical facilities during long missions are all major considerations in designing systems to provide medical support during flight. Proposed missions to the moon lasting 60-90 days, and missions to Mars expected to last up to 4 years present challenges to mission planners in terms of autonomous or tele-supervised medical event management [1]. Just-in-time training, and skills refreshment in flight are two areas that will involve some manner of procedural training and skills practice. In traditional medical education, trainees acquire, improve, and maintain skills largely through a mentorship/apprenticeship model that occurs in concert with actual patient care. Such an approach is not viable for spacecraft Crew Medical Officers (CMOs), and simulation (in its various forms) provides a possible and likely tool for both skills training and maintenance.

B. Space Analogue Environments as Research Settings

As with other lines of research aimed at understanding human behaviour in space, the use of terrestrial environments that mimic one or more aspects of spaceflight represents a feasible alternative to studying crew behaviour in spaceflight. Such terrestrial settings are often termed, "Space Analog Environments." Arctic and Antarctic stations have served as space analog environments for a number of studies over the years, as their isolation, crew size, environmental hostility, and operating characteristics are in many ways similar to long duration space missions [2].

C. Training Skills at an Arctic Research Station

The training exercise described in this paper was conducted at the Eureka weather station, operated by Environment Canada and located on the northern half of Ellesmere Island in the Canadian Arctic. The expedition to this site and the instruction of station participants in advanced medical skills was part of an ongoing series of studies that are using space analog environments to study telemedicine,

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medical autonomy, and procedural skills training to inform space medicine. In terms of modeling spaceflight, the training exercise we are deconstructing in this paper can be described as, "using a high fidelity simulator to teach the procedural skill of intubation to non-physicians located in a space analog environment through telementoring by a medically qualified, but very distant instructor." While the actual training program and its efficacy are not the focus of this paper, understanding the process of delivering such training is of interest as our group and others continue to study the role of simulation in terrestrial modeling of space medical support.

III. Methodological Approach

A. Cybernetics And Social Cybernetics – a Quick Overview

Norbert Wiener coined the modern use of the term cybernetics in in the 19040s [3]. Cybernetics reflects conceptualization of complex and closed loop mechanisms surrounding goal-directed behaviour in both technological and biological systems. Feedback mechanisms, goal-directedness, and purposefulness are key elements of cybernetic systems, and these can be found in virtually all applications of cybernetic theory. Cybernetics has grown over the past half century, and has been applied to biological systems, artificial intelligence, cognitive psychology, and neural modeling [4].

In the 1950s and 1960s, industrial scientists and engineers began to apply principles of cybernetics to human systems, leading to applications of cybernetic theory labeled as "social cybernetics" or "system dynamics"[5]. The application of cybernetics to human, social, and industrial settings is the basis of the approach taken in this paper to better understand the complexity of modeling space medicine crew behaviours through the use of simulation in remote settings.

Although a detailed analysis of all aspects of the skills training activities on site is beyond the scope of this conference paper, a first logical step in analyzing this operating environment is in mapping our the various players and participants, and then ideintifying the various ways in which these elements interest. A major challenge immediately apparent, however, is the challenge of analyzing a system in which the observer is also a participant.

B. Second Order Cybernetics – the Observer as Participant

The problem of studying systems when the scientist himself is part of the system was identified early on by cultural anthropologists. Margaret Mead and Gregory Benson discussed the challenge of studying something of which one is part in an interview published in CoEvolution Quarterly in 1973 [6]**.** This observer-as-part-of-the-system was a significant change from the more objective computer science and biological applications of cybernetics. Second-order cybernetics, as it was termed, emerged in the 1970s as a separate field within cybernetics [7]**.** Key elements of include the recognition that all models are simplified forms of reality, and that these models necessarily remove those elements of complex human systems not essential for the analysis. Another key concept is that the observer interacts with the system in question, responding to it and influencing as a matter of course. As opposed to first order cybernetics that focus on natural and engineering sciences, second order cybernetics focuses on psychology, sociology, human interaction [8]**.**

Our attempts model the various human processes and sub processes of which we were a part are consistent with classical applications of second order cybernetics[1]. Biases inherent in analyzing something of which one is a part will be discussed in the Discussion section of this paper.

IV. Analysis and Resulting Models

The analysis of the teams and communication networks for the intubation training exercise occurred in four stages. The first stage is the mapping of individuals and teams into functional and geographic segments. Although relatively straight forward, it was necessary to decide on start and end times for the event being studied, and to determine if any elements should be disregarded. The criteria form making this determination were guided by identifying those aspects of the exercise that would lead to better understanding and resulting improvements in future efforts by either ourselves or other tams investigating the same scientific question (ie, what to train for spaceflight and how best to train it). In other words, although we could have analyzed the logistic challenges of getting to the Arctic, the results of such analysis would not likely lead to findings of particular interest fro a research team traveling to another site. However, including those factors whose analysis would lead to meaningful improvement for subsequent efforts (for example, improving coordination and recruitment of participants or improved communication systems) would be of interest and are included in this analysis. As such, we decided we would focus on activity on station during the training phase of this project. The analyses were conducted directly by the authors, based on reflection and discussion following return from the arctic. Discrepancies in perceptions were resolved through reflection, discussion, and reworking models though and interactive and collegial process.

