Transdisciplinary Design of Trust-Driven Clinical Decision Support Interface for Cyber-Physical Human Teams in Long-Duration Human Spaceflight

Anna B. Wojdecka[1]
Royal College of Art, London, SW7 2EU, UK
Florida Institute of Technology, Melbourne, FL, 32901, US

Don Platt[2]
Florida Institute of Technology, Melbourne, FL, 32901, US

Astronauts on future long-duration human spaceflight (LDHSF) missions will collaborate with artificial agents to enable crew medical autonomy and support Earth-independent clinical decision-making, working together as Cyber-Physical Human (CPH) teams. Although trust is a well-understood pillar of successful team collaboration, its incorporation into the design of onboard medical systems and clinical decision support (CDS) interfaces has not been systematically addressed. The work presented in this paper advances the development of onboard medical systems and CDS interfaces by integrating CPH team trust considerations from the early design stages. First, we present a framework to facilitate transdisciplinary stakeholder collaboration to envision solutions in the LDHSF future(s) context. Next, we describe the developed design research tools that allow stakeholders to consider CPH trust in the context of future LDHSF missions. Lastly, we illustrate a case-study application of the tools to derive trust-driven future CPH interface requirements and demonstrate how they are reflected within the conceptual development of the Exploration Medical Ecosystem Design Interface (ExMEDI).

I. Nomenclature

CPH	=	Cyber-Physical Human
CDS	=	Clinical Decision Support
DRM	=	Design Reference Mission
ExMEDI	=	Exploration Medical System Design Interface
HAI	=	Human Agent Interface
HCD	=	Human Centered Design
HSIA	=	Human Systems Integration Architecture
LEO	=	Low Earth Orbit
LDHSF	=	Long-Duration Human Spaceflight
LxC	=	Likelihood times Consequences
$T_{H>A}$	=	Human Trust in Agent
$T_{A>H}$	=	Agent Trust in Human
$T_{A>A}$	=	Agent Self-Trust
SME	=	Subject Matter Expert
XAI	=	Explainable AI

[1] Associate Lecturer (Research), MRes Healthcare and Design, School of Design, Royal College of Art
[2] Associate Professor, Space Systems, Spaceport Site Director, Florida Institute of Technology

II. Introduction

Maximizing crew autonomy and self-reliance in medical decision-making and treatment delivery requires a shift from a ground-based support model to artificial agents working with future astronaut crews as Cyber-Physical-Human (CPH) teams. Effective team collaboration requires trust, which affects the performance of individuals and overall results [1]. Human-automation trust has been studied since the 1980s, introduced in classic studies by Bainbridge's seminal research on the impact of technology on society and human-technology interaction [2], and Wiener and Curry in cybernetics and human confidence in automation [3], among others.

The systems should only be trusted if they are trustworthy. A growing body of research looks at measuring the trustworthiness of increasingly complex systems, including AI-supported solutions that cannot be easily understood by human operators [2]. To avoid serious issues around over-trust (complacency) and under-trust ("cry wolf effect"), concepts initially introduced by Parasuraman et al. and Sorkin et al., human performance and engineering psychology domains are developing new approaches to human→agent trust calibration, including display design, operator training as well as automation adaptation [4-6].

In a comprehensive state-of-the-art review of rapidly advancing AI technology applications to clinical practice, Alowais et al. discuss the potential to revolutionize clinical decision-making by offering "increased accuracy, reduced costs, and time savings while minimizing human errors," stressing the need for human oversight as a multidisciplinary effort [7]. New frameworks are required to facilitate transdisciplinary collaboration, and the inclusion of a wide spectrum of stakeholder viewpoints is required to shift the paradigm toward CPH-teams-oriented system architecture design for LDHSF [8].

Recent technological advancements enable cyber agents to interact with humans at a new level, opening the ability to understand the human state and their environment by leveraging capabilities such as biofeedback, modeling, and recognizing patterns in physiological and behavioral data. At the same time, expanding agents' communication modalities beyond text-based interfaces to include image, sound, and haptic feedback, as well as the utilization of multi-modal interfaces and immersive virtual environments, create new opportunities for interaction design.

Interaction design is an integral part of many academic disciplines, including Computer Science, Design, Engineering, Psychology, Social Sciences, and overlapping fields such as Human Factors, Human-Computer Interaction, Cognitive Ergonomics, Cognitive Engineering, and Information Systems [9]. Within the Design Practices, interaction design is carried out by Graphic Designers, Artists, Industrial and Product Designers, Service Designers, and other creative professionals. Human-Centered Design Researchers are concerned with developing methods and tools to understand users' needs and develop solutions that are intuitive to use and improve people's lives while considering multiple aspects, from functionality and usability to aesthetics and emotional appeal. Don Norman highlights the invisibility of "good design," which supports the user to complete the task by creating a seamless experience, whereas bad design—characterized by poor considerations of user needs, affordances, and application of signifiers—leads to human error and accidents [10].

> Human beings make mistakes because the systems, tasks, and processes they work in are poorly designed.
> (Lucian L. Leape, MD, Harvard School of Public Health)

In the context of CPH teams collaborating during future space missions, the effectiveness of the design of clinical decision support interfaces can make or break the human-agent interaction. For CPH crews, the interface is the primary channel of communication. Figure 1 below illustrates the human crew interaction with the agent through an interface. With advancing human-agent interaction character, the current focus on one-way trust considerations—predominantly on the operator trusting the agent—needs to be expanded to account for both directions of the interaction: human→agent as well as agent→human, as illustrated on the grey arrows (Figure 1). Notice that also the agent→agent trust plays a role in the interface and interaction design, as the system must be able to convey to the human user any known uncertainties about the data, model, or decisions.

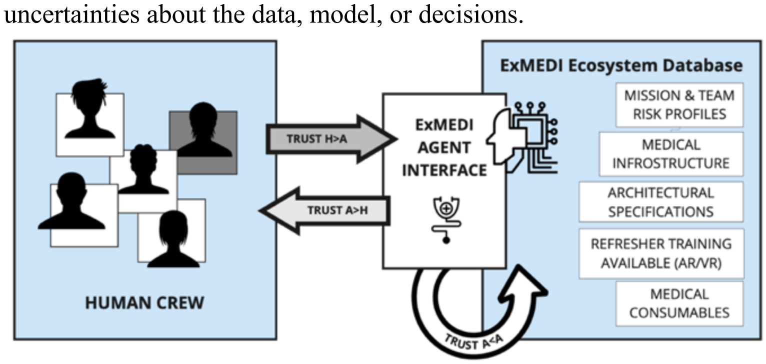

Fig. 1 CPH crew interaction during a mission and the three trust directions. Derived from Ref. [8].

Despite the maturing field of Explainable AI (XAI) in medicine, Antoniadi et al. identify a significant gap in the application to CDS systems and stress the need for more user-centered research around methods of presenting the information in a way that is helpful for making medical decisions [11]. Within the human spaceflight sector, it is conventional practice to consider medical system requirements towards the final engineering stages of the project [12]. To minimize the risk of errors during the LDHSF, a fundamental shift to this approach is required. The longer and more remote the mission, the greater the need for adopting a human-centric approach from the early stages of defining key mission architecture parameters and design constraints, including vehicle habitat planning, environment, tools, equipment, and interface design [13]. The quality of design and implementation of medical systems and interfaces can have a direct impact on the crew's health, wellbeing, and determine the success of treatment administration. Table I below, adapted from NASA's Human Research Roadmap, illustrates two critical risks: the Risk of Adverse Outcomes Due to Inadequate Human Systems Integration Architecture (HSIA) and the Risk of Adverse Health Outcomes and Decrements in Performance due to In-Flight Medical Conditions. Risks are represented as Likelihood times Consequences (LxC), with the level of care required according to mission type. In terms of operational risk, estimates associated with the Risk of Adverse Outcomes Due to Inadequate HSIA are equal to or greater than the Risk of Adverse Health Outcomes and Decrements in Performance due to In-Flight Medical Conditions for longer LEO, lunar and deep space missions [14, 15]. Both are rated as high. Although the direct effects of bad design on health are not quantified in Table 1, research shows that effective use of design for safety is linked to medical error reduction [16].

