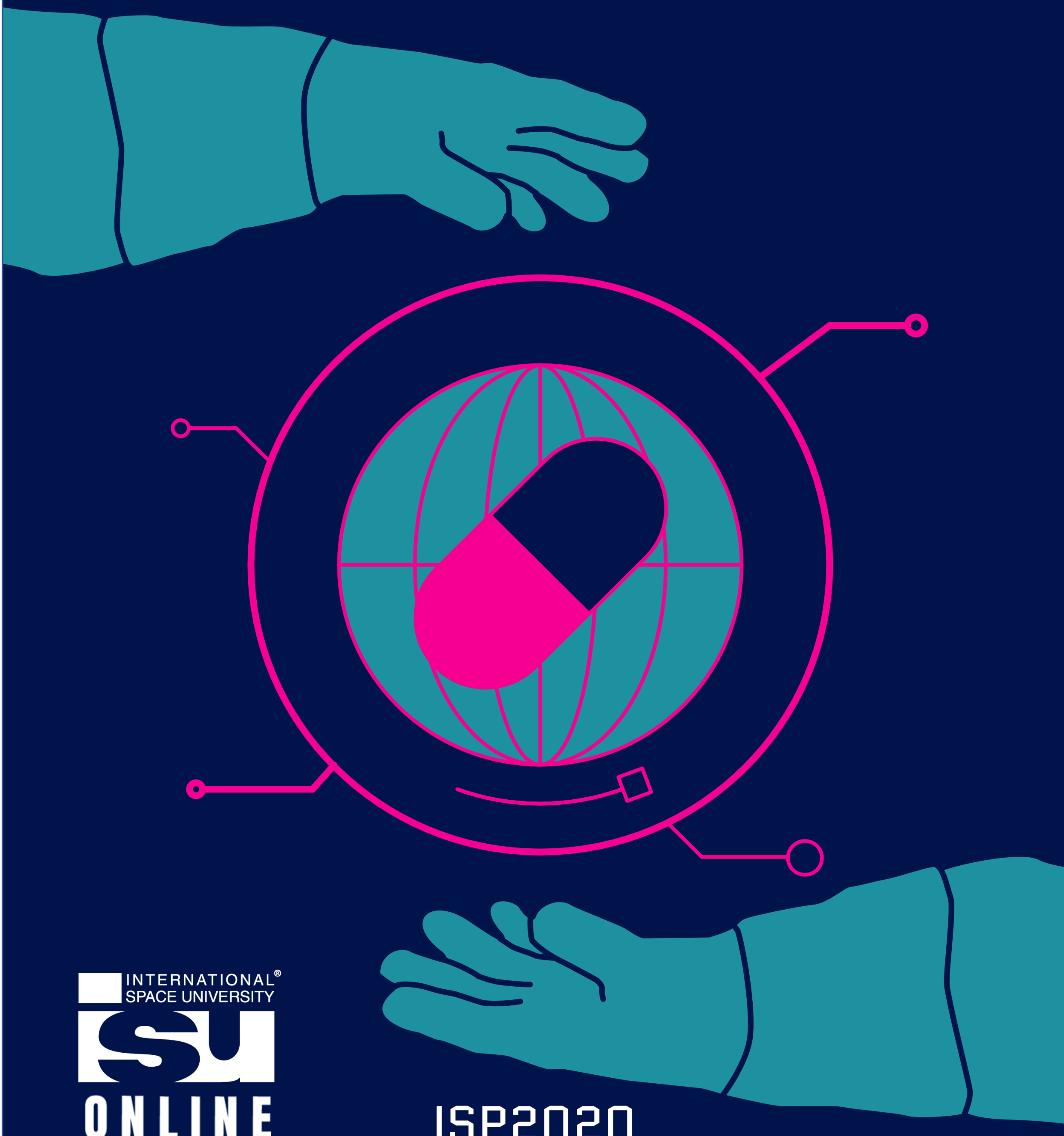
Report

Utilizing Space-Enabled Capabilities for the Mitigation of COVID-19 and Future Pandemics



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ISP2020

Utilizing space-enabled capabilities for the mitigation of COVID-19 and future pandemics

Final report

International Space University

Interactive Space Program 2020

Publication information page

The cover design shows a geometric stylization of Earth as seen from space, orbited by the depiction of a satellite. Earth is overlaid by a pill, representing a medicine or a cure for pandemics. Above and below Earth, there are two hands in astronaut gloves representing the human connection of space. The arms both cradle the Earth (taking care of it) and pass on a cure to each other (the pill). Earth is surrounded by a circle symbolizing a worldwide network both in an ecological and technological sense. This indicates the pandemic is affecting all of humankind and refers to the online format of ISU's Interactive Space Program 20. The four appendages around the circle stand for data and information as one of the tools available to us in the combat against pandemics. The bottom left shows the logo of the International Space University.

All artwork on the cover and the page backgrounds is by the ISP 20 design team.

The mission patch is an original artwork by participants of the Interactive Space Program.

The crew infographic was created by Joshua Bernard-Cooper.

The 2020 Interactive Space Program was held by the International Space University (ISU)

Electronic copies of the Executive Summary and Team Mission Report may be found on the ISU website (httm://isulibrary.isunet.edu/).

International Space University

Strasbourg Central Campus Parc d'Innovation

1 rue Jean-Dominique Cassini 67400 Illkirch-Graffenstaden France

Tel +33 (0)3 88 65 54 30

Fax +33 (0)3 88 65 54 47

e-mail: publications@isunet.edu

website: www.isunet.edu

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ISU Mars team staff

Scott Schneider, Co-Commander
Liang Chen, Co-Commander
Nate Taylor, Habitat Officer
Ruth McAvinia, Supervising Editor

ISU Program Commanders and Officers

Juan de Dalmau, Daily Seminar Co-Commander
François Spiero, Daily Seminar Co-Commander
Farhan Asrar, Commander
Carol Carnett, SEAC & Content Review Lead
Arif Göktuğ Karacalıoğlu, Captain
Lisa Kucher, CapCom
Alexandra Ryan, Chief Academic Officer

Mission Specialists

Name	Organisation
Christophe Lasseur	ESA - ESTEC
Danijela Stupar	ISU - International Space University
DanLing Tang	South China Sea Institute of Oceanology
Dave Williams	Exploration Incorporated
Douglas Hamilton	University of Calgary
Elliott Wobler	Spire
Gongling Sun	ISU - International Space University
Helena Chapman	NASA
Jacques Arnould	CNES - Headquarters
James Green	NASA Headquarters
Joe Mascaro	Planet
John Connolly	NASA Johnson Space Center
John Haynes	NASA Science Mission Directorate

John Logsdon	George Washington University
Jonathan Clark	Baylor College Of Medicine
Kris Lehnhardt	Baylor College Of Medicine, NASA
Ming Li	CASC - China Aerospace Science and Technology Corporation
Pascal Michal	Public Health Agency of Canada
Paul Wohrer	Fondation pour la Recherche Stratégique
Robert Thirsk	ISU
Ross Upshur	University of Toronto
S. Ali Nasseri	University of British Columbia
Serge-Olivier Kotchi	Public Health Agency of Canada
Shrish Ravan	UNOOSA-UN-SPIDER
Stephanie Brazeau	Public Health Agency of Canada
Su-Yin Tan	University of Waterloo
Xavier Pasco	Fondation pour la Recherche Stratégique
Yi Ning	Meinian Institute of Health
Yves-Louis Desnos	ESA

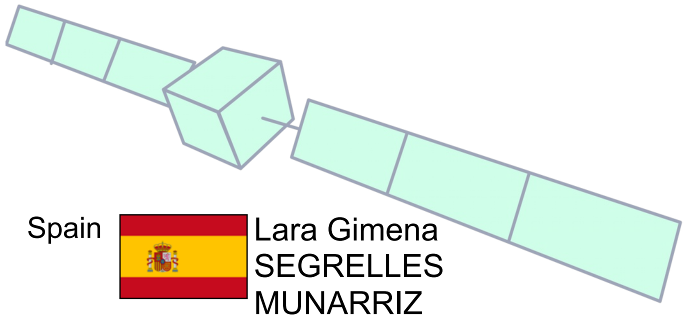
Everyone else involved in the ISP!