A. Mapping Individuals and Groups

Figure 1 shows the breakdown of personnel by geographic location. The accompanying legend indicates identifies of the different categories of individuals. Station Personnel (SP) are shown as a group, but are not identified by distinct numeric codes. *Remote telementors* (physician instructors who would teach the skill over the an audio-video link) and *network/ communications personal* (located both on station as well as thousands of kilometers to the south) are simply identified as two distinct groups. R1 and R2 represent the authors of this paper (the on-site research team). These are schematically laid out in Figure 1. For Figure1, SM=Station Manager; SP=Station Personnel, P_X=Participant (trainee), R_X=Research Team member, TM=Telementor team member, ICT=Information and Communication Technology personnel.

[1] The writing of this paper in first person by the authors is, in fact, a key element of second order cybernetics. As the authors are participants in the field activities being described, to write this paper in the third person would erroneously communicate a sense of objectivity that is not substantiated by the paper's methodology.

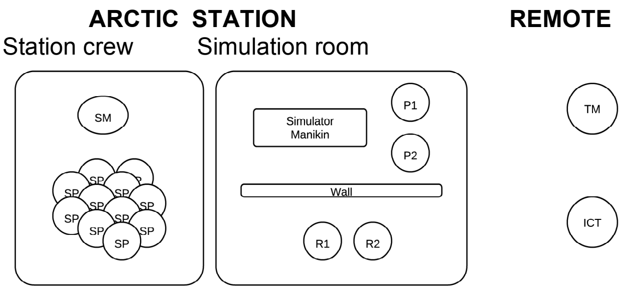

Figure 1. Topological representation of the procedural skills training activity at the arctic station. The left side of the diagram represents personnel at the Arctic Station, the centre box represents the simulation trainig area at the arcirc station, and the two symbols to the left of the diagram representteams/individuals at distant (southern) locations.

B. *Dividing the Activity into Phases*

We felt it made the most sense to deconstruct the training activity into three phases. **Phase I** consisted of preparatory work: planning, organizing, recruiting participants, and negotiating network access. Once accomplished, **Phase II** involved orienting participants to the equipment, the simulator, and to their specific participation in the project. Once this was accomplished, the actual simulation training exercise could begin; this was identified as **Phase III**. A possible 4th Phase was considered, debriefing; but for the purposes of individual skills instruction (as opposed to more complex training scenarios), the debrief is typically either cursor or omitted, and as such we elected to not model that activity.

C. *Team Composition*

Defining team composition is central to any attempt to model the human activity on site, but we found that this was not a straightforward exercise. Team composition was highly dependant upon both the phase of the exercise and on the activity being undertaken. It became apparent that there were natural, preexisting work groups, as well as those that were assembled as part of the training exercise. Furthermore, it became apparent that much activity involved teams interacting with teams, often through complex and highly constrained communications networks (email, satellite, audio-video conferencing). Dividing teams into simple, or first-order teams and into higher level, or second-order teams provided a solution to this somewhat confusing hive of human activity. We determined that **first-order teams** were characterized by interpersonal familiarity, face-to-face communication, individual relationships, informal and frequent interactions, and common and agreed upon goals. **Second-order teams** by contrast were characterized to a large extent by small teams interacting with small teams, and by limited familiarity of players, more formal or electronic modes of communication, competing or unrelated goals, and less frequent interaction.

First order teams, over all phases of the project, are shown in Figure 2. Dark ovals represent the boundaries of the specific teams. Although the telementors and communications personnel could also be conceptualized as first order teams, this has not been included in this diagram.

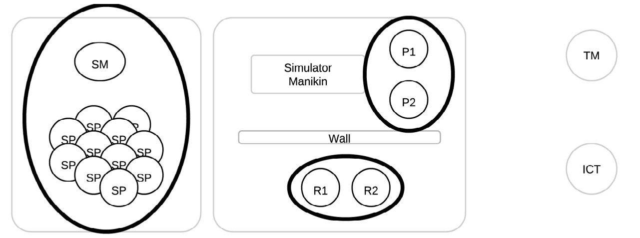

Figure 2. First order teams over all three Phases (collapsed) of the training event

Second-order teams, or teams of teams, are shown in the following diagrams, broken down into the three phases of the project.