Type of mission	Suborbital Flight		Suborbital Crew (Weekly)		**LEO (<30 days)**		**LEO habitation (30days - 1yr)**		**Lunar Orbital (<30 days)**		**Lunar Orbital (30days - 1yr)**		Lunar Orbital & Surface - Deep Space Preparatory (<1yr)		Deep Space, Mars (730-1224 days)	
Return duration	<=1 hour		<= 1hour		<=1day		<=1day		<=5 days		<=5 days		5days - weeks		months	
Level of Care	I		I +		II		III		IV		V		VI		VI	
Medical Capability	First aid, medications (decongestants, antiemetics) basic life support, call with ground medical specialists		Level I + regular monitoring		Level I + clinical diagnostics, response to anaphylaxis and toxic exposure		Level II + ambulatory care, private video, limited advanced life support, trauma care, limited dental care		Level III + med. imaging, advanced life support (defibrillation, ventilator support), limited surgical, dental		Level IV + autonomous advanced life support and ambulatory care, basic surgical care		Level V + surgical care		Level V + surgical care	
Risks	Operations	Health	Operations	Health	Operations	Health	Operations	Health	Operations	Health	Operations	Health	Operations	Health	Operations	Health
HSIA: Inadequate Human System Integration (LxC)	-	-	-	-	5x2	-	5x2	-	5x2	-	5x3	-	5x4	-	5x5	-
ExMC: Adverse Outcomes due to Medical Conditions	-	-	-	-	3x2	3x2	4x2	4x2	4x2	3x2	5x3	4x2	5x4	4x4	5x5	5x4

Table I. Medical capabilities and associated risks based on mission type. Adapted from Ref. [14, 15]

Designing future medical systems and interfaces for exploration LDHSF, such as missions to Mars, requires a paradigm shift. The CPH medical collaboration demands reimagining crew health support as a concept, from medical capabilities to ethics, challenging the status quo. Although the potential future solutions need to be informed by past knowledge, they cannot be evaluated within the constraints of today's perspective and must be designed to apply within the futures context. To design effective CPH-oriented medical systems, we need to envision how humans and agents collaborate during LDHSF missions, how they leverage complementary skills, and how they develop and maintain trusting relationships. The ambiguity and uncertainty of distant futures, characteristic of the long-term Horizon 3 anticipatory work, require a collaboration of diverse stakeholders [17]. The CPH trust needs to be envisioned within the context of possible futures, to design out unwanted health futures, and specify the desired characteristics of the human-agent interaction within the preferable future(s).

The Goal and Contribution

The key contributions of this paper are:

- *Methodological and Theoretical*, where we present a new framework to facilitate transdisciplinary collaboration to envision and design out unwanted health futures, as well as the application of research tools to consider trust as a first-class element of CPH team system architecture from early design stages. We discuss the application of developed CPH Trust Mapping tools to take into account trust-affecting factors within three directions of trust: human trusting agent ($T_{H>A}$), agent trusting human ($T_{A>H}$), and agent self-trust ($T_{A>A}$). We introduce CPH trust research tools, including two-dimensional trust landscape maps and scenario blueprinting which considers $T_{H>A}$ as well as $T_{A>H}$.

- *Practical and Interdisciplinary*, where we illustrate a case study application of the framework and the developed CPH trust research tools with stakeholders from multidisciplinary backgrounds to design the Exploration Medical Ecosystem Design Interface (ExMEDI)—a medical ecosystem to support the health, medical autonomy, and decision-making of crews during exploration missions by integrating trust into critical space systems. We reflect on how the design-led process facilitated the elicitation of the interface requirements within a future Mars mission context. We illustrate the high-level conceptual design of a multi-modal interface and discuss opportunities around the design of the trust-adaptive CPH interactions.

III. Methods

Involving diverse stakeholder groups from the early stages of the project, we adopted a human-centered design-led research approach with second-order cybernetic reflective cycles [18]. The methods included grounded theory with constructivist components [19, 20], followed by a series of co-design sessions to guide the development of the conceptual interface design [21].

Subjects

Twenty-five Subject Matter Experts (SMEs) were interviewed in two rounds of qualitative interviews. The SMEs were recruited to represent key areas related to Human Spaceflight: Astronauts and Training, Computing and Systems, Space Medicine, Engineering and Architecture, Human Factors and Design, and representing both Commercial Space and Governmental Space Agencies.

The stakeholder co-design workshop sessions ranged from 4-15 participants and were conducted both in-person and virtually via Zoom, utilizing the Miro.com online whiteboard for real-time collaboration [22]. The experts represented commercial, governmental, and academic sectors.

Ethical Considerations

The research spanned between July 2022 and January 2024, with ethical clearance IRB Exemption Nr: 22-064 and Nr: 23-005. The first author conducted SME interviews, led stakeholder workshops and SME design meetings.

IV. Results

The results section is divided into three parts. First, we present the developed framework to facilitate transdisciplinary stakeholder collaboration to envision solutions in future(s) LDHSF context. Next, we illustrate the developed design research tools that allow stakeholders to consider CPH trust in the context of future LDHSF missions. Lastly, we present a case-study application of the tools to derive trust-driven future CPH interface requirements and how they are reflected within the conceptual development of the Exploration Medical Ecosystem Design Interface (ExMEDI).

A. The Futures Framework

The developed framework employs future foresight methods alongside design thinking and design research tools to *Design Out Unwanted Health Futures* (Figure 2) [23]. The framework facilitates transdisciplinary projects with long-term time horizons. It incorporates a temporal dimension, a journey along Minkowski spacetime [24], to allow stakeholders to collaboratively examine health(care) challenges within multiple pasts and futures contexts. It distinguishes between undesirable and preferable futures [25], allowing stakeholders to form a common understanding of the target landscape and generate solutions for the target context.

The framework has been developed to assist the collaboration of professionals from diverse backgrounds in addressing long-term healthcare challenges. It was initially applied in academic design research education of professionals with diverse expertise, including medical, engineering, art, design, policy, and social sciences, working in teams to develop transformative solution pathways for the future of health(care), and was iteratively developed during the global COVID-19 pandemic [23]. The insights gathered from the application of the framework during three-day long workshops, which were conducted both in-person and online, allowed us to iterate and inform the framework and adapt it for the application with SMEs collaborating on the design of future space medical systems and the integration CPH trust considerations. Figure 2 illustrates the seven steps of the framework, which we describe below.