Name	Title	Organisation
Konstantin Chterev	Academic Officer	SAGA Space Architects
Sasiluck Thammasit	Academic Officer	ISU - International Space University
Laurence Heiser	Accountant	ISU - International Space University
Dimitra Stefoudi	Associate Commander	Leiden University
Julien Tallineau	Associate Commander	VEOWARE SPACE
Nahum Romero Zamora	Associate Commander	KOSMICA Institute - Nahum Studios
Scott Ritter	Associate Commander	DLR - Cologne
Lisa Kucher	CapCom	Paris-Saclay University
Arif Goktug Karacalioglu	Captain	ISU - International Space University
Alexandra Ryan	Chief Academic Officer	ISU - International Space University
Geraldine Moser	Chief Communications Officer	ISU - International Space University
Joel Herrmann	Chief IT Officer	ISU - International Space University
Sebastien Bessat	Chief Logistics Officer	ISU - International Space University
Muriel Riester	Chief Research Officer	ISU - International Space University
Daniel Garcia Yarnoz	Co-Commander	ISU - International Space University
Joseph Pellegrino	Co-Commander	ISU - International Space University
Liang Chen	Co-Commander	Beijing Interstellar Glory Space Technology Co., Ltd.
Natalia Larrea Brito	Co-Commander	Euroconsult
Scott Schneider	Co-Commander	Alvitha
Walter Peeters	Co-Commander	ISU - International Space University
Farhan Asrar	Commander	University of Toronto, Institute for Better Health, Dalla Lana School of Public Health & ISU
Kerrie Dougherty	Commander	University of New South Wales

Taiwo Tejumola	Commander	ISU - International Space University
Tanja Masson-Zwaan	Commander	International Institute of Air & Space Law, Leiden University
Amanda Michelle Simran Sathiaraj	Communications Officer	ISU - International Space University
Amélie Morel	Communications Officer	ISU - International Space University
Nikhitha Chadde C	Communications Officer	ISU - International Space University
Siyun Chen	Communications Officer	ISU - International Space University
Tommaso Tonina	Communications Officer	ISU - International Space University
Cécile Paradon	Counsellor	ISU - International Space University
François Spiero	Daily Seminar Co-Commander	CNES - Headquarters
Juan de Dalmau	Daily Seminar Co-Commander	ISU - International Space University
Imre Végh	Expedition Facilitator	TrueVoice.NL
Niamh Shaw	Expedition Facilitator	Dream Big Space & Science Communications, Ireland
Omar Hatamleh	Expedition Facilitator	NASA Headquarters
Paolo Nespoli	Expedition Facilitator	NASA Johnson Space Center
Yinghui Li	Expedition Facilitator	China Astronaut Research and Training Center
Sylvie Mellinger	Finance	ISU - International Space University
Carlos Manuel Entrena Utrilla	Future SSP Host Representative	ISU - International Space University
Carlos Sampedro Matarin	Future SSP Host Representative	ISU - International Space University
Sergio Navas Concha	Future SSP Host Representative	Universidad de Granada
Vanessa Martos Nuñez	Future SSP Host Representative	Universidad de Granada
Camilo Reyes	Habitat Officer	ISU - International Space University
Dillon O'Reilly	Habitat Officer	EUROAVIA
Hilda Palencia	Habitat Officer	NASA Ames Research Center
Jonas Tobiassen	Habitat Officer	ISU - International Space University
Kristyn Rodzinyak	Habitat Officer	McGill University
Kyran Grattan	Habitat Officer	ISU - International Space University
Léo Baud	Habitat Officer	University of Strasbourg
Nate Taylor	Habitat Officer	ISU - International Space University
Paul Iliffe	Habitat Officer	ISU - International Space University
Rishi Khan	Habitat Officer	ISU - International Space University
Shrrirup Nambiar	Habitat Officer	Politecnico di Torino
Hugh Hill	ISU Central Campus Faculty	ISU - International Space University
Christine Jenck	ISU Central Campus Staff	ISU - International Space University
Didier Guillaume	ISU Central Campus Staff	ISU - International Space University
Nassim Bovet	ISU Central Campus Staff	ISU - International Space University

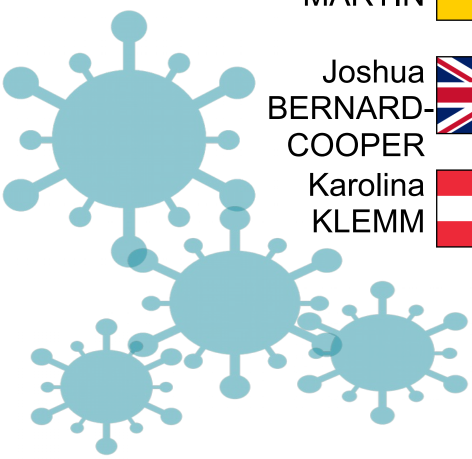
Benjamin Gurtl	IT Officer	Benjamin Gurtl Consulting - BGC
Bernd Weiss	IT Officer	Space job fair
Kavindi De Silva	IT Officer	ISU - International Space University
Nicolas Moncussi	IT Officer	ISU - International Space University
Omar Darwich	IT Officer	ISU - International Space University
Leonardo Valencia Restrepo	Logistics Officer	ISU - International Space University
Antonino Salmeri	Mentorship Officer	ISU - International Space University
Gary Martin	Moon Commander	Luxembourg Space Agency
Pete Worden	Orbital Stations Commander	Breakthrough Foundation
Chiara Manfletti	Panelist	Portugal Space Agency
Francis Chizea	Panelist	NASRDA - National Space Research and Development Agency
Johann-Dietrich Woerner	Panelist	ESA - Headquarters
Michal Szaniawski	Panelist	Industrial Development Agency JSC
Oleg Atkov	Panelist	Russian Medical Academy of Continuous Professional Education
Pascale Ehrenfreund	Panelist	DLR - Cologne
Timiebi Aganaba	Panelist	North South Star Research
Valanathan Munsami	Panelist	SANSA - South African National Space Agency
Supprabha Nambiar	Research Officer	Alliance Française d'Ahmedabad-Inde
Carol Carnett	SEAC & Content Review Lead	Seven Horizons, Ltd
Andrée-Anne Parent	TM Designer	University of Quebec in Rimouski
Wendy Mensink	TM Designer	Wendy Mensink
Andrea Gini	TM Editor	Space Safety Magazine
Merryl Azriel	TM Editor	ISU - International Space University
Ruth McAvinia	TM Editor	ISU - International Space University
Vanessa Stroh	TM Editor	NASA Kennedy Space Center
Ravi Kapur	Visitor	
Agnieszka Lukaszczyk	Workshop Instructor	Planet Labs
Alexander Soucek	Workshop Instructor	European Space Agency
Arnaud Runge	Workshop Instructor	ESA - ESTEC
Carrie Paterson	Workshop Instructor	
Daniel Sors Raurell	Workshop Instructor	Open Cosmos Ltd
Emeline Dahlstrom	Workshop Instructor	International Space Consultants
Eric Dahlstrom	Workshop Instructor	International Space Consultants
Ewan Reid	Workshop Instructor	Mission Control Space Services Inc.
George Tahu	Workshop Instructor	NASA Headquarters
Hagen Betzwieser	Workshop Instructor	
Helen Schell	Workshop Instructor	

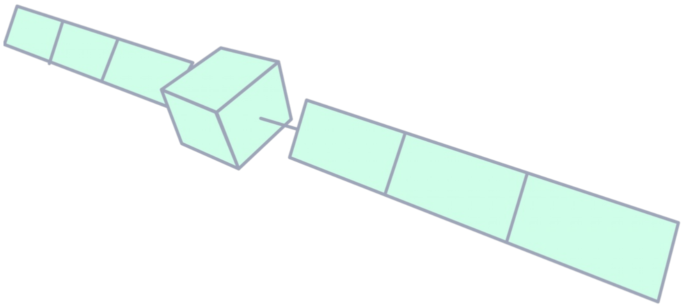
Joanna Ruiter	Workshop Instructor	Netherlands Space Office
Joerg Kreisel	Workshop Instructor	Jorg Kreisel International Consultant (JKIC)
Lucie Campagnolo	Workshop Instructor	MEDES
Miguel Angel Olivares Mendez	Workshop Instructor	
Neta Vizel	Workshop Instructor	Neta Vizel- People and Organizational Development
Niklas Hedman	Workshop Instructor	United Nations Office for Outer Space Affairs
Percy Blount	Workshop Instructor	Université du Luxembourg
Randy Segal	Workshop Instructor	Hogan Lovells
Stefan Siarov	Workshop Instructor	Valispace
Steve Kaufmann	Workshop Instructor	
Storm Boswick	Workshop Instructor	Brock Capital Group
Werner Balogh	Workshop Instructor	World Meteorological Organization