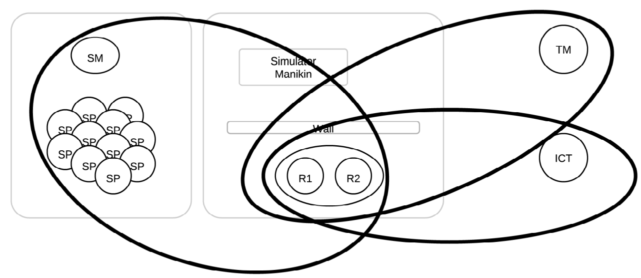

Figure 3. Second order teams in Phase I. The Research Team (R1 + R2; the authors) interacting separately with station personnel, remote telementors, and network communicatons team characterize Phase I.

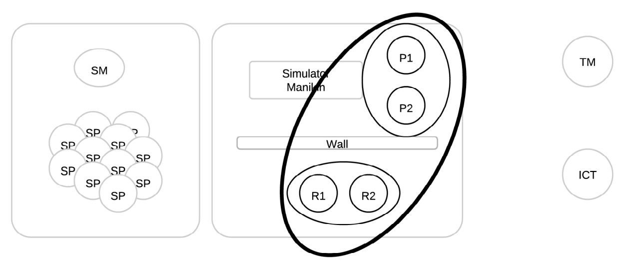

Figure 4. Second-order team activity in Phase II of the event; the research team oreints and prepares the particpants for the training exercise.

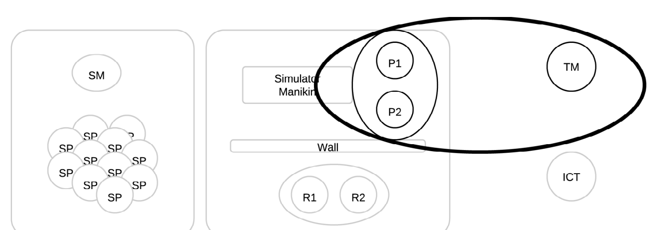

Figure 5. Second order teams in Phase III. Telementors interact directly with the on-site trainees, while research team withdraws and manages the simulator manikin.

TABLE I. FIRST AND SECOND ORDER TEAMS SUMMARIZED

Team Level	Phase	Team Composition	Code
First Order Teams	***All Phases***	Research Team (R1+R2)	FO1
		Participants (P1+P2)	FO2
		Station Personnel	FO3
		Remote Tel-mentor/Provider (1 or more inviduals)	FO4
		Network Adminstration (both remote and onsite)	FO5
Second Order Teams	***Phase I***	Research team + Station Personnel	SO1
		Research Team + Telementor	SO2
		Research Team + Network Team (ICT)	SO3
	Phase II	Research Team + Particpants (1 or more)	SO4
	Phase III	Particpants + Telementor team	SO5

Figure 6. First order and second order teams , organized by Phase of project, and with specific team composition identified.

Table I, above, lists the teams of both first and second order, along with an alphanumeric code for each team. For each first-order and second-order team, multiple characteristics can be identified. These include team composition, team structure, temporal characteristics, goal orientation, modes of communication, technologies facilitating or hindering team performance. These will be detailed and distinct for each team relationship identified. Detailed descriptions are beyond the scope of this paper.

V. DISCUSSION

This paper represents a formal effort to model the relatively complex team and task activities involved in bringing high fidelity simulation to a remote, terrestrial "space analog" environment. Subsequent efforts will involve more detailed analyses of the specific nature and characteristics involved in each of the identified team relationships. Specific team interactions have been identified *a priori* as highly relevant. These include the first-order team FO2. In this team, station participants (or astronauts) must coordinate activities in order to achieve their shared goal. In an emergency intubation procedure, this would entail gaining control over the compromised airway of a fellow station or crewmember. An existing body of study, Crew Resource Management, first developed in aviation and now being applied to both astronaut crews and medical teams (Ref – Musson) will likely play a major role in understanding the performance of these teams.

Another area of team activity of tremendous interest is that of the second-order team SO5 – the interaction between crew or station members and the distant telementor (in our case, a physician educator communicating to a crew via audio-video conferencing). Verbal communication protocols, information flow, medical telemetry, camera position and resolution, satellite bandwidth limitations, and signal transit time delay are all factors that impact on the performance of this team and that warrant further study. Indeed, the study of how this team operates was a major impetus for creating this space analogue environment simulation test bed in the first place.

There are certainly limitations in the analysis presented in this paper. As mentioned previously, the biases of researcher/participants are inescapable and are an acknowledged complication of second order cybernetics. All training activities were videotaped, and independent analysis of these may help address this issue. Also, as discussed in the Methodology section of this paper, the authors must determine what to include and exclude from the models developed. We freely acknowledge that areas of particular concern to us (such as medical teamwork, and the challenges of medical supervision) received a higher priority in this analysis that other activities that occurred on site.

Despite the shortcomings described above, we hope that this systematic deconstruction of our experiences and activities helps shed light on how to best move forward in this new but challenging research effort.

VI. ACKNOWLEDGMENT

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