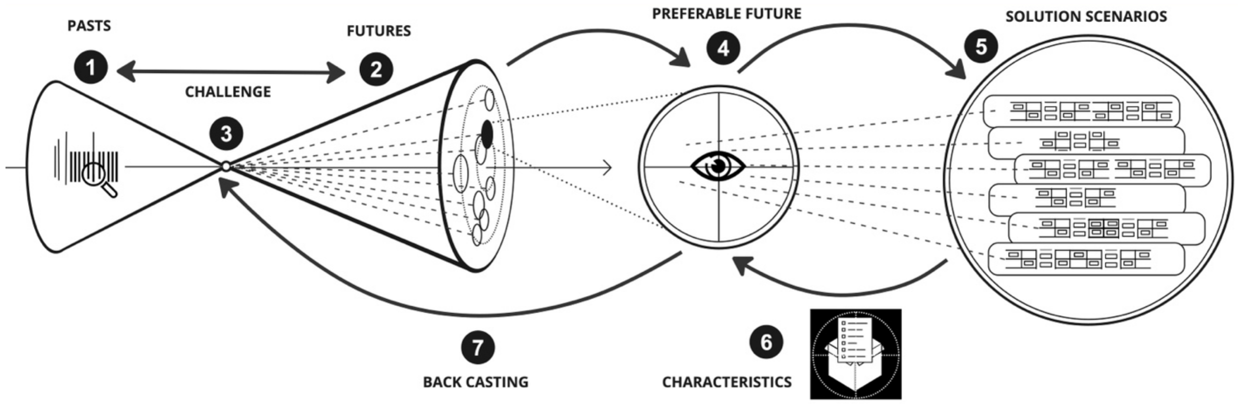

Fig. 2 Designing Out Unwanted Health Futures Framework. Adapted from Ref [8]

Transdisciplinary Framework for Designing Out Unwanted Health Futures:

1) ***Examining the Challenge from Multiple Past Perspectives.*** Alongside the literature review, the facilitator conducted interviews with SMEs from diverse backgrounds to explore the past(s) challenges of astronaut medical systems. Following constructivist grounded theory procedures, where data collection procees alongside theory co-construction, enabled us to gather rich qualitative insights about the space medical systems, seen as a part of the broader landscape [20].

2) ***Projecting Multiple Futures.*** The open-ended character of SME interviews allowed co-exploration of CPH trust within a wide range of probable, plausible, and possible futures. Figure 3 represents the role of the design facilitator in including diverse viewpoints and expanding the collective field of vision [26]. Alongside the interviews, the technical aspects of the futures were informed by the conceptual human Mars reference missions detailed in NASA's Engineering and Safety Center Technical Assessment Report on Safe Human Expeditions Beyond Low Earth Orbit (LEO) [27].

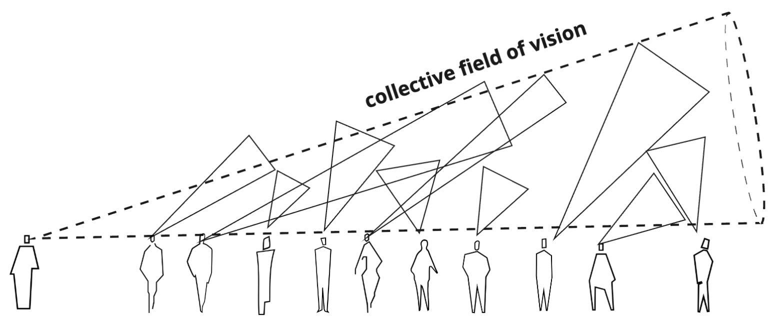

Fig. 3 Fields of vision. Adapted after Ref [26].

3) ***(Re)defining the Challenge Now.*** The challenge was iteratively co-constructed and co-defined with SMEs, which proceeded together with the pasts and futures research [20]. This reflective process encouraged incorporating emerging insights while rapidly testing assumptions. Alongside defining the challenge, we developed CPH trust mapping tools to support the next stages of stakeholder collaboration. The developed tools included the CPH Trust Maps and CPH Trust Blueprints, tools that make it easy to consider human-agent trust as a first-class component during transdisciplinary research. We describe these tools in the following subsection.

4) ***Defining the Preferable Future*.** Negotiating the preferable future gave a foundation for envisioning the target context in detail. During the stakeholder meetings, we selected a two-year opposition short-stay Mars mission, with a 30-day long stay at the surface stay and only two out of four astronauts descending. The desired care was set to Level 5 according to the Space Flight Human-System Standard NASA-STD-3001 [28]. As the concept of operations, we adopted the NASA HRP Exploration Medical System Goals [29]. During the hands-on SME workshop, we used design thinking tools to detail the astronaut's personas and the mission context (Figure 4). We developed the profiles of four astronauts, out of which two had medical

backgrounds (a medical doctor and a psychologist), aligning with NASA-STD-3001 [28]. The agent's role was discussed as a digital crew member assisting the crew. The agent was depicted as both an advisor to the medics, offering in-depth assistance with using specialized terminology, and as general medical support to all team members when required, including preventive advice and emergency support.

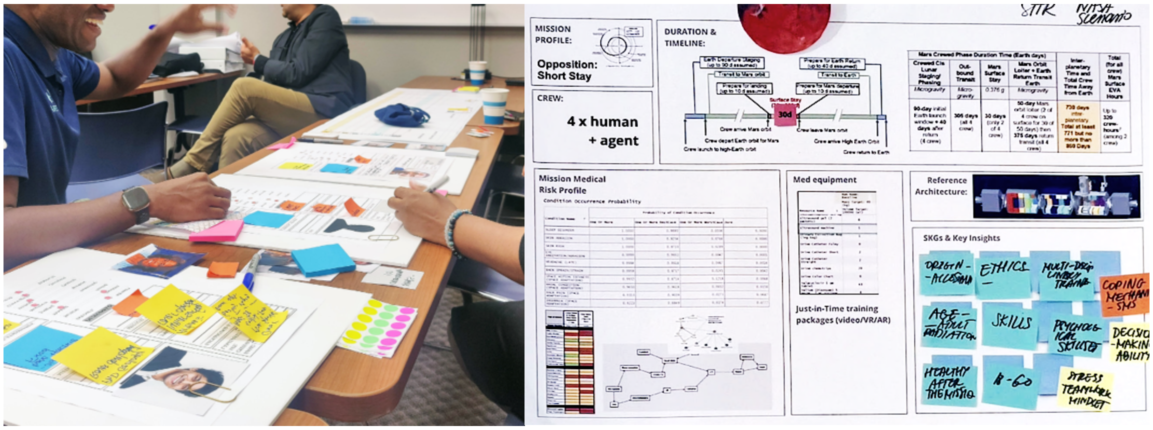

Fig. 4 Mission context and astronaut persona development during the SME workshop.

5) ***Generating and Probing Solution Scenarios:*** Brainstorming CPH crew health scenarios within the detailed future context enables testing them in the target context. During two SME workshop sessions, we generated six detailed scenarios of agent-crew medical interaction (Figure 5). Throughout the human-agent interaction, we mapped the CPH trust dynamic, recording both human and agent trust levels throughout the medical interaction on the developed trust blueprinting tools (Figure 5, Figure 8).

