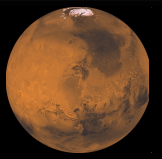
Supporting Crew Medical Decisions on Deep Space Missions: Real-Time Performance Monitoring



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NASA Human Research Program
Exploration Medical Capability Element
Clinical Decision Support Team

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IAASS 2021 – Managing Risk in Space

Earth Dependent

Mercury

Apollo

ISS

MIR

Shuttle

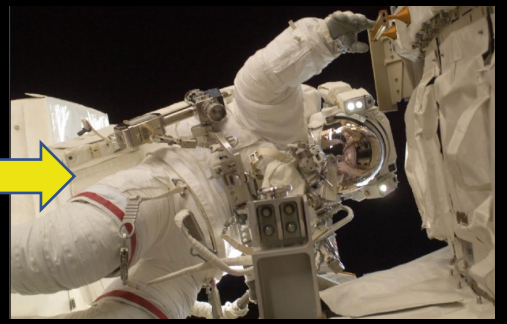
- Flight
- CAPC
- FDO
- GPO
- PROP
- GNC
- DPS
- EVA
- PDRS
- EECO
- EGIL
- INCO
- RIO
- GC
- FAO
- PAYL
- MMA
- SURGEON
- MOD

Earth Dependent

Payload Operations & Integration Center

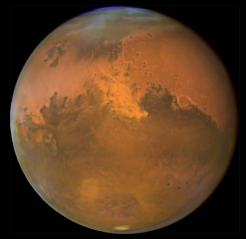
Mission Evaluation Room (MER)

Mission Control



The Risk

From Earth Dependent → To Earth Independent



Communication - Delays (up to 42 min)
Communication - Disruptions

NASA Human Research Program (HRP)
Human Factors & Behavioral Performance (HFBP) Element
Human System Integration Architecture (HSIA) Risk

Risk of Adverse Outcome Due to Inadequate Human Systems Integration Architecture (HSIA)

Given decreasing real-time ground support for execution of complex operations during future explorations missions, there is a possibility of adverse performance outcomes including that crew are unable to adequately respond to unanticipated critical malfunctions or detect safety critical procedural errors.

Time Critical Tasks

Complex Tasks

Exploration Goal

Maintain Vehicle & Habitat

GOAL: Maintain vehicle/habitat		
	Tasks	
	3	**Respond to unanticipated major vehicle/habitat malfunctions**
	a	Respond to hatch failure during docking.
	b	Respond to major fault of the cooling system.
	c	Respond to failure of autonomous software in the avionics system.
	d	Respond to major Electric Power Systems (EPS) failure.
	4	**Perform installation/activation/inspection of vehicle/habitat systems**
	a	Deploy supports/structures, manually, to configure dedicated area of spacecraft for medical procedure.
	b	Perform first-time or dormant activation of vehicle/habitat system.
	c	Anticipate known vehicle/habitat issues through inspection, or troubleshoot for unknown vehicle/habitat issues.
	5	**Manufacture hardware, software, and fuel**
	a	Connect flexible hose to fittings on the fuel production storage tanks and Mars Excursion Vehicle (MEV)/Mars Ascent Vehicle (MAV), manually to prepare for refueling.
	b	Activate pumps on fuel production system, manually to transfer fuel from storage tanks to Mars Excursion Vehicle (MEV)/Mars Ascent Vehicle (MAV).
	c	Manufacture replacement parts to repair oxygen generation equipment.
	6	**Modify, maintain, repair, and replace hardware, software, and procedures**
	a	Monitor (i.e., measure and estimate) and predict vehicle system performance.
	b	Enter control inputs, manually, to load software patch / reload software.
	c	Review documentation / enter control inputs, visually / manually, to diagnose software problem.
	7	**Perform nominal system commanding**
	a	Reconfigure communication system for private calls.
	b	Manually configure habitat settings (i.e., temperature, light, etc).
	c	Adjust surface EVA suit controls, manually to operate mobile communications with Mars habitat personnel.

Time Critical Tasks

Complex Tasks

Exploration Goal
Perform Mission Related Tasks

1. Maintain vehicle & habitat
2. Perform mission tasks

GOAL: Perform mission-related tasks		
	Tasks	
	8	**Perform piloting/navigation task**
	a	Operate propulsion controls to maneuver spacecraft for either near- or far-field rendezvous or docking.
	b	Adjust attitude control thrusters, manually, to dock Mars Excursion Vehicle (MEM)/Mars Ascent Vehicle (MAV) to spacecraft in Mars Orbit.
	c	Monitor system displays, visually, to assess proximity and verify docking with spacecraft in Mars Orbit.
	9	**Perform space or planetary EVAs**
	a	Conduct surface EVA on unfamiliar terrain as part of a scientific mission.
	b	Descend gully while carrying hand tools and wearing surface EVA suit to conduct geological research.
	c	Conduct space EVA to repair failed equipment.
	10	**Perform planetary rover vehicle ops**
	a	Deploy and attach battery cables to surface rover, manually while wearing surface EVA suit, to prepare for recharging rover batteries.
	b	Deploy surface rover vehicle, manually/visually while wearing surface EVA suit, to prepare for use.
	c	Navigate rover to a predetermined research site.
	11	**Perform robotics activities**
	a	Deploy and operate robot, remotely during cruise phase, to inspect external features of spacecraft.
	b	Operate robot, remotely on surface, to assemble system elements to prepare field camp for humans.
	c	Operate multiple robotic drones to survey geological sites of interest.
	12	**Perform science activities**
	a	Conduct and record Mars observations using onboard equipment and telescopes.
	b	Conduct life science experiments involving crew members, manually using various instruments in the surface habitat, to generate data.
	c	Collect geological samples, manually using Apollo-type scoop (1m handle) and sample bags, while wearing surface EVA suit.
	13	**Perform scheduling, planning, and task allocation**