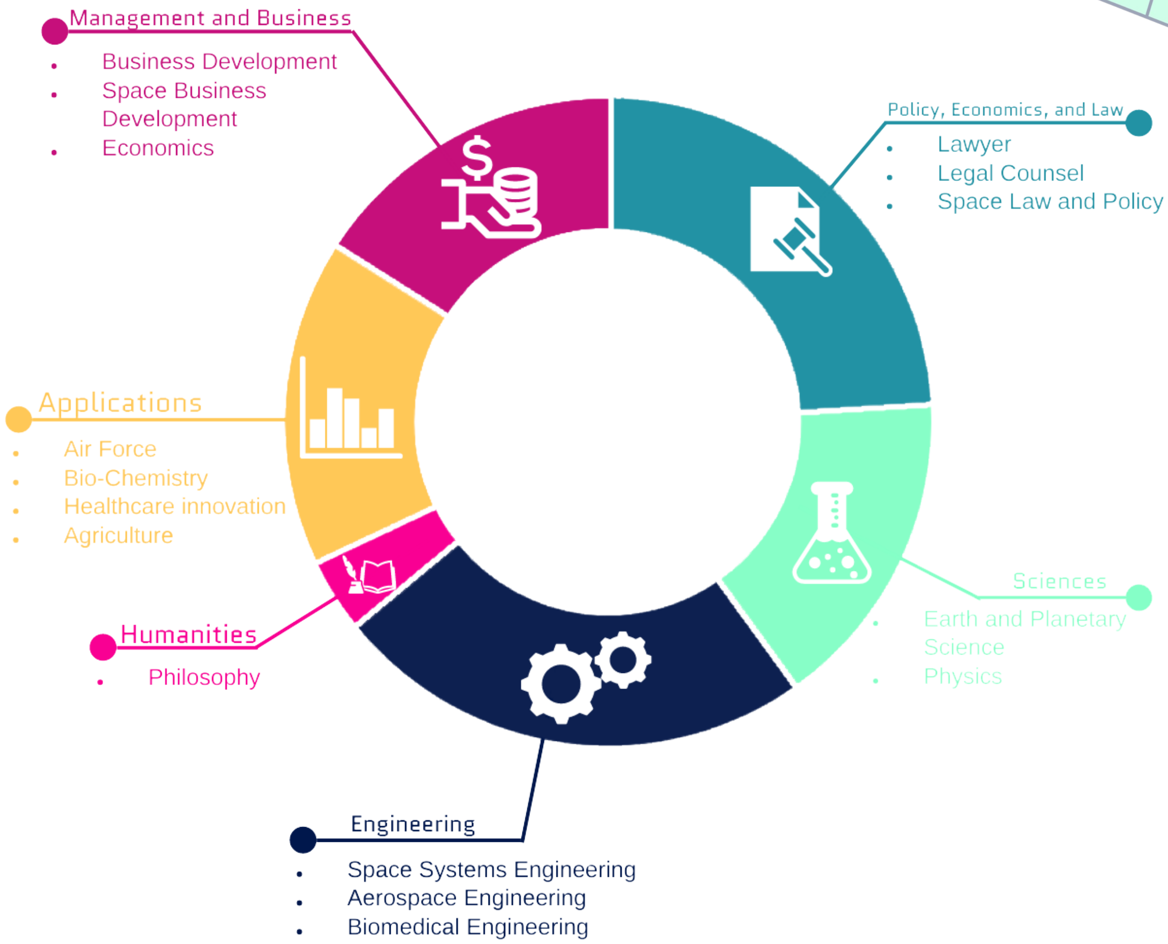
List of crew members

Abhishek CHAKRABORTY	India
Alice PAIS DE CASTRO	Portugal
Aras KUMAR RAJANNA	India
Arthur VAN DEN BOSSCHE	Belgium
Benjamin SHAPIRO	USA
Dylan SIGAUD	France
Elisabet FONALLERAS NADAL	Spain
Gerardus Julius LANCEE	Netherlands
Hussain HAIDER BOKHARI	Canada
Jan VAN BAELEN	Belgium
Janet GLENN	UK
Jeremy MYERS	USA
Johannes MARTIN	Germany
Joshua BERNARD-COOPER	UK
Karolina KLEMM	Austria
Lara Gimena SEGRELLES MUNARRIZ	Spain
Marc HEEMSKERK	Netherlands
Matthias FRENZL	Austria
Medeni SOYSAL	Turkey
Nadia KHAN	UK
Oscar MILES	UK
Poofa GOPALAN	India
Priyanka ROY CHOWDHURY	India
Rebecca HARWIN	UK
Satoru KUROSU	Japan
Thomas CHRETIEN	France
Tiffany ROSE	Mauritius/ France
Veronica OBODOZIE	Nigeria
Vinicius ALOIA	Brazil/Italy

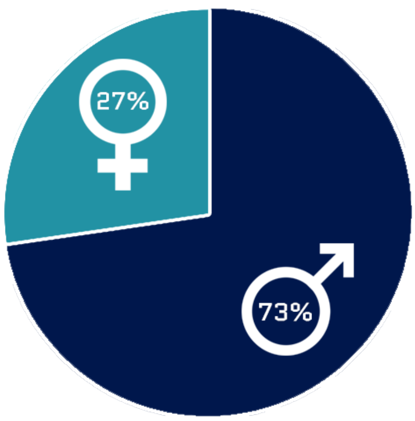




Crew infographics



Backgrounds of the members of Team Mission Mars



Gender representation in Team Mission Mars

Abstract

The 2020 coronavirus pandemic has had a lasting effect on humankind. Aside from the deaths caused by the virus itself, the measures required to control the pandemic have had adverse effects on the economy, public health, and society as a whole. Some of the impacts of the virus have been mitigated by space assets and technologies, with communications satellites helping people connect via mobile networks when face-to-face communications became impossible. As demonstrated in this report, space has greater potential to help in pandemic mitigation through the wide range of space assets and technologies available. For example, Earth observation data has provided valuable insights into the movements of cargo ships and airplanes, as well as the reduction in pollution resulting from the lockdown. In this report, key areas are identified in which space capabilities can help to mitigate the pandemic. We discuss space as a critical infrastructure, remote healthcare provision, monitoring of populations to inform decision makers, and countering the impacts of pandemics on the supply chain. We then present innovative space-based solutions, such as the development of an International Charter for Pandemics, similar to the existing International Charter for Space and Major Disasters. Finally, a concept is developed for a smartphone application to improve children's mental well-being, using the inspirational nature of space.

Faculty preface

For over 30 years, the International Space University (ISU) has sought to use its leading and unique role in outer space collaboration and outreach for the benefit of space exploration and human progress. ISU's endeavors in these objectives have initiated and contributed to important and pertinent discussions concerning the use and understanding of outer space to help solve challenges of humanity on Earth.

In the face of the 2020 coronavirus pandemic, ISU set out to administer an alternative to the long-standing annual Space Studies Program (SSP) – itself an on-site, interactive and intense nine-week course. In lieu of the SSP, the ISU worked incredibly fast to conceive, design, and prepare a remarkable and more than worthy substitute, one which nevertheless harnesses the three core elements of the university's collaborative philosophy – international, interdisciplinary and intercultural.

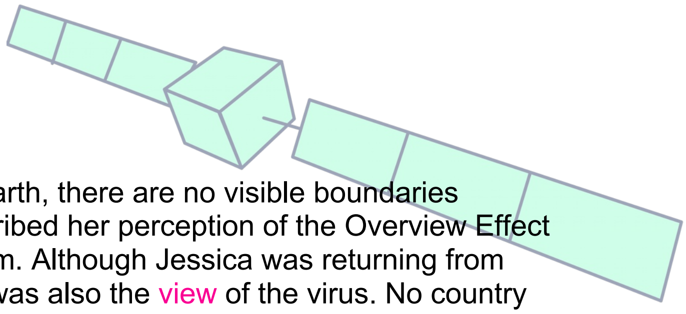
The inaugural Interactive Space Program (ISP) was held for five weeks in July through to August 2020. The participants of the ISP engaged in the program from their own workspace across 21 countries using the internet to communicate with one another. As the internet is progressively becoming a product of artificial satellites, the format of the ISP in its own right already illustrates how outer space may be harnessed when seeking to facilitate human engagement during a pandemic.

With the hard work of ISU and with the enthusiasm and commitment from the program's participants, the ISP carried over the interactivity and intensity of the SSP. The participants were tasked as crew with duties particular to one of three virtual habitats, each researching varying perspectives on how space can further assist humanity in circumstances of a global pandemic. The virtual Orbital Habitat focused on how space can aid the monitoring of pandemics while the virtual Lunar Habitat looked at how space can be harnessed for the prevention of pandemics on Earth. This present report is produced by 29 crew making up the virtual Mars Habitat to consider recommendations on how space-enabled capabilities can mitigate the effects pandemics on Earth in the context of COVID-19.

The highly competent and diverse Mars crew added greater benefit to this report through attending sessions and discussions with experts from within the seven primary disciplines driving the ISU curriculum: humanities, policy economics and law, science and research, engineering, business and management, life sciences/human performance in space, and applications of space. The Mars report forms its recommendations for mitigation through a lens of social considerations focusing on health, physical proximity, and economic impacts connected to COVID-19.

The faculty of this Mars report is incredibly privileged to have worked alongside, observed, and learned from the amazing crew who researched, structured, and presented this pertinent report while also fulfilling their various other ISP duties outside of the Mars mission. We wish them all the best in the next stages of their careers post ISU and welcome them to the amazing family that is the ISU alumni network.

Liang Chen	Scott Schneider	Nate Taylor
Commander	Commander	Habitat Officer



Crew preface

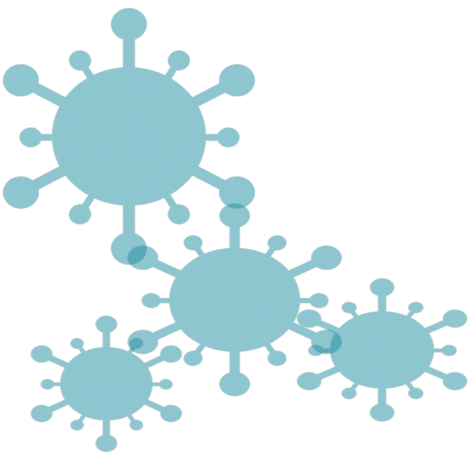
“Looking down from the ISS to our fragile planet Earth, there are no visible boundaries between nations and societies.” Jessica Meir described her perception of the Overview Effect in the astronaut panel event during the ISP program. Although Jessica was returning from her space mission amid the COVID-19 crisis, this was also the view of the virus. No country or society was spared from its disruptive nature.

People were working from home, social distancing rules were in place, and social events were canceled. The pandemic also affected the International Space University (ISU). The yearly Space Studies Program, taking place every June-August in a different location across the globe, had to be halted. Instead, the ISU proposed a grand new concept, set to change the way of learning in the 21st century. And so, the Interactive Space Program was born. The aim of our project was to identify how space could contribute to monitoring, mitigating, and eventually preventing a pandemic. A team of 86 space enthusiasts, coming from all different backgrounds, gathered to participate in this fully online program. From a range of cultures and nationalities, young graduates to senior managers, experts in medicine to die-hard space engineers all gathered to answer one common question: How can space help?!

Addressing the three facets of space contributions in separate groups, the Mars team was tasked with investigating the mitigation of the effects of pandemics. Following a design thinking process, the 29 crew members of the Mars habitat were divided into subgroups named Opportunity, Curiosity & Insight, making sure each subgroup was intercultural, international, and interdisciplinary. Each subgroup discussed the impacts of the pandemic in their own countries. After selecting the impacts of the pandemic where space could make a significant contribution, the subgroups brainstormed possible solutions that would use space assets. The team further researched the solutions with clear mitigation potential, using insights from several experts. Combined with daily seminars and interactive workshops covering a range of topics, the Mars team developed strong recommendations on the mitigation of pandemics with the utilization of space assets and technologies.