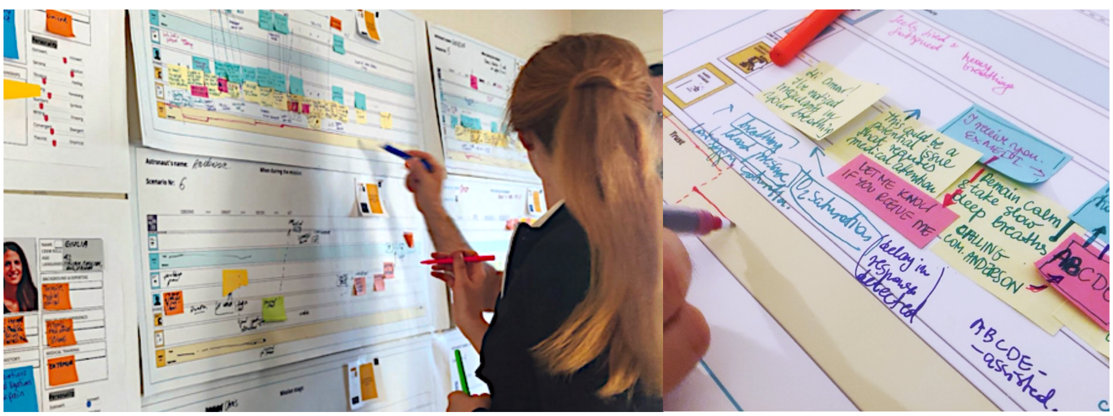

Fig. 5 Envisioning CPH interaction scenarios during SME design meetings.

6) ***Defining the Desired Design Characteristics***. Specification of the desired characteristics and the success criteria derived from the transdisciplinary research was a crucial step before designing solutions for the target future. Applying the developed CPH trust maps (Figure 7), we elicited the requirements list for trust-driven exploration medical systems [8]. Incorporating the insights from health scenario workshops, we defined the CPH medical interface characteristics.

7) ***Back-Casting and Concept Detailing.*** Considering the envisioned system characteristics, we developed the high-level concept of ExMEDI. Using rapid prototyping methods and digital mockups, we iteratively prototyped and tested the design of the ExMEDI interface (Figure 6).

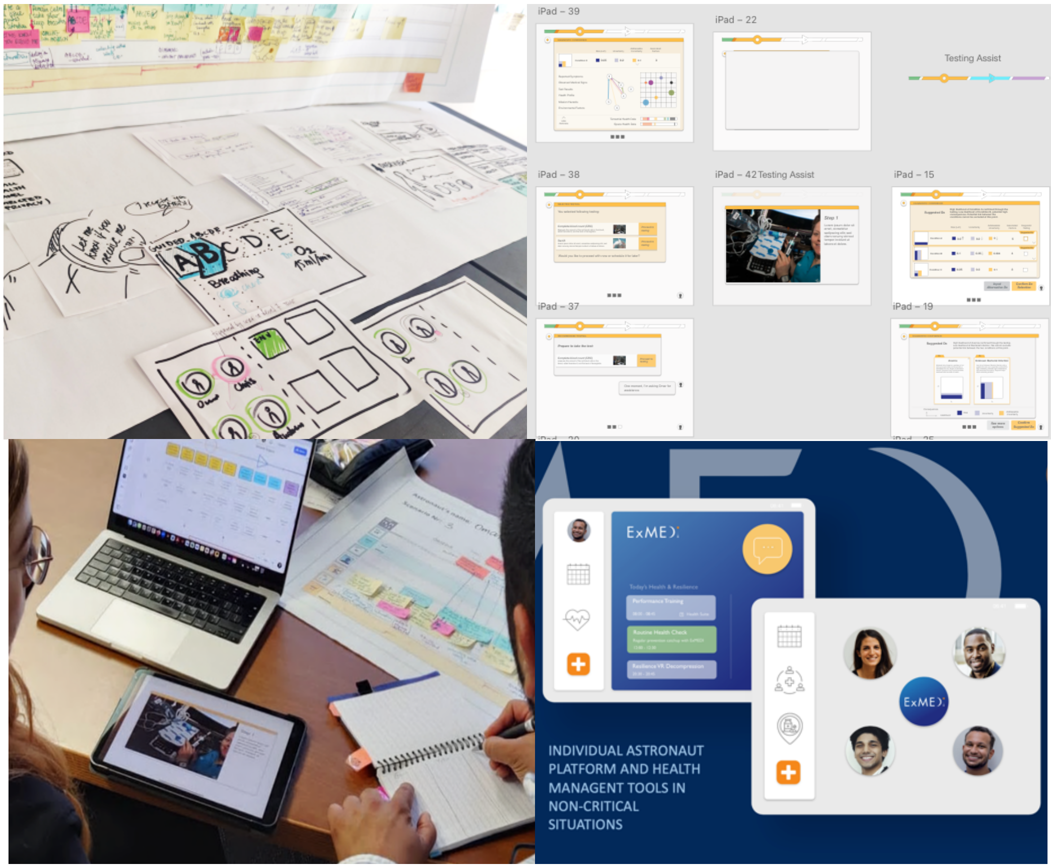

Fig. 6 Iterative stages of conceptual development for ExMEDI.

B. CPH Trust Research Tools

The collaborative envisioning of different CPH health(care) futures informed our understanding of the astronaut↔agent trust relationship and the CPH trust in the context of exploration missions. We defined three CPH trust directions separately to reflect the differences between human and agent perception and cognition while specifying these within the context of human-agent medical collaboration. We describe $T_{H>A}$ trust as human readiness to follow agents' advice based on human knowledge of agents' performance and agent's supportive behavior characteristics. $T_{A>H}$ refers to the agent's assessment of the human's ability to perform a task based on the observed human state, circumstances, environmental considerations, and prior knowledge of the human. To make the correct assessment and communicate potential errors to the crew, the agent needs to have a degree of self-awareness. $T_{A>A}$ is the agent's confidence in the data and model integrity related to its ability to provide support to the astronaut.

As a result of the conducted SME interviews and SME workshops, we derived the factors related to each direction of trust and represented them within two-dimensional CPH trust maps. The trust factors are codified within two-dimensional space on the introduced CPH trust maps (Figure 7). The factors are numbered and organized in relation to cognitive-affective and personal-mission dimensions ($T_{H>A}$ and $T_{A>H}$) and limitations related to model and measurement, as well as a-priori and real-time ($T_{A>A}$). The factors originating from diverse disciplinary expertise insights are presented together, which makes it easy for stakeholders from different backgrounds to collaboratively consider them during the early stages of CPH medical system requirements elicitation.