Time Critical Tasks

Exploration Goal
Maintain Crew Health

1. Maintain vehicle & habitat
2. Perform mission tasks
3. Maintain crew health

GOAL: Maintain crew health		
	Tasks	
	1	**Respond to medical/behavioral health events**
	a	Respond to sudden cardiac arrest: Limited to BVM, chest compressions, AED, IO and epinephrine; treatment lasting < 45 mins.
	b	Use medical software along with vitals/test results to help diagnoseis condition of unconscious injured/ill crewmember.
	c	Respond to behavioral emergency: Treatment period is short (0-3 days) and well defined (acute, organic event).
	d	Respond to unexpected traumatic injury in the context of an interplanetary mission.
	2	**Maintain physical and psychological crew health and fitness**
	a	Manage sleep, evaluating disorders as they arise.
	b	Coordinate exercise device availability among crew to ensure access to maintain cardiovascular conditioning, muscle strength, and bone density.
	c	Manage diet, including nutritional intake, food growth, and meal preparation.
	d	Maintain hygiene, e.g. during dental cleaning, or during waste management.
	e	Perform social and recreational activities during rest hours.

1. Maintain vehicle & habitat
2. Perform mission tasks
3. Maintain crew health
4. Cross-cutting tasks

Exploration Goal

Coordinate, Communicate, Solve Problems & Make Decisions

Cross-cutting tasks (Task enablers)		
A		**Coordination, leadership, and team work**
	a	Coordinate simulator availability among crew to ensure refresher training for all required skills and functions.
	b	Schedule tasks and monitor performance of work to ensure that opportunities and resources are allocated appropriately among crew personnel.
	c	Coordinate multi-teams towards a single objective.
B		**Communication**
	a	Speak with other members of the crew accurately and concisely concerning technical and task-related topics.
	b	Communicate with team members proactively to enhance situation awareness among the team.
	a	Communicate on different modalities with Earth/MCC under different time delay regimes.
C		**Problem solving/decision making**
	a	Define goals and acceptable performance.
	b	Integrate information from existing sources (i.e., hardware, software, human, and operational aspects).
	c	Trend monitoring / data analysis.
	d	Detect anomalies.
	e	Utilize lessons learned/historical data (e.g., Skylab, ISS lessons-learned documents).
	f	Determine candidate paths / solutions, workarounds / alternatives, and consequences / impacts.
	g	Validate solutions.
	h	Document resolutions, new data, and lessons learned.

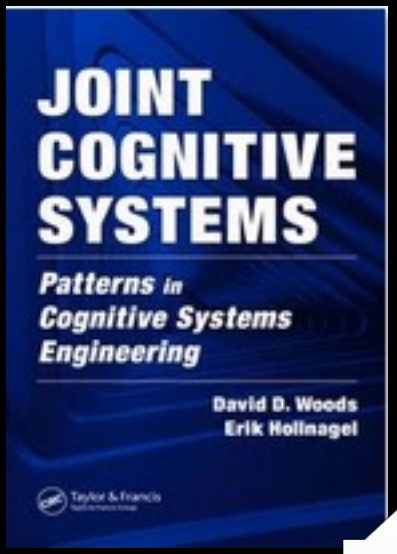
Holden, K., et al. (2019). Human Capabilities Assessment for Autonomous Missions (HCAAM) Phase II: Development and Validation of an Autonomous Operations Task List. Final Report delivered to the NASA Human Research Program, HFBP Element

How Do People Respond to Anomalies?