Due to the nature of the program, the crewmembers worked remotely across different continents and time zones, all synchronized by the Universal Coordinated Time (UTC). This caused a few communication gaps as people across the globe adjusted to UTC. Other than the team project, crewmembers also had a busy schedule with daily seminars, interactive workshops, online social events, and the constant screen use contributed to overall fatigue. On the other hand, working from home brought a personal touch with pets of crewmembers dropping into meetings, dance sessions during breaks, and sporting challenges to keep us moving, including walking to the sun!

From this exceptional experience of working together with people of very different backgrounds and cultures, connecting from everywhere in the world, we experienced effective international cooperation first-hand. This is reflected in the strong recommendations and outcomes of our report. We hope to not only enhance the contribution of space to mitigate the effects of pandemics, but also set an example for international collaboration and show the extraordinary results that can be achieved by a diverse group pursuing a common goal.



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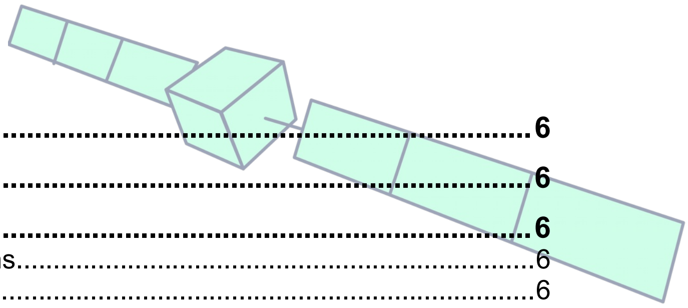

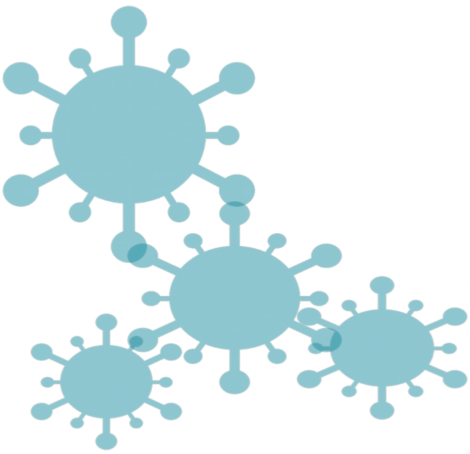

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List of acronyms

AIS	Automated identification system
COVID-19	Coronavirus disease 19
DARPA	Defense Advanced Research Projects Agency
EO	Earth observation
GEO	Geostationary orbit
GIS	Geographical information system
GNSS	Global navigation satellite system
HIV	Human Immunodeficiency Virus
ISP	Interactive Space Program
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISU	International Space University
LEO	Low earth orbit
MOOC	Massive open online courses
MERS	Middle Eastern Respiratory Syndrome
MITIE	Houston Methodist Institute for Technology, Innovation & Education
NASA	National Aeronautics and Space Administration
PHEIC	Public Health Emergency of International Concern
PPE	Personal protective equipment
RNA	Ribonucleic acid
SARS	Severe Acute Respiratory Syndrome
SSP	Space Studies Program
UAE	United Arab Emirates
UAV	Unmanned aerial vehicle
UK	United Kingdom
UN	United Nations
UN's SDGs	United Nations' Sustainable Development Goals
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
UNOOSA	United Nations Office for Outer Space Affairs
WHO	World Health Organization

1. Introduction

At the start of 2020, an outbreak of the Coronavirus Disease 2019 (COVID-19), caused by the SARS-CoV-2 virus, occurred in Wuhan, China (WHO, 2020a). The virus spread around the world within weeks, and was declared a global pandemic (WHO, 2020b).

The effects of the pandemic were sudden and dramatic, resulting in humans across the world having to change their habits and ways of interaction. Governments issued containment measures to restrict the spread of the virus, impacting public health, society, and the economy. The most impactful governmental policy at that time was a “lockdown”, the physical restriction of movement to reduce the spread of the virus (Caulcins, et al., 2020).

1.1. Mitigation and the importance of the space sector

The Cambridge Dictionary defines mitigation as "the act of reducing how harmful, unpleasant, or bad something is” (Cambridge Dictionary, 2020). Here, we define mitigation of a pandemic, as distinct from preparedness, prevention or recovery, as the actions are taken to reduce the severity of the pandemic and to limit its consequences.

This report explores the space sector’s influence on current and potential mitigation measures for the COVID-19 pandemic, as well as for future pandemics, focusing on health, social, and economic aspects applicable across the globe.

First, the report provides a short introduction to pandemics, with particular reference to COVID-19. Section 2 explains the approach and methodology, and Section 3 discusses the use of space to support critical infrastructure. In Section 4, the report discusses the use of space technologies to enable and support remote health care delivery, using satellite-supported telemedicine and space spin-offs. Section 5 describes the use of Global Navigation Satellite Systems (GNSSs) and Unmanned Aerial Vehicles (UAVs) to support the monitoring of lockdown measures, and Section 6 explores the use of space technologies to support supply chains and discusses the use of in-situ production to mitigate the impact of pandemics. In Section 7, the team proposes a charter to provide data from space to help authorities mitigate the effects of pandemics. Finally, to showcase an applied mitigation tool, Section 8 proposes a mobile app for the mitigation of the impacts of the pandemic on children’s wellbeing.

1.2. What is a pandemic?

The World Health Organization (WHO) declared the current COVID-19 outbreak a Public Health Emergency of International Concern (PHEIC) on 30 January 2020, and a pandemic on 11 March 2020 (WHO, 2020b).

Since there is no uniformly acknowledged definition of the word “pandemic,” several institutions have tried to narrow it down (Morens, Folkers and Fauci, 2009). The definition used in this document is "an epidemic occurring worldwide” (Heath, 2011).

1.3. What are the characteristics of COVID-19?

1.3.1. Virus type and strain

COVID-19 is a viral disease caused by SARS-CoV-2, a single-stranded ribonucleic acid (RNA) virus that is highly contagious in humans. It is likely to have come from animals as it has close genetic similarity to bat coronaviruses. The virus shows little genetic diversity, meaning that future mutations are hard to predict and could pose threats to the effectiveness of any developed vaccines.

1.3.2. Symptoms

Symptoms are varied, including cold-like symptoms, coughing, shortness of breath, fever and sudden loss of taste and smell (Ahmad, et al., 2020). The disease can cause severe pneumonia and organ failure, which can be fatal.

1.3.3. Spread

Epidemiological studies estimate the infection rate R0, defined as the number of people each infected person passes the disease to, to be between 1.4 to 3.28 (Australian Government - Department of Health, 2020). The virus primarily spreads between people through close contact and via respiratory droplets produced from coughs or sneezes. It mainly enters the human system via the lungs or mucous membranes. (WHO, 2020c)

1.4. How does COVID-19 differ from previous pandemics?

Table 1: Comparison of COVID-19 with other viral diseases, as of 18 August 2020.

Pandemic	COVID-19	SARS	MERS	Swine flu	Spanish flu	HIV
Fatality rate	3.4%	14-15%	34.4%	1-4%	2%	Unknown
R0	2.79	2-4	0.6-0.7	1.4-1.6	1.4-2.8	Unknown
Family	Corona virus	Corona virus	Corona virus	H1N1	A/H1N1	Retrovirus
Number of deaths	773,000	770	850	20 000 (estimation)	50 million (estimation)	32 million

SARS: Severe Acute Respiratory Syndrome; MERS: Middle Eastern Respiratory Syndrome; HIV: Human Immunodeficiency Virus. Data from Silverman and Washburne, 2020; Australian Government – Department of Health, 2020; Johns Hopkins, 2020; WHO, 2003; NHS, 2019; WHO, 2019; Dee, 2014; Fraser, et al., 2009; CDC, 2020; Mills, Robin and Lipsitch, 2004; Ferguson, et al., 2006; Hagemann, 2020; UNAIDS, 2020; Livingston Raja, et al., 2019; Newman, 2020.

COVID-19 is transmitted without the need for direct contact, unlike HIV. It is also from a different disease family than the H1N1 influenza, also known as swine flu, and we do not know if any other viruses confer immunity. Two things make this virus especially dangerous: lack of immunity in the population (Newman, 2020), and its ability to mutate and transmit rapidly.

1.5. What are the impacts?

At the time of writing, COVID-19 has directly resulted in over 21.8 million confirmed cases and 773,000 deaths (WHO, 2020e). The pandemic has also had indirect impacts on humankind.

Physical distancing (also referred to as social distancing) to prevent the spread of the virus required lockdowns, recommended by the WHO and implemented by many governments. Where possible, countries introduced remote working for non-critical infrastructure business, governmental services, and the education sector. However, indirect impacts of these lockdowns resulted in massive gross domestic product decreases around the world (WHO, 2020d). The full impact of the pandemic is not yet known.

2. Methodology and approach

2.1. Methodology

Pandemics affect the entire global population, so an interdisciplinary, intercultural and international approach was required. To complement our research, experts were invited to speak to the team on a range of topics including Earth observation, telemedicine, public health, and space ‘big data’.