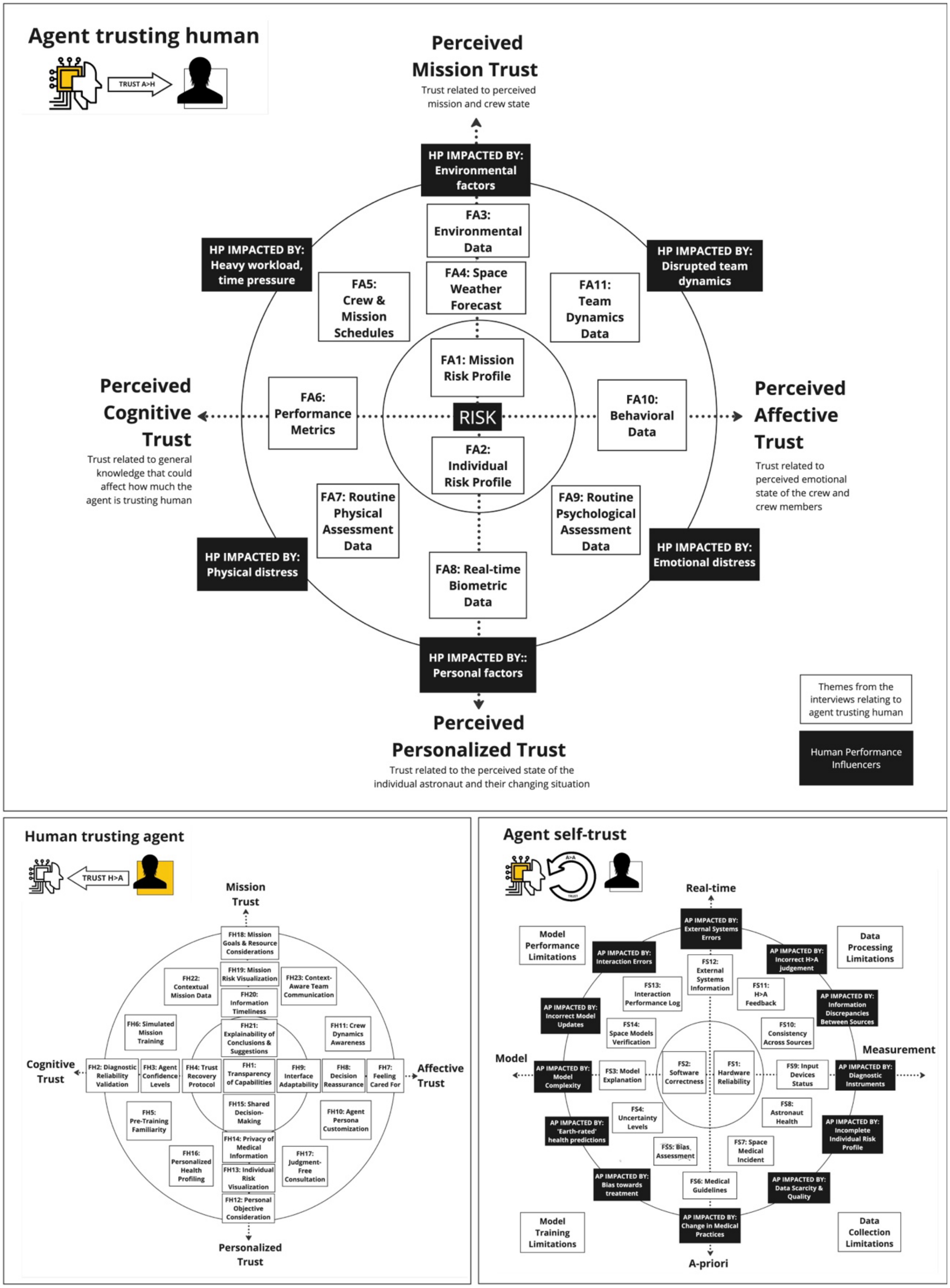

Fig. 7 CPH trust maps.

We applied the CPH trust maps to elicit trust-driven requirements for an exploration class medical system within the case study DRM. The resulting requirement list integrated all trust factors from across all trust directions. Table II below illustrates the example requirements with corresponding trust directions and trust factors. The selected example requirements are related to the human-agent interaction through the interface. This example selection illustrates how each requirement has been constructed to connect multiple trust-influencing factors related to different trust directions.

Req #	Requirement Description	Trust	Trust Factors	Rationale
2.2.1	The system shall be able to collect information for the astronaut health risk profile during the training.	H>A A>H A>A	FH16: Pers. Health Profiling, FA2: Individual Risk Profile, FS8: Astronaut Health Profiles	The agent learns about the astronaut's health and performance, medical history, designated tests.
6.2.1	The system shall provide different levels of assistance and shared decision-making depending on a context and urgency of the situation.	H>A	FH9: Interface Adaptability, FH15: Shared Decision-Making, FH20: Information Timeliness, FH22: Contextual Mission Data	The agent adapts the interaction, simplifying the interface when required. The level of autonomy can be adjusted if needed.
6.2.2	The mode of interaction and amount of information displayed shall be context and astronaut-state-aware.	A>H	FA8: Real-time Biometric Data, FA6: Performance Metrics, FA5: Crew & Mission Schedules	The system knows the astronaut's location, daily schedules, and tracks their biometric measurements.

Table II. Example system requirements derived from the maps.

Trust Blueprinting for Health Scenarios

The research highlighted the importance of the astronaut↔agent trust relationship during the medical interaction. One of the identified desired characteristics of the CPH interface was the ability to adapt the conversation depending on the context, reflecting the qualities of patient↔human doctor conversation. To envision the medical scenarios within the target future mission context, we utilized design thinking tools, including role-play, personas, and the developed trust blueprinting tools, and applying them during the SME co-design meetings. The trust blueprinting worksheets were designed to map the astronaut↔agent trust interaction during a medical scenario, considering changes in $T_{H>A}$ (blue field) and $T_{A>H}$ (yellow field) as the interaction progresses (Figure 8, Figure 5). During the design session, the facilitator encouraged the SME teams to engage in a role-play, with each participant acting as one of the developed astronaut personas or the ExMEDI agent, to envision medical interactions in the target mission context. The interactions and trust dynamics were recorded on the worksheet, and emerging themes were discussed. Six scenarios were blueprinted, with medical conditions of different severity (selected from NASA's most likely conditions list), and occurring at different mission stages. The aim was to collaboratively uncover how trust interaction changes and evolves over time, and the implications of trust evolution on the human↔agent interaction and CPH interface characteristics.

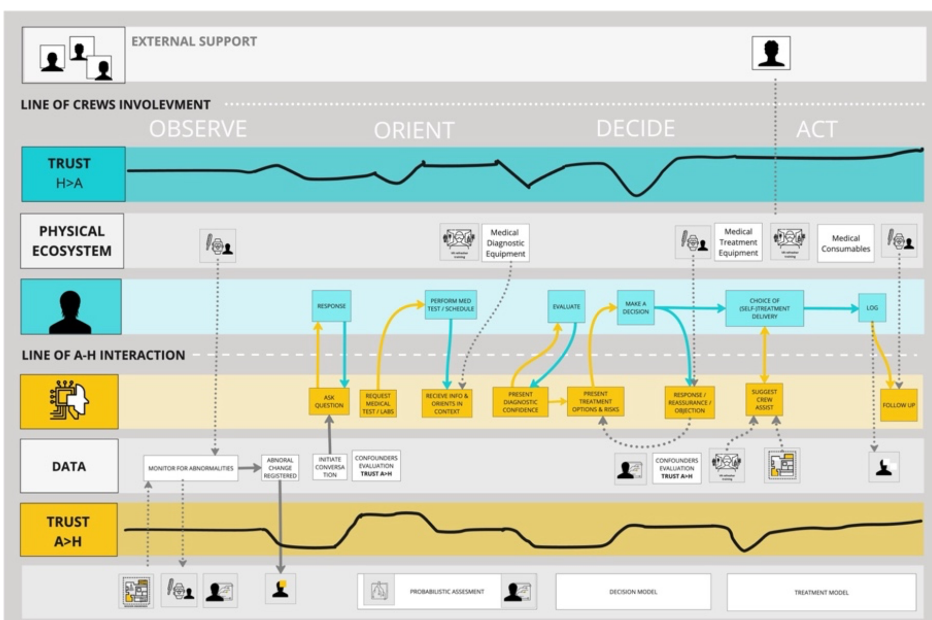

Fig. 8 H>A and A>H trust blueprinting within medical scenarios.