Clinical Decision Support

Anomaly Response Categories

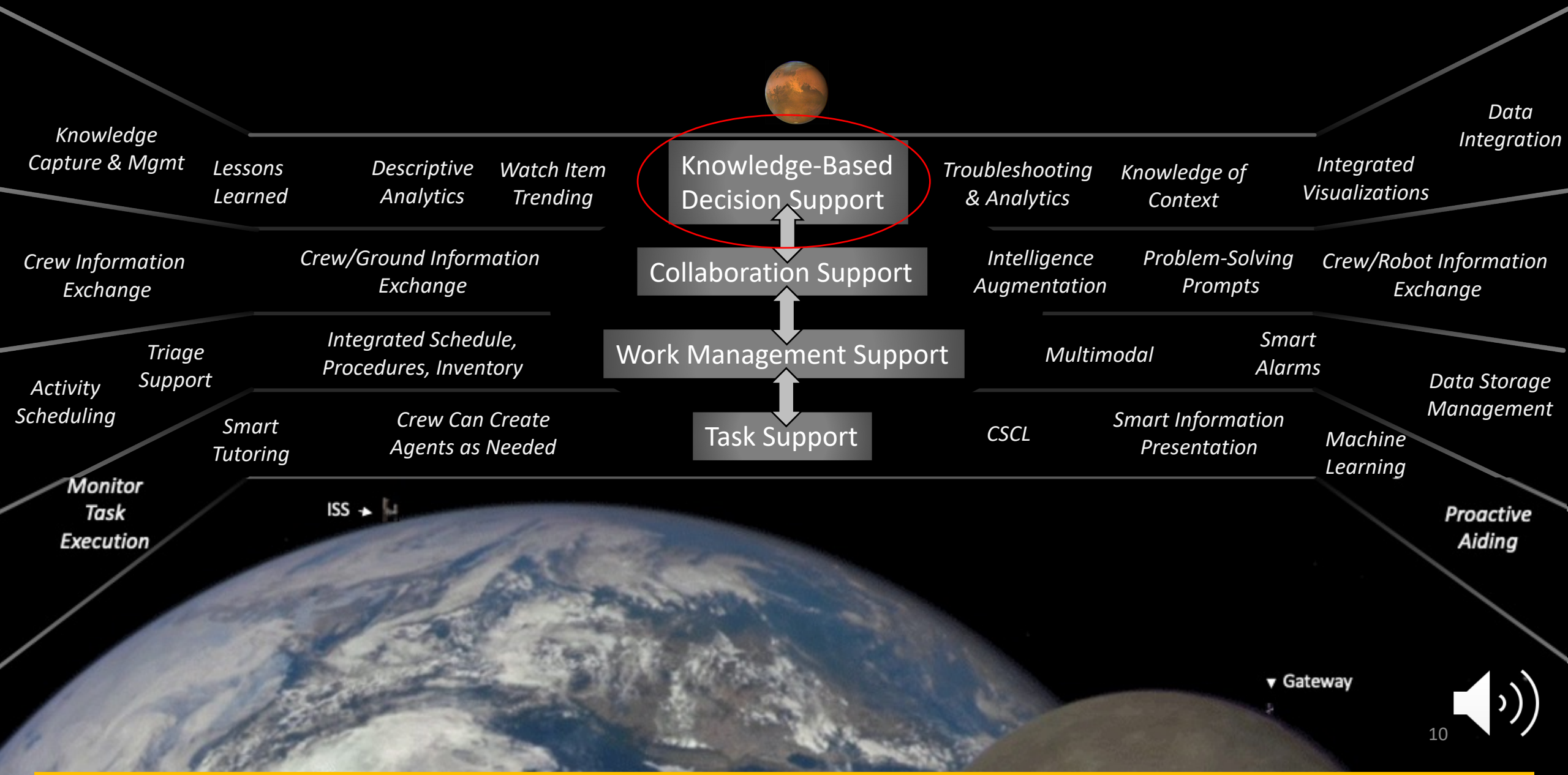
a) Detect and Recognize
b) Troubleshoot/Diagnose
c) Treat
d) Manage



Woods, D.D., Hollnagel, E., 2006. Joint Cognitive Systems: Patterns in Cognitive Systems Engineering. CRC Press, Boca Raton, FL

Exploration Enabling Capabilities

and exemplar processes, practices or technological goals



Exploration Enabling Capabilities

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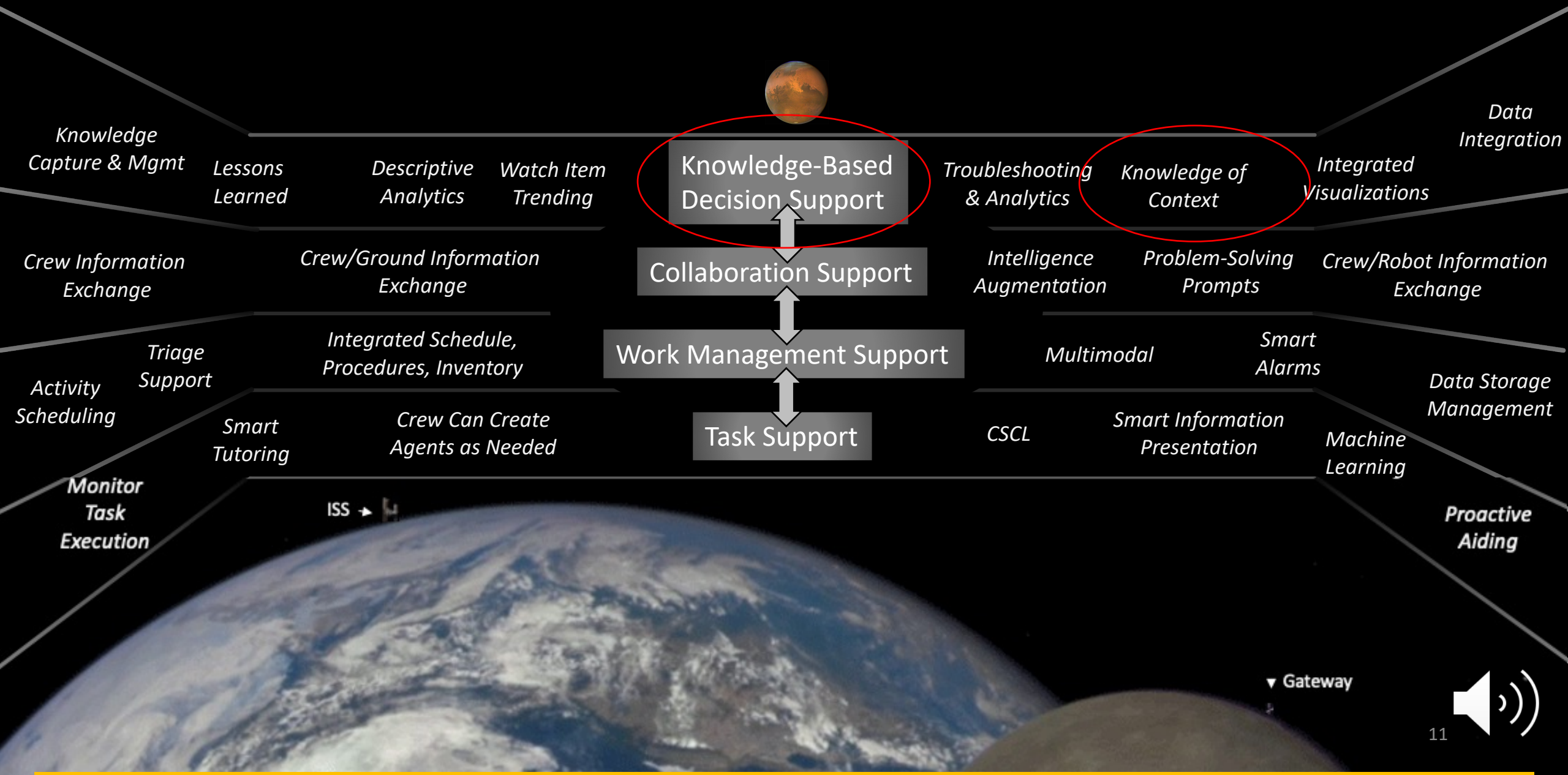