We started by considering the issues resulting from COVID-19. We divided these issues into three main sectors and explored how these sectors could mitigate the effects of COVID-19:

2.1.1. Health

- Reduce/stop the spread of COVID-19
  - Minimize the number of active hosts who can cause infection
  - Decrease the contact rate for active hosts
  - Decrease the period of time for which hosts are infectious
  - Decrease the risk of contact resulting in infection
- Reduce/mortality from COVID-19 and other illnesses
  - Develop therapeutics and vaccines quickly
  - Increase intensive care capacity
  - Increase home care capacity

2.1.2. Social

- Social contact is important for mental well-being
  - Reduce the lockdown to a minimum and target affected clusters
  - Increase access to telecommunication equipment such as smartphones and laptops

2.1.3. Economic

The world economy can be described as a complex adaptive system (Holland,1988), which can be modeled by system dynamics models (Forrester, 1977). When it comes to the COVID-19 pandemic, some key features of mitigation can be seen:

- Keep people employed
  - Increase work-at-home capabilities
- Keep companies alive
  - Grant subsidies
  - Automation
- Reduce the lockdown to a minimum and target affected clusters
- Maintain and strengthen supply chains

2.2. Aims, objectives and approach

The areas that could benefit significantly from space assets, best practices and technologies we identify in this report are:

- Space as a critical infrastructure
- Remote healthcare delivery
- Monitoring populations and informing decision makers
- Countering the impacts of pandemics on the supply chain
- Mitigating mental health problems as a result of social isolation

As possible solutions, we propose a charter for the use of space data in the response to pandemics, and an app to showcase and address some of the issues identified, using a space-based approach.

3. Space as a Critical Infrastructure

3.1. Introduction

Critical infrastructure refers to the assets that are required for the functioning of society. This includes health care, commerce, and education. Providing this critical infrastructure amid a pandemic can put people at risk of spreading disease if physical distancing is difficult. Space technologies can be considered as critical infrastructure that can protect the health of the population while ensuring the essential needs of society are met.

Space assets include GNSS, which enable a receiver to passively determine its position in real time, and satellite communications. GNSS constellations are inherently expensive but underpin modern position, navigation and timing technologies. To date, all GNSS constellations have been publicly funded. The US-owned GNSS constellation is estimated to have over 4 billion users globally and the next generation of satellites will cost over $10 billion (Phys.org, 2018). Satellite communications constellations are extremely expensive to develop and maintain. New and up-coming satellite communications networks promise low-latency global coverage which could revolutionize global connectivity (Deloitte, 2020). Space infrastructure is used to coordinate every aspect of modern civilization, ensuring other vital infrastructure to keep people safe, for example, enabling working from home and online education.

3.2. Issue Statement

To identify applications of space assets and technologies in the provision of critical infrastructure for the benefit of society.

3.3. Recommendations

3.3.1. Health Sector

3.3.1.1. Space-enabled UAVs

Space technology can be used effectively in the health sector. UAVs could be used to transport medical supplies (test kits, medicines) to remote places. In order for UAVs to operate, they require a navigation system and a communications link to connect to the pilot.

Using a GNSS receiver, UAVs can determine their absolute position, enabling them to navigate to a series of waypoints. UAVs that travel for long distances can use terrestrial communications links wherever available. As well as reducing human interactions and therefore the risk of disease transmission, UAVs allow faster delivery of emergency medical supplies.

In the United Kingdom (UK), Skyports is working with the National Health Service on a pilot study to use UAVs to provide supplies such as masks to a remote hospital in the Scottish Isles (UK Space Agency, 2020). UAVs have also been used to deliver blood to remote clinics (Fleming, 2018) and could also be used for medical waste management by monitoring landfill (Airscope, 2020). In the future, UAVs could be a key part of the health sector supply chain.

3.3.1.2. Automated Medical Kiosks

Recently, many countries have introduced temperature scanning as a means of screening for COVID-19. In some places, this screening is done automatically by a machine. An automated scanning kiosk can be augmented to act as a PPE vending machine. The kiosk would keep track of purchases of PPE, such as face masks and hand sanitizers, as well as the results from the temperature scanning. The data from these kiosks could be used to develop a GIS (Geographical information system) (GIS Geography, 2020), which allows important information to be overlaid on maps. This could map COVID-19 hotspots and areas of high demand for PPE, providing valuable information to governments and local authorities.

Any personal, identifiable data will be subjected to the privacy laws of that nation. For data to be shared, permission will have to be obtained from the user before the screening takes place. One solution could be to ensure that the person provides contact details, either by email or text, and confirms their agreement to retain the data. At the same time, the system would explain the reasons for collecting the data and the purposes for which the data would be used. Safeguards would also be put in place to ensure the data is not misused or mislaid. For example, in South Korea there was controversy as the authorities tracked people's movements to contain the spread of the virus, which was considered an invasion of privacy (Zastrow, 2020).

3.3.2. Commerce Sector

Geo-fencing is the use of a GNSS receiver to identify potential customers in a certain geographic area, a valuable marketing tool. These geofences can be used by businesses to promote their products and services to targeted consumers nearby. As well as this, geofences could be used by shops, restaurants, and food banks, to identify locations which are open during a pandemic. (Gravy Analytics, 2020).

3.3.3. Transportation Sector

The COVID-19 pandemic has led to more demand for autonomous vehicles to become reality (Beatrice, 2020). Autonomous robotic vehicles could be used for disinfection purposes, using electrostatically charged disinfectants to spray on contaminated surfaces (Krainock, 2016), as well as for the delivery of medical and food supplies. Autonomous vehicles need GNSS for position, navigation, and timing (Hexagon Positioning, 2020) and also make use of geofencing technology for accurate positioning (Hardigree, 2019).

3.3.4. Education Sector

UNESCO has launched its Global Education Coalition, investing in remote learning worldwide (UNESCO, 2020). Although it includes solutions that do not require internet, access to online learning, opportunities such as massive open online courses (MOOCs) and mobile reading applications would greatly increase the range of educational content available. Additionally, Landmrk Limited, a UK-based company, has developed a mobile platform to incentivize young people to exercise, learn, and practice COVID-19-safe behavior (UK Space Agency, 2020). New satellite constellations such as Starlink (Goswami, 2020) will connect remote areas to the internet, providing a high bandwidth for data uploading/downloading and enabling everyone to benefit from good quality internet access.

3.3.5. Information Technology Sector

Remote working has increased drastically during the COVID-19 induced lockdown and quarantine. The IT sector is able to survive by means of remote working. Google recently posted a COVID-19 mobility report showing that 39% fewer people were in workplaces (Kiniulis, 2020), indicating more people working from home, in many cases requiring internet.

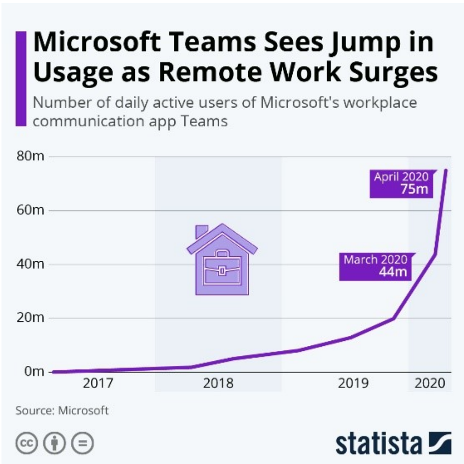

Figure 1: Number of daily active users of Microsoft Teams. Figure generated using Statistica.

3.3.6. Entertainment sector

Satellite communications play a larger role in rural and remote areas during a pandemic. Video streaming services have become very popular during the COVID-19 crisis (Budholiya, 2020), requiring real-time internet access to stream TV shows and movies. Geostationary satellites can provide downstream data speeds up to 506 Mbps. However, latency is still a problem for such online video streaming.

3.4. Summary

GNSS and satellite communications both contribute towards critical infrastructure. Modern society relies heavily on GNSS for position, navigation and timing capability. Satellite communications provide global connectivity. Space assets and technologies serve as a critical infrastructure in the mitigation of the COVID-19 pandemic. Space-enabled UAVs, autonomous disinfecting robotic vehicles, geofencing, remote working applications are effective solutions for COVID-19 and similar future pandemics.

4. Remote Health Care Delivery

4.1. Introduction

The COVID-19 pandemic has put a strain on health-care systems worldwide. To mitigate the health and economic impacts of the global health crisis, governments have widely implemented physical distancing measures, one of the only effective ways to contain the spread of the virus. Despite these measures, health-care services must remain fully operational, putting both health-care workers and patients at direct risk. Remote health care can enable some essential health-care services to take place without direct physical contact between staff and patients, reducing the demand for PPE and ensuring the implementation of physical distancing.

4.2. Issue Statement

Remote areas with scarce financial resources may be disproportionally affected by a pandemic, increasing the demand for health-care services and frontline health-care workers in those isolated communities. Additionally, some health care services must continue remotely during a pandemic, minimizing the transmission risk to staff and patients, and must comply with privacy and data protection laws.

4.3. Recommendations

4.3.1. Tele-consultations and privacy considerations

Throughout the COVID-19 pandemic, there has been a rise in the use of telemedicine. Telemedicine connectivity has been used by the Mexican Secretariat of Health in the fight against COVID-19, for telemedicine, diagnostics, data transfers (Mexican Government, 2020). The use of technology for medical purposes is set to increase as patients and health-care workers become more comfortable with tele-consultations.

However, to be successfully implemented, these remote health-care services must take privacy and data protection laws into consideration. Health-care workers are also subject to liability issues when handling their patients, which makes many of them reluctant to perform their medical services remotely. There is still a mistrust regarding the need to disclose personal information online, especially due to the fear of misuse or unauthorized commercialization of personal data. As a result, a significant portion of the population is reluctant to share their medical data, which makes it difficult to create a wide database for medical use. These rules and regulations, in addition to ethical issues relating to the use of data, may pose a significant obstacle and hinder the effectiveness of tele-consultations.