Next, incorporating insights from the SME scenario work and the trust-driven medical system requirements, we defined the key ExMEDI interface characteristics:

1. **Multi-modal multi-device interface.** Integration across multiple devices is required to support the astronaut and the crew within different contexts. The interface shall be able to support initiating interaction on different devices, including a screen of a personal astronaut device (tablet/computer), main cockpit display, wearable device (notifications), heads-up display, VR/AR display, and voice user interface.
2. **Team Health Suite.** A dedicated team-facing health suite interface provides easy access to crew health management, while preserving the medical privacy of individual team members. It enables initiating emergencies, displays team health preview, gives access to the team health calendar, and provides a detailed map of the medical suite with the location of medical equipment and consumables, training packages, etc. The main screen is a low-power display for compatibility with the dark cockpit approach (e.g., a monochrome e-paper screen, which lights up or changes in off-nominal situations).
3. **Personal Health Suite.** An individual astronaut-facing interface supports routine health check-ups, facilitates symptomatic assessment, provides an overview of personal health data, and schedules medical events. It allows fast initiation of emergency assistance and displays emergency alerts.
4. **Emergency Interaction (EI) Conversation.** The interface supports the crew in delivering emergency assistance screens with instructions. All crew members, including the agent, can activate the emergency assist through any interface modalities. An emergency call for crew assistance is also displayed on the main team health suite screen; alerts are sent through the personal companion wearables of the other team members.
5. **Symptomatic Interaction (SI) Conversation.** The diagnostic interaction can be initiated by the astronaut or the agent through multiple interface modalities (voice interface, wearable companion, or personal health suite). ExMEDI can also initiate the interaction based on the analysis of the astronaut data. Additionally, the medical officer can initiate symptomatic interaction for any of the crew members.
    - **Interaction staging:** The symptomatic interaction shall be facilitated through a step-by-step guided sequence that is both visible and understandable to the user. It shall also be easy to follow for anyone who might join the interaction at any later stage.
    - **Interface Adaptability:** The interface shall be able to adapt the interaction and information presentation (complexity, detail, salience, flow) based on observed context (e.g., distress, high mental workload, environmental conditions, etc.)
6. **Prevention Interaction (PI) Conversation.** Passive health monitoring data is regularly validated with the astronaut during Prevention Interaction (PI). PI is conducted as a routine chat conversation concerning physical and behavioral health, facilitating emotional regulation. When required, it is initiated to verify observed inconsistencies of data (e.g., conflicting readings), as well as gather reported $T_{H>A}$.

C. Case Study Interface Development: ExMEDI

The conceptual diagram illustrates the ExMEDI interface with the three types of health interactions—prevention, symptomatic, and emergency assistance—accessed accordingly for personal health suite and team health suite screens as needed (Figure 9). The prevention conversation is conducted primarily in a chat form. The emergency assistance interaction provides visual step-by-step instructions following a medical ABCDE protocol. The symptomatic interaction provides support in diagnosis, treatment selection, and delivery.

The symptomatic conversation is divided into three stages: diagnostic cycle, treatment selection, and treatment delivery support. The stages reflect the human doctor-patient interaction stages, organizing the information gathering (green line), supporting the decision-making process (yellow circle), assessing and choice of available treatment options (blue triangle), and assisting in treatment delivery (purple square). The diagnostic interaction stages are color-coded and represented on the progress bar at the top of each screen. Highlighting the progress stages also makes it easier for another crew member to step in to help as required.

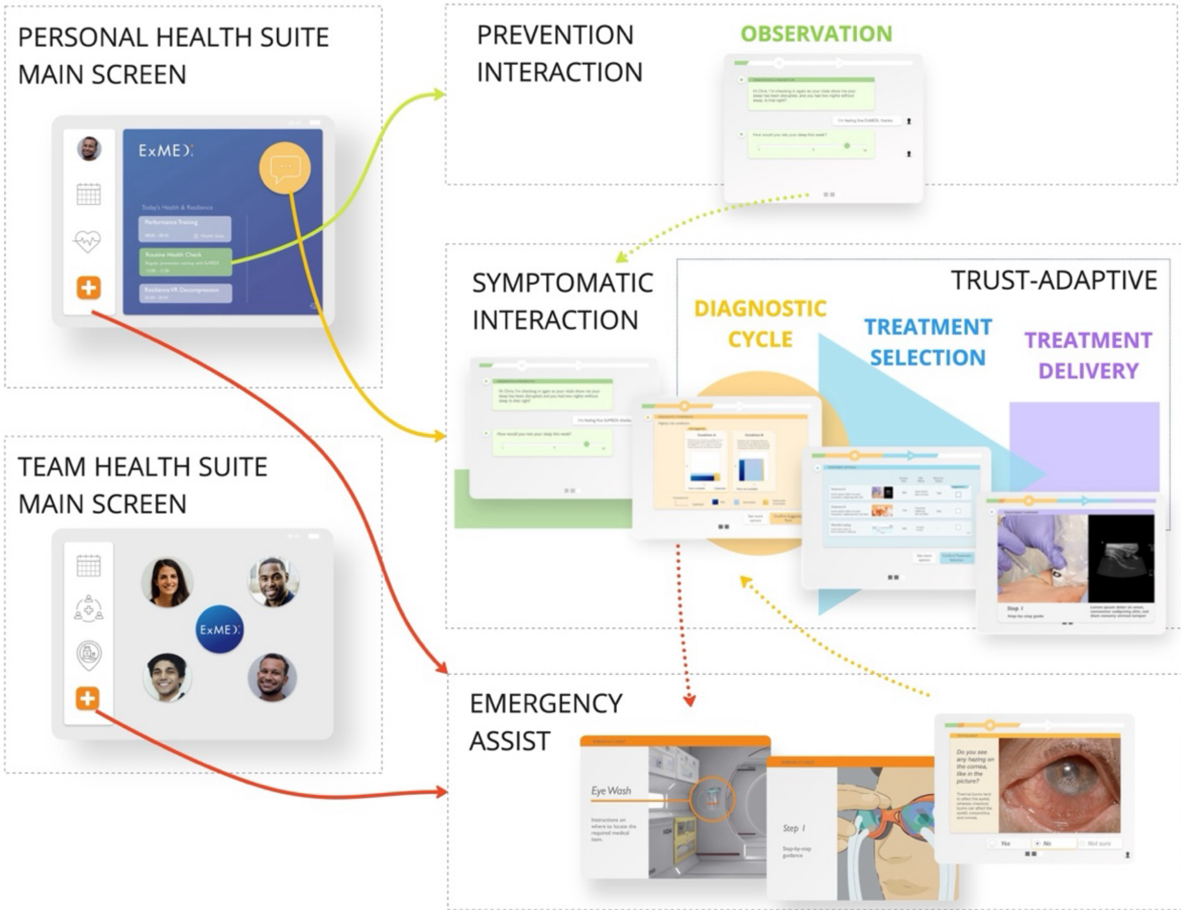

Fig. 9 ExMEDI conceptual interface diagram.

The diagnostic cycle, represented on the diagram by a yellow circle, offers step-by-step guided assistance to support symptom matching, providing diagnostic confidence regarding the most likely conditions, aiding in the consideration of available testing options and their impact on resources (Figure 10).