Methods used to Understand Current Context (examples)

- Performance Measures (e.g., cognitive testing)
- Questionnaires
- Sensors (e.g., activity measures, local CO_2 monitoring)
- Computer-controlled events
- Electroencephalography (EEG)
- Cameras

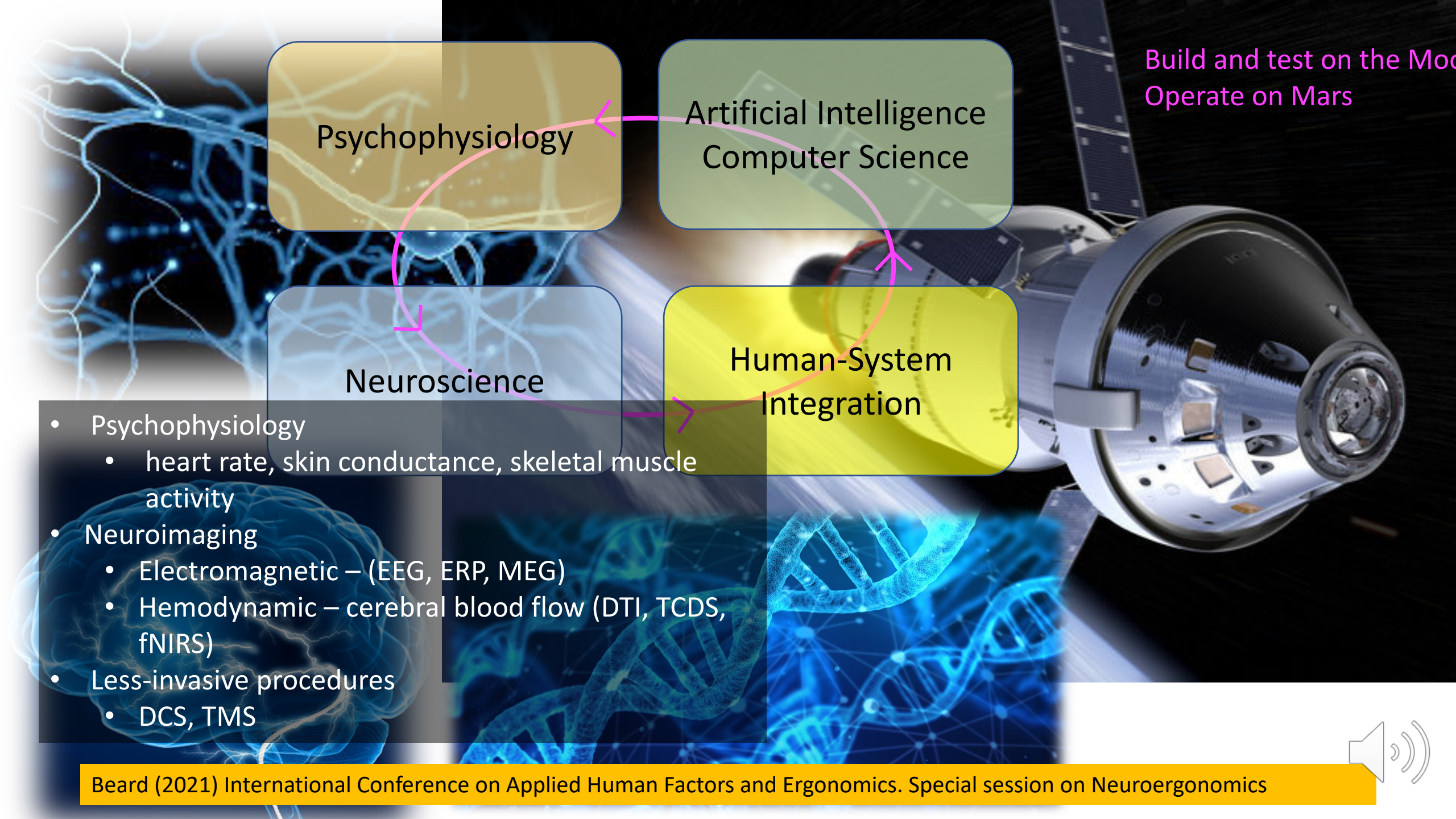
EEG

Monitor vitals during exercise

ActiWatch

CO_2 Monitor

Cognitive Testing

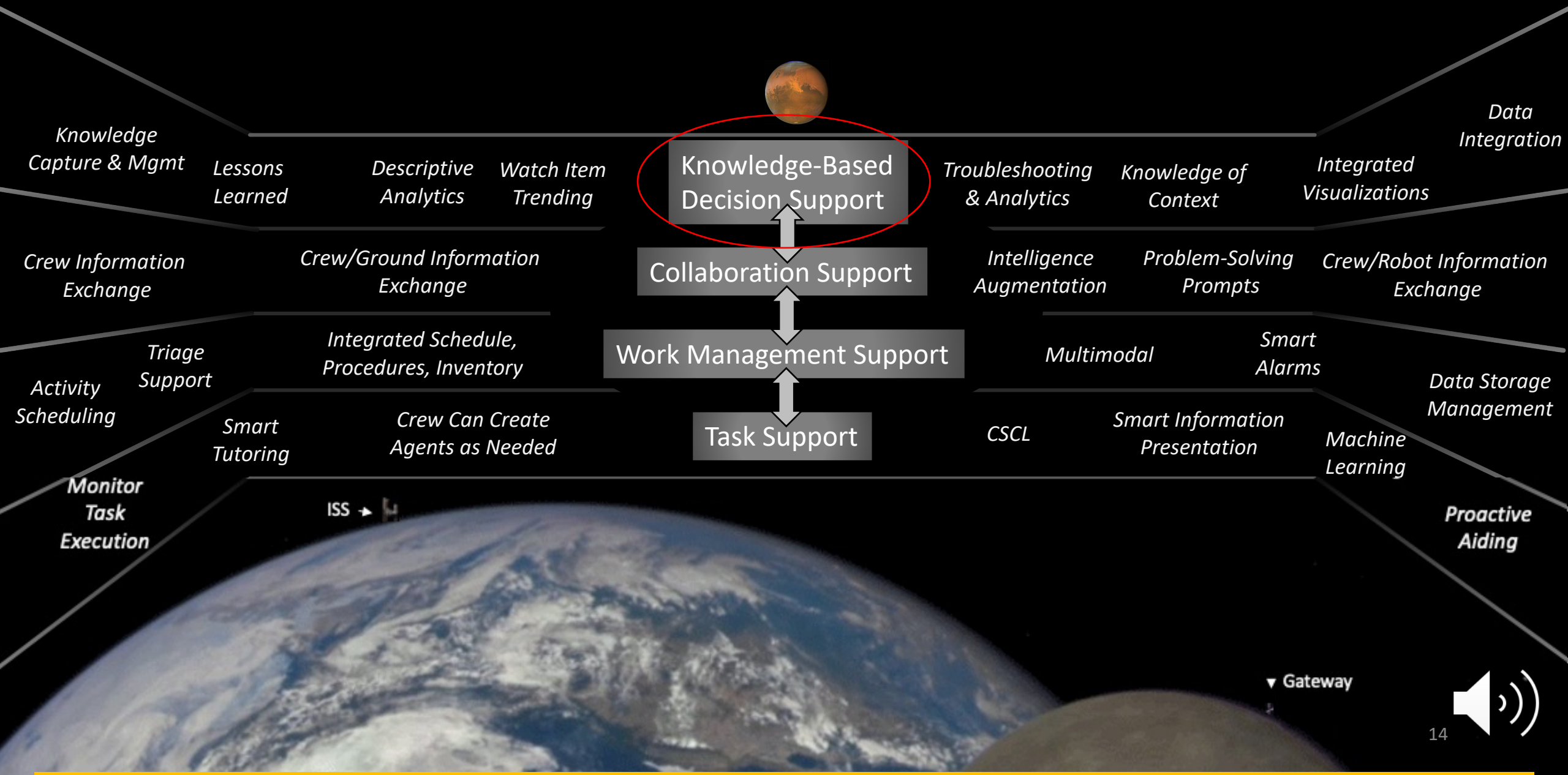


- Psychophysiology
  - heart rate, skin conductance, skeletal muscle activity
- Neuroimaging
  - Electromagnetic – (EEG, ERP, MEG)
  - Hemodynamic – cerebral blood flow (DTI, TCDS, fNIRS)
- Less-invasive procedures
  - DCS, TMS

Beard (2021) International Conference on Applied Human Factors and Ergonomics. Special session on Neuroergonomics

Exploration Enabling Capabilities

and exemplar processes, practices or technological goals



Leveraging Existing Clinical Decision Support Capabilities

Typical CDSS Functions and their Applicability to Deep Space Missions		
Example Historical CDSS Functions	**Anomaly Response Category Addressed**	**Potentially Relevant to Crew Emergency Medical Response**
Manage medical information (e.g., EHR)	(a) (b) (c) (d)	✓
Information retrieval tools	(a) (b) (c) (d)	✓ if rapid
Patient triage support	-	✓
Nutrition tracking	(a)	
Sleep tracking	(a)	
Records and presents vitals	(a) (b)	✓
Laboratory interpretation	(b)	✓
Diagnostic code standardization	(b)	
ID most-appropriate imaging test for diagnostics	(b)	✓
Vitals interpretation	(b)	✓ if rapid
Imaging interpretation	(b)	✓ if rapid
Lab interpretation	(b)	✓ if rapid
Clinical guidelines	-	
Preventative care	-	
Flagging patient research eligibility	-	
Medication alternatives	(c)	✓
Drug dosing	(c)	✓
Automated warning for drug contraindications	(c)	✓
Medications tagged with radio-frequency identification (RFID)	(c)	✓
Medication reminders	(c)	