4.3.2. Remote diagnosis of COVID-19

Although only patients with symptoms currently benefit from remote diagnosis, as they get tested first, asymptomatic people can spread COVID-19 up to 14 days after their first exposure to the virus (Oran and Topol, 2020). Therefore, both people with and without symptoms must be tested, unlike the influenza virus.

Remote diagnosis is used as a first step in tele-consultations to determine the priority and severity of patients' conditions, including likelihood of recovery. Anyone with serious symptoms is instructed to seek medical attention immediately whereas for less severe symptoms, patients are advised to manage their symptoms at home. This prevents the virus from spreading any further and stops patients at lower risk of death from coming into contact with high-risk groups, such as the elderly. The use of remote diagnosis enables frontline health-care workers to identify serious cases of COVID-19 much faster and prescribe the most effective and timely treatment possible, including hospitalization, without the need for the patient to attend a health-care facility (Liu, et al., 2020).

Remote treatment prevents the overflowing of emergency departments and the collapse of the health-care system (Rademacher, et al. 2016) by reducing the need for physical contact and guaranteeing physical distancing measures.

4.3.3. Satellite connectivity

The current infrastructure for terrestrial telecommunications is primarily composed of submarine fiber-optic cables delivering internet at high speeds, but this does not reach remote areas. The provision of additional satellite capacity for connectivity is set to improve the ability of health-care workers to contact remote areas, allowing more reliable transfer of medical data and better capacity for diagnosis. This would be further assisted by a satellite constellation capable of providing internet access to remote areas (Liu, 2020).

Satellite-based internet is typically provided through communication satellites in geostationary orbit (GEO). GEO constellations, however, are expensive, starting at USD 100 million per satellite (Grossman, 2020). Although only three GEO satellites are required for global coverage, the latency of GEO constellations is too high (~700 ms) to support high performance applications such as telemedicine. In addition, since GEO is essentially a ring around the equator, it is considered a limited natural resource. To reach remote regions and urban areas with poor connectivity and compete with telecommunication companies and internet services providers (ISPs) providing broadband internet to the mass market of consumers everywhere, several private companies have planned constellations in low Earth orbit (LEO) to provide global internet connectivity. Although the placement of communication satellites in LEO requires far more satellites to ensure global coverage, they have the advantage of much shorter propagation delays, low latency (~50 ms) and high throughput. LEO constellations still face many challenges, including congested orbits, high operational complexity, high operating and ground terminal costs, and unfocused capacity. To tackle these issues, new innovations in satellite communication technology, such as the new transceiver developed at Tokyo Tech (Grossman, 2020), will increase efforts in providing low-latency access to communication and internet without the need for a more substantial ground-based infrastructure. Once successfully launched, this satellite capacity can offer critical support for telemedicine and support the popularization of remote diagnosis and tele-consultations.

4.3.4. Treatment Technologies and Technology Transfer from the International Space Station

Maintaining crew welfare is an important element in space missions. Several space agencies use autonomous systems for communication, medical care, and to assist astronauts with the effects of extended isolation during their missions. During a pandemic, these systems can be implemented to mitigate the impacts of the pandemic. In 2018, Carré Technologies of Montreal, Canada, developed the Bio-Monitor, a technology which consists of a shirt made up of several sensors worn by astronauts. The Bio-Monitor has been tested on the ISS and it is used to monitor and analyze several health indicators, such as blood pressure, temperature, etc. (Canadian Space Agency, 2018) without the presence of doctor onboard or any other bulky equipment. After performing the analysis, the patient connects the Bio-Monitor to a Bio-Analyzer to send the data to be processed (Canadian Space Agency, 2019). Such technology can support remote diagnosis and provide the public with wider access to medical services. Although promising, the transfer of technology and mass manufacturing of equipment are still challenging. As research is still lacking, the market for this kind of space-based spin-off is unknown, which makes its implementation financially uncertain.

NASA and General Motors, in partnership with the Defense Advanced Research Projects Agency (DARPA), developed the Robonaut Program, a humanoid robot able to perform complex tasks. Initially, Robonauts have been employed for less complex, repetitive tasks or to operate in hazardous conditions for human activity. In 2014, tests carried out on the ISS proved that a Robonaut was able to perform complex tasks with a good precision (Dean and Diftler, 2015). After the successful missions and to expand their capabilities, Robonauts have passed surgical tests at the Houston Methodist Institute for Technology, Innovation &

Education (MITIE). This success brings the Robonauts one step closer in the technology readiness level, and closer to on ground implementation. Humanoid robots in hospitals could reduce treatment times and keep contact between medical personnel and infected patients to a minimum, improving the working conditions in the hospitals and allowing for a better management of the disease itself.

4.4. Summary

In conclusion, space contributes to the remote delivery of healthcare and therefore the mitigation of the direct impacts of the pandemic. Satellite communications can provide critical infrastructure to enable telemedicine in remote areas which lack terrestrial infrastructure. Space spin-offs such as Bio-Monitor and Robonaut are examples of technology transfer from space which have enormous potential to solve problems related to the lack of health-care diagnosis through space-enabled capability. The use of space technologies in remote health-care delivery, however, requires attention to privacy and data protection laws in any given jurisdiction, which can be an obstacle for their implementation. These solutions would contribute towards the United Nations Sustainable Development Goals (UN's SDGs), such as Goal 3: Good Health and Well-Being and 11: Sustainable Cities and Communities.

5. Monitoring Populations and Informing Decision Makers

5.1. Introduction

During a pandemic, there are three key parameters to consider: the source of the pathogen, the route of transmission, and the population it affects. With COVID-19, as the route of transmission is contact between people, lockdown measures have been the most common means of controlling the spread. These measures varied across the globe but overall included restrictions in movement (lockdowns) as well as physical and social distancing (FT Visual & Data Journalism Team, 2020). This helped to slow down and even prevent the spread of COVID-19 by reducing contact between people, as well as protecting vulnerable populations (Kaneda and Greenbaum, 2020). However, these mitigation measures directly impact the economy, due to restrictions imposed on normal activities and businesses.

This section explores how space can be used to improve the accuracy of a lockdown measure, track and control people's movement, and, therefore, mitigate the impacts of a pandemic.

As with telemedicine and remote health care, personal information can be inferred from this monitoring, which has different consequences and considerations in different countries. Privacy of personal data is becoming more important as our digital footprints grow, with larger volumes of data collected and stored (Ologeanu-Taddei, 2020). It is crucial to ensure these data sets are safely handled, as they could potentially be used for malign purposes. It is therefore recommended to ensure the working of a proper and secure infrastructure before the application of any large-scale population monitoring systems. (OECD, 2020).

5.2. Issue Statement

A pandemic scenario is complex and the consequences vary over time and geographical location. To effectively mitigate the negative impacts of a pandemic, it is essential that policymakers, stakeholders, and the public are able to make accurate and informed decisions. All these people need to obtain and implement data from globally available information systems.

5.3. Recommendations

Using GNSSs with other data sources allows the development of GISs, which can be used to mitigate pandemics and their side effects. Different datasets with positional information can be overlaid in layers and result in a powerful method to identify trends and understand complex situations. A GIS solution could incorporate a heat map of population movement with an additional layer of geographic tracking and mapping of infected cases. First, GISs enable decision-making authorities to have a systematic and optimized lockdown plan that enables the safe movement of people, reducing the economic and social impact. Second, a GIS can provide inputs to take real-time action to control pandemics and avoid overwhelming the health care system (Eurisy, 2020).

Possible methods to control population movement using space-based solutions are:

1. **Identification of potential pandemic affected population/zones and monitoring the effectiveness of lockdown, using smartphones.**

Smartphones can transmit their position using GNSS signals. Many apps can be developed to extract the user's location periodically. Such information can be collected by remote servers and overlaid with other users' location history. This data could be used to create a heatmap of population density on GIS platforms. If any person is infected, they can update the status voluntarily, using an app, or medical staff can update the information on behalf of the user. This provides an opportunity to track all individuals who might have come in contact with the infected person and alert them via text message so they can get tested. This information is very useful in identifying probable cases at the earliest possible opportunity to avoid the spreading of disease (Vinceti, et al., 2020; Servick, 2020). Such a GIS platform could assist the production and distribution of vaccines globally, allowing the populations most in need of vaccines to be identified.

In places where GNSS signals cannot reach smartphones, apps can be developed to identify contacts by the exchange of low-energy Bluetooth signals. Each phone generates a random numerical ID that it broadcasts to nearby phones, which record such Bluetooth "handshakes." If a user experiences symptoms or tests positive, this system can be used to notify their recent contacts. Using such contact tracing data on a GIS, effectiveness of lockdown measures can be precisely monitored, providing real-time input to decision makers.

2. **Identify and update safe corridors, transportation channels, zones and regions using GIS platforms, enabling local authorities to take quick decisions on the safe movement of people for both essential and normal activities.**

Minimal checks and screening should be carried out so drivers and passengers do not need to leave their vehicles. With this system, smooth movement of population through safe zones would reduce the economic impact of a lockdown.

3. **Geo-fencing of a quarantine zone.**

Geo-fences could be used to create virtual boundaries around a quarantined location, so people can avoid travelling into quarantined zones. Users can be notified by a smartphone app or a similar communication device, which automatically alerts them when they are near to any quarantine zones (Gravy Analytics, 2020).

4. **Resource locator.**

Lifesaving apps can be developed to display GISs with information on hospitals with available beds, treatment costs (if not free), places offering medical aid, current waiting times in grocery stores, pharmacies that are open and places where PPE can be purchased (Boulos, 2020).

5. **Incentivizing individuals, based on their movements (GNSS-based tracking) within the allowed zones, to obey lockdowns.**

Satellite images and GNSS-enabled UAVs can carry out periodic monitoring to enable governments to implement lockdown measures effectively. Incentives could include tax relief, waivers on loans, unemployment packages, or provision of essential supplies.