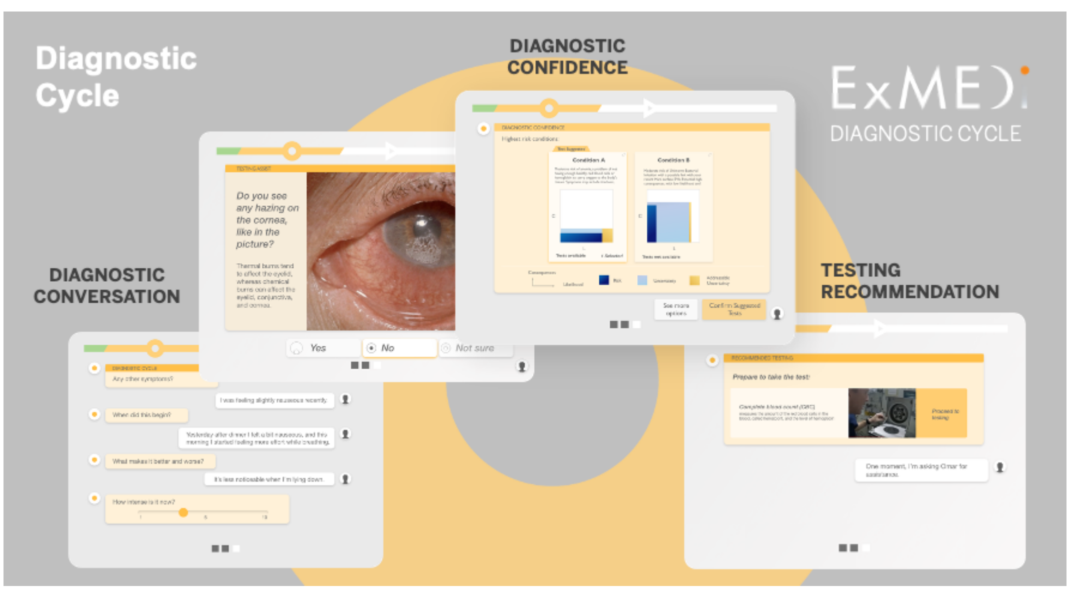

Fig. 10 ExMEDI Diagnostic Cycle.

The agent's diagnostic confidence is visually represented as the surface area corresponding to the likelihood and consequences (LxC), as shown in Figure 11. This representation illustrates the risk (dark blue area), along with the diagnostic uncertainty (light blue) and the addressable uncertainty (yellow), which can be reduced through testing available on board. The addressable uncertainty aids the CPH team in deciding whether to allocate resources for further testing. This cycle continues until a diagnosis is reached, transitioning to the next stage: treatment selection.

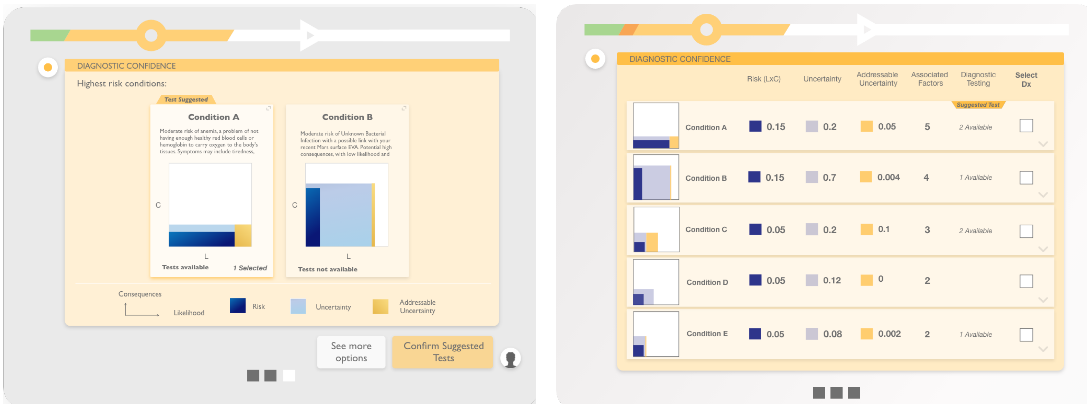

Fig. 11 ExMEDI Diagnostic Confidence.

The treatment selection stage provides an overview of treatment options available on board, including potential side effects, success rates, and impact on mission resources. Next, the treatment delivery stage offers step-by-step support on performing the treatment, presenting follow-along visual guidance or just-in-time training, as well as scheduling follow-ups, as required.

An important aspect of the symptomatic conversation is the adaptability of the interface and interaction to provide the right amount of information at the right time, depending on the context. This can be illustrated by the analogy of a pilot's cockpit display, which declutters and simplifies during an emergency landing. Human doctors adapt to the patient's needs intuitively. The ExMEDI interaction adaptation reflects that adaptation by tailoring the interaction flow of the interface based on $T_{A>H}$[3] related to human performance (mental processing and salience), knowledge of the human, and systems situational awareness (adaptation to location and context). This means that if the agent $T_{A>H}$ level indicates that the astronaut is in distress or in a time-critical situation, interaction is simplified, and the interface presents fewer options or agent's direct instructions (Figure 12). Depending on $T_{A>H}$, the agent can adjust the level of assistance. In low $T_{A>H}$ situations, such as observed astronaut distress, hypoxia, or behavioral changes, the agent can adapt the response to provide adequate support. The interface is not only adaptive, but also the choice of the trust mode is adaptable - the astronaut can switch to a detailed or simplified mode if required.

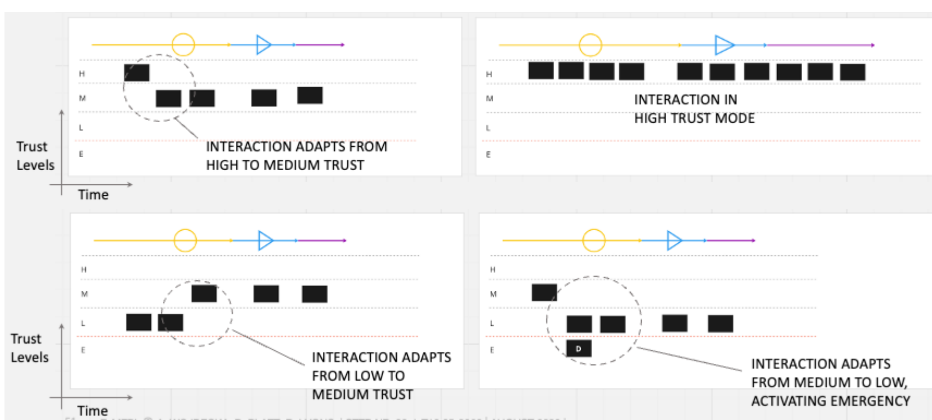

Fig. 12 $T_{A>H}$ interface adaptation.

[3] ***$T_{A>H}$ Definition**: Agent's assessment of the human's ability to perform a task and the perceived level of agent's assistance needed, derived from the observed human's state (such as biometric data, stress, accuracy, attention, etc.), prior knowledge of the human (training data), the observed state of the human's environment, and knowledge of the human's personal circumstances [8].*

The interface and interaction design characteristics are informed by the trust-driven system requirements and the trust factors from three directions of CPH trust: $T_{H>A}$, $T_{A>H}$, and $T_{A>A}$. The interface adaptation is modulated based on the $T_{A>H}$ trust levels. Figure 13 illustrates the dynamic adaptation of ExMEDI within two selected scenarios. In the top scenario (Scenario 3), the interaction is initiated by the astronaut and takes place in multiple locations, spanning a longer period. Medical support is delivered through multiple devices (heads-up display, wearable, and a tablet) and involves three crewmembers at different stages: the astronaut, the point of contact, and the medical officer). The ExMEDI interface adapts based on the $T_{A>H}$, beginning with medium trust, dropping to low trust, and eventually rising to high trust mode when the medical officer joins the interaction. In the bottom scenario (Scenario 2), interaction is initiated by the agent and starts as a routine checkup in high-trust mode. It decreases during the interaction, eventually dropping to low-trust mode when a potential mental health crisis is identified. At that point, the agent takes emergency steps, raising the alert to the medical officer and the ground medical team.