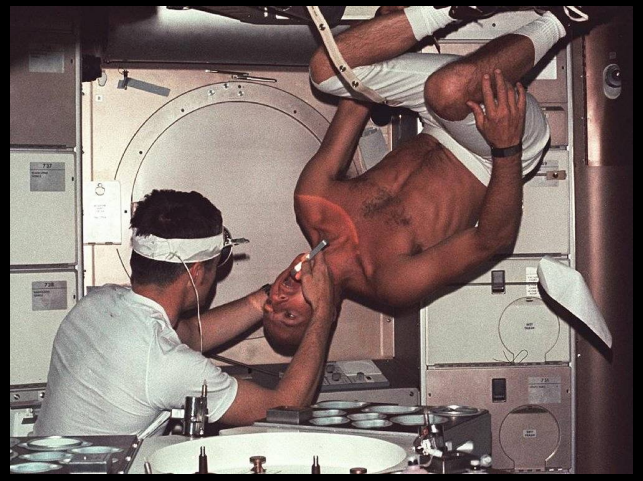
Anomaly Response Category

a) Detect and recognize
b) Troubleshoot/Diagnose
c) Treat
d) Manage

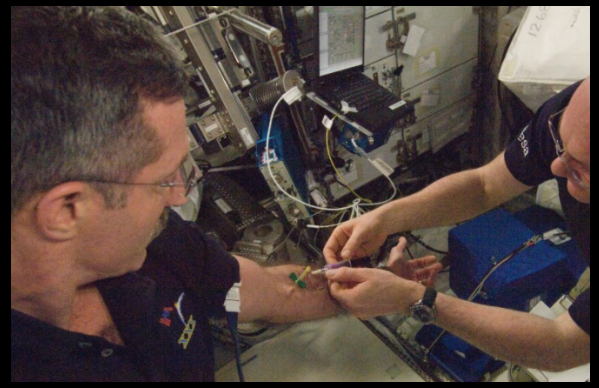
Additional Decision Support Functions

Different Levels of Expertise

CMOs sometimes non-physicians



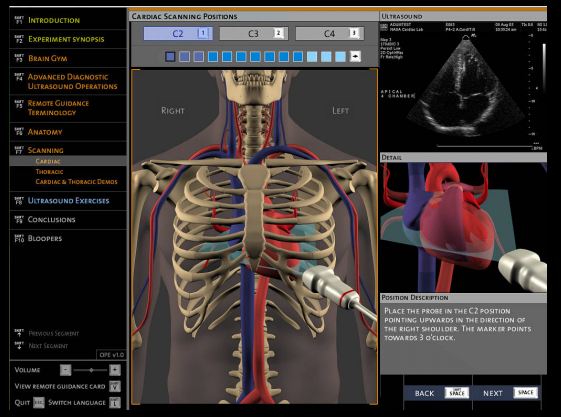
Checkup on Skylab



ESA Crew

Crew Medical Officer or CMO

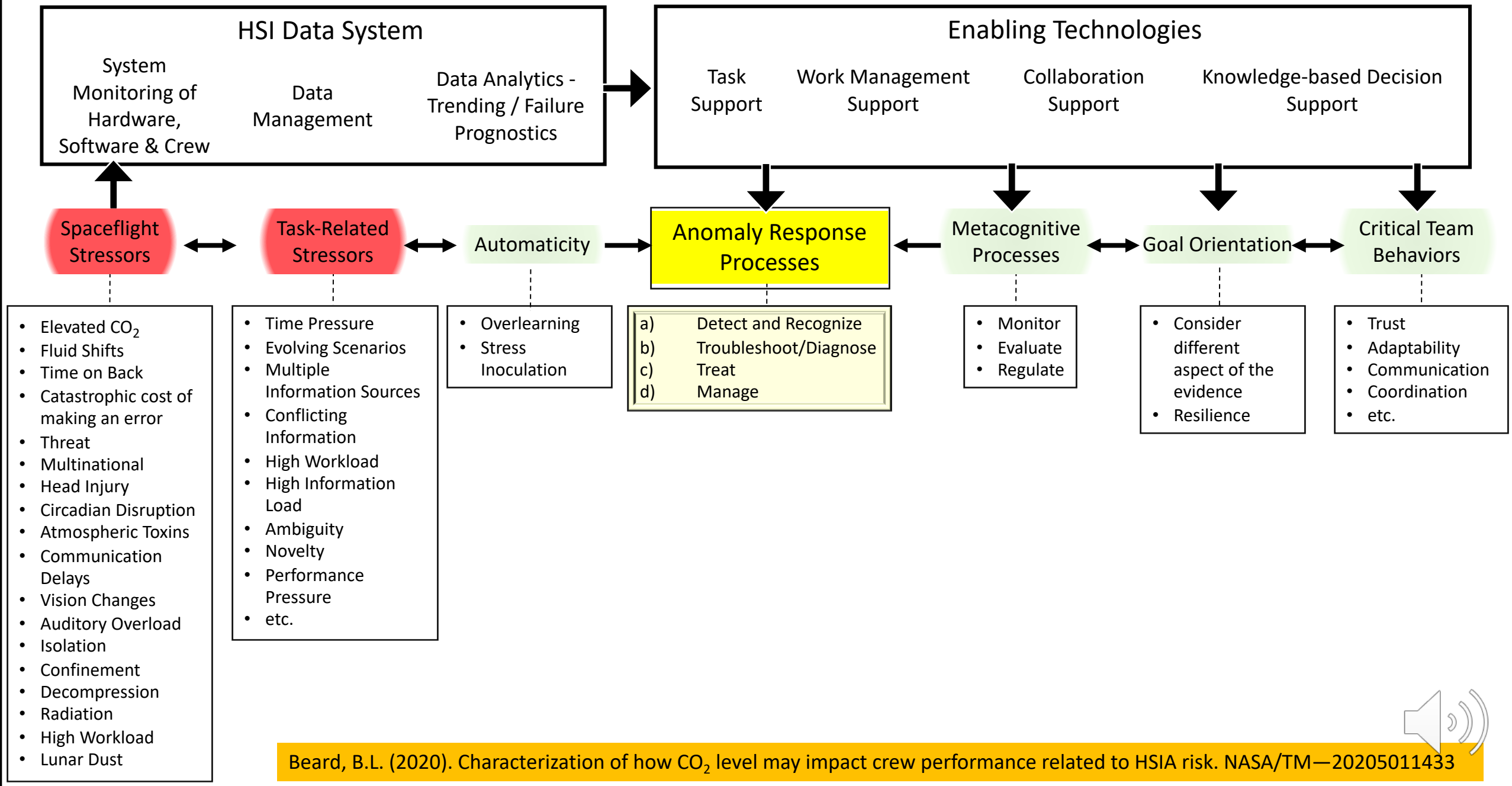
CMO Non-Physician Training



Ultrasound Training

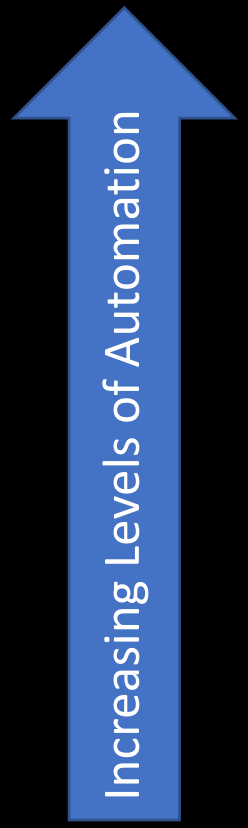
Tooth Extraction

Anomaly Response Framework



Beard, B.L. (2020). Characterization of how CO_2 level may impact crew performance related to HSIA risk. NASA/TM—20205011433

Need to Know the Current Status to Best Support Medical Decisions



Levels of Decision Support

System acts autonomously

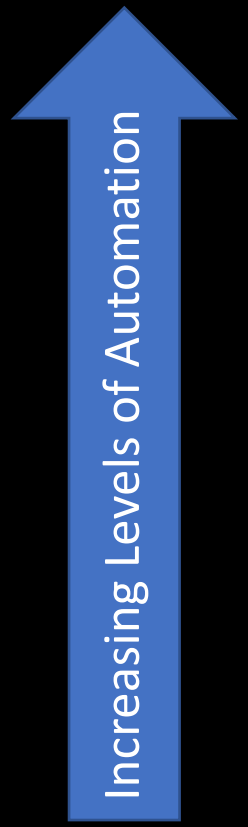
-
-
-
-
-

System makes suggestions

-
-

Crew make decisions autonomously

Determine the Current Status/Context to Best Support Medical Decisions



Levels of Decision Support