Before implementing these kinds of tracking facilitators, we must consider the privacy of those being tracked. To ensure safe handling of any large-scale personal data sets, an independent and not-for-profit organization should be placed in control. The data should only be stored for the minimum required amount of time, all data should never be traceable to any single individual, all users of these tracking systems should be able to report any errors at all times, and when no longer needed or required, these systems, including all of their data, should be completely deleted (Zwenne and van Graafeiland, 2020).

The above solutions rely on GNSS or Bluetooth functions and therefore require a smartphone or similar location trackers. In some developing countries, such solutions are not applicable since the whole population cannot afford such devices. In these regions, containment of the population to prevent disease spread has to be controlled by local authorities. However, these authorities can update information for that particular region/zone, which could be used in creating the overall GIS map for assessment of the situation.

One of the challenges for GIS during the COVID-19 pandemic is that consistency and reliability of information is not the same in every country. As a result, it can cause problems when comparing different sets of data. A solution for this would be to decide on a set of standards to collect and feed data into a global GIS (European Commission, 2020).

When implemented correctly, according to our recommendations, an increased speed and effectiveness of pandemic mitigation through better informed decisions from local policymakers will help several of the UN's SDGs: besides improving the Good Health and Wellbeing (no. 3), it will improve the Quality of Education due to less school time missed (no. 4), create Sustainable Cities and Communities (no. 11), and, hopefully, contribute to a general improvement of Peace (no. 16) through better international communication and collaboration.

5.4. Summary

To control the transmission of COVID-19 in a community, many of the affected countries have opted for different ways of locking down. Optimal lockdown planning will be very effective with periodic monitoring and distribution of key information to the public and stakeholders in real time. The solutions mentioned are focused on addressing the issue of the effectiveness of lockdown measures during pandemics and reduce the impact on the economy by controlling the population movement. They rely on the space critical infrastructure as well as effective conveying of information through GIS. The technology exists for effective track and trace but there are challenges when it comes to implementing it, since there are concerns on privacy and data protection, which is one of the major issues to be addressed during the tracking and monitoring of human movement during pandemics.

6. Countering the impacts of pandemics on the supply chain

6.1. Introduction

A supply chain is the system of people and processes involved in getting a product from the place where it is made to the person who buys it (Cambridge Dictionary, 2020). Supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer (Kozlenkova, et al., 2020).

As globalization intensifies, global supply chains become more interconnected. This poses the risk of a global disruption when one component of the supply chain is affected by a slowdown in production, forced reduction of manpower, malfunctioning of transportation, or sudden changes in demand for products. Consequences of supply chain disruption are even more evident in developing countries, which are highly sensitive to sudden changes in goods demand, particularly sustenance goods. The lack of sustenance goods also has demoralizing effects on society, which is a concern across the globe. Protecting the supply chain can prevent businesses from forced closure due to a lack of supplies, which in turn improves job security and also increases the mental well-being of the population.

6.2. Issue statement

Focusing on the impacts of the pandemic on the supply chain, this section will show how Earth observation (EO) and ground data can be used in the distribution of goods. Alternatively, two additional solutions are presented to solve the impacts of the pandemic on the supply chain: the local production of goods and the use of UAVs.

6.3. Recommendations

Supply chain problems in the light of the COVID-19 pandemic can be addressed by using a satellite-based tracking system, similar to the satellite automatic identification system (Sat-AIS) used to keep track of vessels, and facilitate collision avoidance between ships (Bhattacharjee, 2019). Goods will be located in real time anywhere in the world, using satellite-based communication channels in areas without mobile coverage.

Data from the tracking system can then be combined with GIS and EO satellite imagery. (Jiang, Sun and Yang, 2016). Using these tools will not only allow identification of viable routes, but can also map areas that will experience a rise in demand. As a result, all supplies can be managed in spite of blockages arising from, for example, transport restrictions such as border controls and airport and harbor closure (EY Global, 2020). Taking this one step further, the combined data of EO and GIS can also be used to predict the situation in different areas (Ahmad, et al., 2014). Hence, shortages could even be predicted by calculating the demands ahead in time and foreseeing any possible freeze of transportation channels which is currently already facilitated by projects such as the “Galileo for Green Lane” app (European Commission, 2020).

Another approach to mitigating supply chain issues arising from pandemics is the in-situ production of goods such as PPE (Justgiving, 2020) (NASA, 2019) and even vaccines as soon as they are tested, approved, and released for human treatment. This allows the fast and sufficient provision and distribution of goods within households, neighborhoods or local clusters. Since each scientific community has its own definition of the term in-situ, we are using the following definition: in-region, in-neighborhood or in-house production of products by use of local resources.

Although these methods were not initially developed for space activities, the space industry is currently pushing the technology forward. NASA in particular runs the In-Situ Resource Utilization (ISRU) research program (NASA, 2017) within their Artemis Program (NASA, 2020) with the objective to avoid expensive carriage of goods into space and instead produce them where and when they are needed. In-situ production on the ground can be performed by building rapid production units from scratch or re-configuring and teaching existing factories to produce what is needed (NASA JPL-Caltech, 2020). The transfer of that knowledge and technology to production processes on Earth can provide a more resilient and efficient supply chain in times when regular chains are disrupted. As there would be no need to have mass production of PPE at one location, multiple local production units could be set up to 3D-print critical supplies.

This would have a beneficial social effect as there will be no local shortages, which is also a major contribution to the UN’s SDG Number 3 – Good Health and Well-Being and SDG Number 10 – Reduced Inequalities (UN, 2020). While in-situ production of goods is to some extent considered or even already implemented by governments, the technology for the in-situ production process of safe and useable vaccines is still under development, showing promising results (Li, et al., 2016).

As discussed in Section 3.3.1, UAVs assisted by positional information from EO systems, can provide fast and reliable delivery services, avoiding ground traffic congestion, without the need for human contact (Amazon, 2020), (World Economic Forum, 2020). UAVs have the potential to reliably deliver emergency medical equipment and health-care essentials, and even provide patient transport (Rosser, et al., 2018). UAV-based food and postal services are also gaining popularity, tying in with UN’s SDG Number 2 – Zero Hunger, as well as

Numbers 3 and 10 (Dickson, 2020; Nicholas, 2020; UN, 2020). Around 25 countries across the world are currently either trialing or planning to test UAV-based delivery operations. For example, countries in sub-Saharan Africa trialed UAV-based deliveries of medical essentials (Butterworth-Hayes, 2019), and the United Arab Emirates (UAE) decided to use UAVs to deliver essential commodities and government postal services to the public (Kerr, 2014; Sleiman, 2014). Although UAV-based civilian services are still restricted in many countries, given the associated security threats and ethical risks (Finn and Wright, 2014), restrictions have been eased recently. To realize the potential of UAV-based delivery systems, countries will need to tighten their safety and security precautions, promote the expansion of the industry to produce tailor-made UAVs, and enhance public awareness and participation (Rosser, et al., 2018).

6.4. Summary

EO and ground data can be used in the reallocation of high-demand goods in areas of short supply by tracking them using EO data. In combination with GIS, a reallocation and efficient distribution of all emergency goods can be established. Additionally, in-situ production and space-enabled UAVs are alternative solutions that will significantly contribute to the UN's SDGs and also mitigate both the current pandemic and any future pandemics. Lastly, these approaches will also have positive effects on society, and in particular the mental and financial well-being of the population.

7. Charter on International Space Collaboration for Pandemic Mitigation

7.1. Introduction

The International Charter: Space and Major Disasters aims to enable a worldwide collaboration that makes available satellite data to stakeholders in areas which have been affected by disasters (Disasters Charter, 2020). The data is delivered throughout the duration of the Charter activation and provides valuable information that cannot be obtained on the ground. As a result, the end-users such as disaster relief organizations receive the satellite data of affected areas relatively fast, assisting them in their response, however, a pandemic is not included as a disaster.

The effects of the pandemic were felt across the globe in terms of freedom of movement not only across borders but within countries. Varying response times and approaches to the mitigation of the pandemic between countries along with strict lockdowns affecting various aspects of life previously explored in this report. Consequences of these disruptions due to the lack of a standardized response have primarily affected countries with weaker infrastructure or public health mandates set in place.

7.2 Issue Statement

With the impacts of the varying response times to the pandemic, this section will show how an International Pandemic Charter can improve the effectiveness of the measures being taken to mitigate the pandemic.

7.3. Recommendations

To mitigate adverse effects of pandemics, an internationally coordinated response is required, managed by a central international body such as the existing United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), with the aim of specifically initiating a response to pandemics.

Our recommendation is to create a charter to mitigate pandemics. This charter should follow the approach of the UN-SPIDER network but needs to be tailored specifically for pandemics. By using the existing space assets and a similar approach as the UN-SPIDER network, the costs of implementing the charter can be greatly minimised and a quick realisation can be assured.

The proposed charter would allow for the release of satellite data of the affected areas for stakeholders to best decide on how to put in place measures such as physical distancing, telemedicine, and supply chain issues. The charter could also retain a repository of useful data sources, promote international collaboration and inform other organisations such as the WHO.

7.4. Summary

To support the mitigation of the effects of pandemics and encourage worldwide collaboration, a dedicated charter under the UN-SPIDER network could be introduced. Countries could activate this charter in response to pandemics and members would provide stakeholders with satellite data to help organize the mitigation efforts at international level. In addition, the charter could promote research into new mitigation techniques for pandemics.