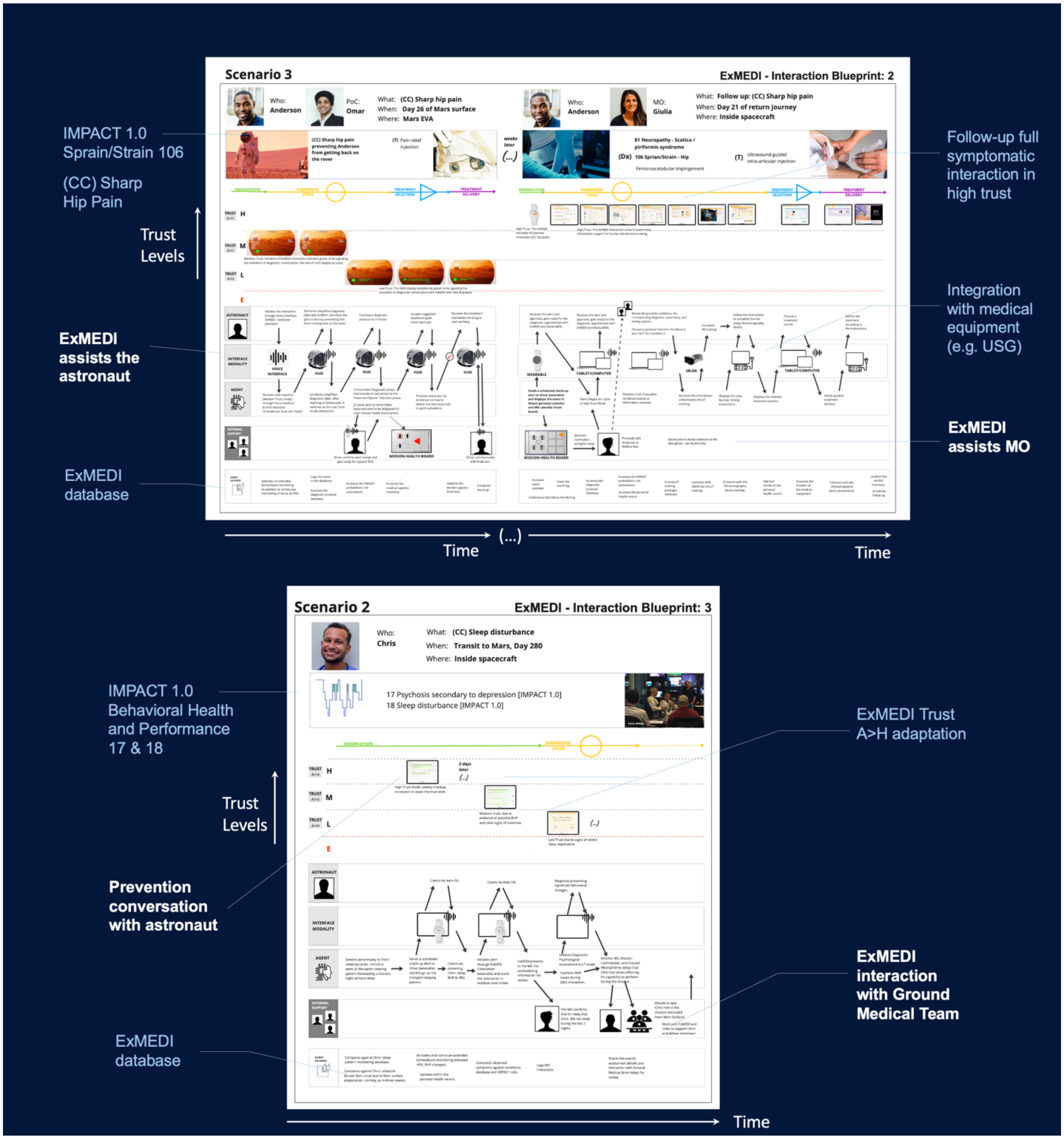

Fig. 13 Interface trust adaptation illustrated in the context of example medical scenarios.

V. Conclusion

CPH team collaboration will play a crucial role in enabling crew medical autonomy and Earth-independent medical decision-making. Future LDHSF missions will require new approaches to facilitate the development of onboard medical systems and CDS interfaces that incorporate trust in CPH team interactions. Designing the future CPH-team-oriented system architecture requires transdisciplinary collaboration among stakeholders from different backgrounds. The CPH-team trust and medical interaction characteristics need to be envisioned in a future context. New frameworks are needed to facilitate the inclusion of diverse stakeholder expertise from the early mission planning stages. To design effective CPH-oriented medical interfaces, new tools are required to consider CPH trust as a fundamental part of the system.

In this paper, we described a transdisciplinary framework to design out unwanted health futures, which facilitates diverse stakeholder collaboration applied to the design of a CPH-team-oriented medical interface. We developed CPH trust maps that allow diverse stakeholders to consider trust factors related to three trust directions: $T_{H>A}$, $T_{A>H}$, and $T_{A>A}$. We illustrated the application of CPH trust maps and trust blueprinting to elicit trust-driven requirements and define human-agent interaction characteristics. As a case study, we presented a conceptual design of Exploration Medical System Design Interface (ExMEDI), a CDS system that utilizes trust adaptation to improve human-agent interaction.

The application of the framework illustrates how the anticipatory structure of the work facilitated the effective inclusion of diverse stakeholder expertise from the early mission planning stages. The incorporation of design thinking allowed stakeholders to effectively envision human-agent medical collaboration in the context of exploration missions and explore through a role-play the CPH team medical interaction. The presented CPH trust maps effectively supported the inclusion of diverse stakeholder perspectives while considering CPH trust as a first-class component. The derived exploration medical system requirements covered all CPH trust influencing factors within the three trust dimensions and included considerations that would otherwise be missed. The developed trust blueprints facilitated the collaborative observation of $T_{H>A}$ and $T_{A>H}$ as dynamic variables during the agent-human medical interaction and informed the formulation of CPH interface characteristics. Mapping human ↔ agent trust throughout the CPH medical scenarios highlighted the opportunity to develop an interface that dynamically adapts to meet astronaut needs based on mission and individual context. The developed ExMEDI interface specifies the CPH team-facing and astronaut-facing health suites, as well as different types of human-agent health(care) interactions, which are structured into distinctive phases. To provide the appropriate level of support to the astronaut depending on the situation, ExMEDI allows for dynamic interaction and information presentation that is trust-adaptive.

Our future work will further develop ExMEDI, taking advantage of the identified opportunities related to trust-driven and trust-adaptive CPH medical interfaces. We will focus on exploring the neuroeconomics of dynamic medical decision-support interfaces, along with the effects of CPH trust calibration on medical decision-making under pressure.

This research advances the development of frameworks and tools for the collaborative development of future CPH-team-oriented medical system architecture. The framework and tools for transdisciplinary collaboration introduce new approaches to trust-informed design and trust-driven CPH team collaboration during LDHSF, thereby creating a pathway to future crew medical autonomy and Earth independence.

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