System acts autonomously

-
-
-

System provides levels of automation based on context

-

System makes suggestions

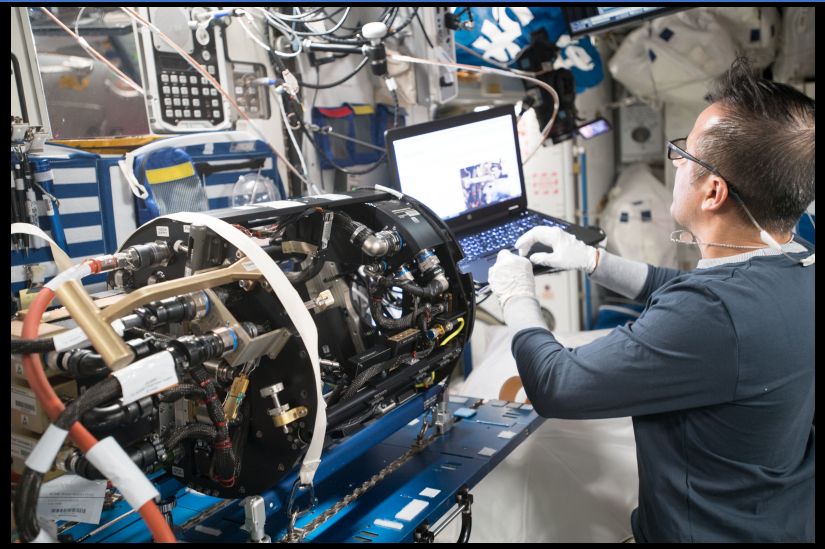
-
-

Crew make decisions autonomously

Semi-continuous, Real-Time, Unobtrusive Performance Monitoring

Everyday behavior

Maintenance Activities
(Andrew Morgan)



Materials flammability investigation
(Joe Acaba)

Work with Science Equipment
(Samantha Cristoforetti)

Semi-continuous, Real-Time, Unobtrusive Performance Monitoring

Passive assessment of daily behaviors

Useful devices and methods to measure current context

Devices Include

- Video Cameras
- Microphones
- Sensors
  - Accelerometers
  - Vibration
  - Wearable Inertial
  - Infrared
- RFID tags

Metrics Include

- Real-time Fatigue Assessment
- Computer Use Patterns
  - Typing Speed
  - Word Complexity
  - Cursor Positioning over time
- Touchscreen Use Patterns
- Gait Analysis
- Eye Movements
- Social Interactions
- Speech Analysis
- Facial Expressions

Use of personal robots to continuously monitor performance?

Astrobee2 robot

e.g., Stringer, G., et al. (2018). Can you detect early dementia from an email? A proof of principle study of daily computer use to detect cognitive and functional decline. *International journal of geriatric psychiatry*, *33*(7), 867-874.

Semi-continuous, Real-Time, Unobtrusive Performance Monitoring

Driving Ability

Cognitive impairment ➡ Driving performance

Driving performance ➡ Cognitive impairment

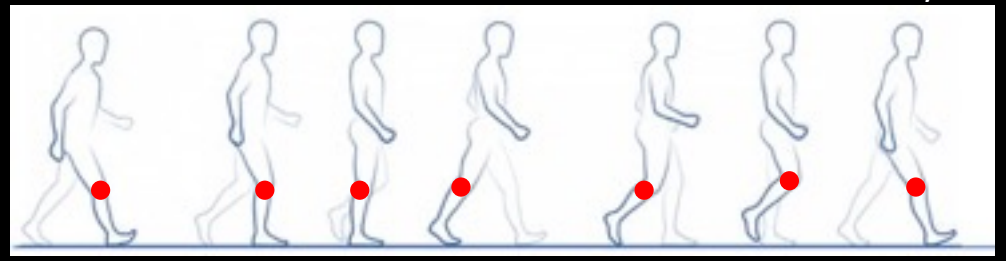
Apolinario, D. et al. (2009). Cognitive impairment and driving: A review of the literature. *Dementia & Neuropsychologia*, *3*, 283-290.

Semi-continuous, Real-Time, Unobtrusive Performance Monitoring

Gait Analysis

Compromised Mobility

Kinematic feature analysis



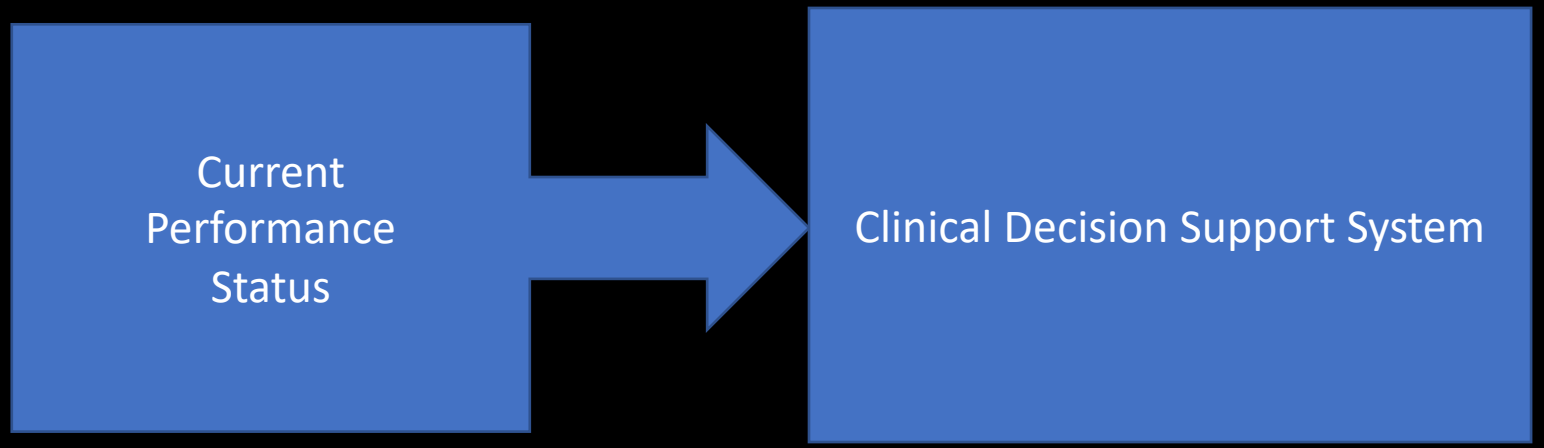
Roberts, M., et al. (2017). Biomechanical parameters for gait analysis: a systematic review of healthy human gait. *Phys. Ther. Rehabil*, *4*(6).

Passive infrared (PIR) motion detectors

Hagler, S., et al. (2009). Unobtrusive and ubiquitous in-home monitoring: A methodology for continuous assessment of gait velocity in elders. *IEEE transactions on biomedical engineering*, *57*(4), 813-820.

Take Away

- Crew will need to be self-reliant
- Decision support should address the current context of the situation, including crew task performance status



- Crew will need more than static decision support to respond to time-critical anomalies
- Support should be
  flexible
  situationally aware
- The unobtrusive monitoring of individual crewmember motor and cognitive behaviors should be considered a critical line of research & development.