8. Mitigating mental health problems as a result of social isolation

8.1. Introduction

Pandemic-fighting policies around the world have focused on saving lives. However, these policies have had significant mental health impacts (UN, 2020). Studies into the effects of COVID-19 on mental health have reported increases in depression, anxiety, psychological distress, and poor sleep quality (Vindegaard and Benros, 2020). There are multiple drivers for this: economic and financial insecurity (American Psychological Association, 2020); social isolation caused by lockdown measures; loss of normal coping mechanisms; strain on those providing frontline services; and reduced access to mental health services (Marshall, Bibby and Abbs, 2020). The effects of the pandemic have not been limited to adult mental health. Over 1.5 billion children have been significantly impacted by lockdowns and school closures. Quarantine and isolation have resulted in 30% of children or parents suffering acute stress or depression (Madan, 2020).

8.2. Issue statement

To find a space-enabled solution to mitigate mental health issues that might affect children during a pandemic.

8.3. Recommendations

In the past, the space domain has demonstrated incredible powers to unite nations and inspire generations. The space race instigated a whole new era of exploration. The International Space Station has promoted international collaboration. Astronauts have reported a significant shift in perspective and pro-social behaviors as a result of seeing the Earth from space (Chirico and Yaden, 2018), a phenomenon known as “The Overview Effect” (White, 1987). This is characterized by a feeling of awe and self-transcendence (Yaden, et al., 2016). It is possible to elicit the same feelings from the surface using simulated environments (Chirico, et al., 2017; Stepanova, Quesnel and Riecke, 2019). With this in mind, we propose an app for all ages that would allow the Overview Effect to be simulated. This would provide a live view from the space station, which is not a new concept (Blueturn Earth, 2020; NASA, 2018).

However, this app would also allow people to place their pictures at their location, interact with one another, and share their artistic creations, inspired by our experiences of connecting with each other during the Interactive Space Program. Such an application could have challenges in finding traction with contenders such as Facebook. However, since children are dealing with the same challenges of isolation during this pandemic, we designed our app for children, since there are no apps in direct competition. This had the additional benefit of addressing concerns about the quality of remote education.

With this audience in mind, the team has designed a mobile application concept that aims to use the topic of space and elements of the Overview Effect to promote pro-social behaviors and mitigate the mental health issues arising from a pandemic. The team envisions this app being developed as part of a collaborative outreach program, involving space agencies around the world as well as the International Space University (ISU).

The app, named Starship Earth, will provide children with an interactive, immersive environment that encourages physical activity and learning using space subjects. To accomplish these goals, the developer should keep in mind the importance of “gamification” of the platform through the entire experience. There are five main functions of the app:

The Space Career allows the user to create an avatar to represent themselves. This section will also provide a summary of the user’s achievements as they progress through the other functions and receive awards, patches and cards. This section will introduce a personal element as the user becomes attached to their avatar and progress.

The Simulator, Starship Earth, is the centerpiece of the application. The name itself is a reminder that we are a crew on a starship that we know as Earth (Buckminster Fuller, 1969). The goal is to help the child gain the benefit of the “Overview Effect.” This would provide a live view from the space station with fun, interactive features. Users would see the avatars of other users all around the Earth, as well as famous space locations and historical space figures to collect.

The Space Walks section will encourage physical activity, which is shown to boost mental health (Taglin, 2012). By monitoring the step count of the user, the avatar will progress on a spacewalk through the Universe, learning about all the interesting space objects on their way. At the end of each day, the user will be “placed into orbit” with the avatars of other users around the globe who have achieved the same level of activity.

The Night Sky Viewer will enable the user to observe and explore the stars using their device. The child would search and collect night sky objects. In addition, they would be able to see a visualization of their avatar in their spacewalk superimposed on the night sky.

The Educational section will provide space agencies and educational bodies with a platform to present their content. The aim is to provide all app users with the same unified learning objectives and build a common goal for space learning and exploration. Mission Progress will provide a mechanism to track users’ progress and achievements through tests and monitoring. The main mechanisms to ensure engagement from the users include space events, where the users have the opportunity to meet and interact with famous and influential space figures and also educational space content. This would include videos, projects, and reading.

The ultimate goal for the child using the Starship Earth App is to collect enough awards, patches, and cards that they obtain a ticket for their avatar to fly on a space launch. By working with space agencies and their commercial partners, these avatars will fly on a memory chip aboard a spacecraft. On the day of launch, the program could announce how many children’s avatar cadets are on board and how many countries are represented.

To keep the users engaged with the app, intelligent game design mechanics as well as elements like triggers, rewards, and active personal involvement are applied. Those elements will encourage the user to involve their family and friends and enables self-reinforcing user acquisition and engagement loops. (Eyal, 2014; Schell, 2020; Tynan, 2013; Patel, 2020; Nogood, 2020)

Figure 2: Concept artwork of the Starship Earth App.
(left) View of the simulator with avatars and space subject cards to be collected by the user. (right) Night Sky Viewer. The child's avatar can be seen on a Space Walk. See https://tinyurl.com/StarShipISP20 for a demo.

8.4 Summary

Pandemics have been shown to cause significant increases in anxiety, loneliness, and depression through social isolation and other drivers. There is great potential to use the universally inspiring nature of space combined with the ease of access of a mobile application to improve quality of life during a pandemic. Additionally, although Starship Earth is an application concept for children, there is further scope to create similar applications targeting different demographics.

9. Conclusions

Pandemics are a significant threat to humankind. Past pandemics caused many fatalities and the current COVID-19 pandemic has had a significant impact across the globe. Our lives will never be the same again. Pathogens such as SARS-CoV-2 have direct impacts on our health as well as indirectly affecting society, the economy, and global public health. We have found that space can play a vital role in mitigating many of these issues. During a pandemic, healthcare systems are stretched to simultaneously maintain routine treatment while diagnosing and treating a potentially novel disease and containing its spread. Technologies developed for use in space can be used on Earth. An example of this is telemedicine, which is used to care for astronauts while they are in space. The same techniques can be used on Earth to reduce the physical interaction between healthcare staff and patients, which reduces the risk of pathogen spread.

GNSS and satellite communications contribute towards infrastructure which is critical to modern society. Both systems are key enabling technologies for many of the mitigation activities and also inherently expensive to provide global coverage. The upcoming low Earth orbit satellite communications constellations promise to revolutionize global connectivity. Remote areas on the planet can benefit from remote delivery of healthcare. In areas that lack terrestrial communications infrastructure, satellites can connect patients to the necessary healthcare resources.

The same satellite communication technology can also provide education in remote areas. The emergence of global satellite communications constellations with low latency and relatively high bandwidth will be able to provide internet anywhere on the surface of the planet. This enables developing countries to provide education to areas that are currently off the grid. Tele-education is vital for a robust education system, to achieve UN's SDG number 4, even during a pandemic.

Some tasks completed by humans in the fight against COVID-19 are life-endangering. Space-enabled automation will help to prevent this risk by minimizing the human spread of pathogens. GNSS constellations can enable autonomous navigation and this has been demonstrated with unmanned aerial deliveries of PPE to remote islands. Additionally, satellite communications networks will provide connectivity to autonomous fleets, which allows vital infrastructure and supply chains to continue operating during a pandemic.

GIS solutions can fuse satellite data with many other data sets. These tools are an effective way to convey complex, location-based information to decision makers. With the help of GIS, governments can target areas in lockdown that are most in need of support. This limits the impact on the economy while also minimizing the infection risk to the population. To protect personal data, there are different data privacy laws worldwide which need to be taken into account. Another challenge for global GIS solutions is that the quality of data varies between countries. In a future pandemic, nations will be able to make more informed decisions if they are all using the same set of data standards and can share this data freely.

GIS can also be used to build and manage a resilient supply chain. This is critical in the production and delivery of commodities around the planet. Unobstructed access to this global information can ensure that stakeholders and decision makers continue to satisfy the needs of the global population.

During a pandemic, localized lockdown measures and changes in supply disrupt the supply chain. Looking ahead, there are valuable lessons to learn from upcoming human space-exploration which will enable in-situ production of commodities and therefore reduce the global impact of supply chain disruption.

Space is a collaborative and inspiring domain that can bring people together. We explored ways to create a virtual space, helping with the mental health strains during pandemic times. A space-themed app can be a powerful tool to unite global citizens, foster international relations, and maintain hope.

Earth observation resources are valuable in mitigation activities during a pandemic however not all nations have the same access to these resources. A dedicated pandemic charter, analogous to UN-SPIDER, would improve pandemic prevention and mitigation through cooperative and targeted monitoring.

In conclusion, space assets and technologies have been pivotal in the fight against COVID-19. Pandemics are far-reaching, both geographically and across aspects of society and the economy. With respect to pandemic mitigations, there are three broad areas in which space can help:

- Provision of enabling critical infrastructure
- Informing mitigation activities
- Technology transfer

For current and future pandemics, it is crucial to recognize ways in which space can help to mitigate the negative impacts. Space is a global resource and therefore success relies on interdisciplinary cooperation coupled with international and intercultural collaboration.

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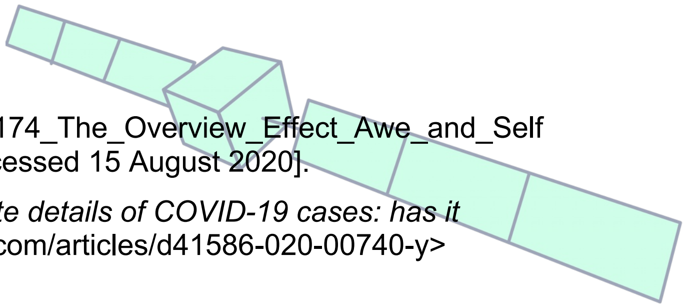

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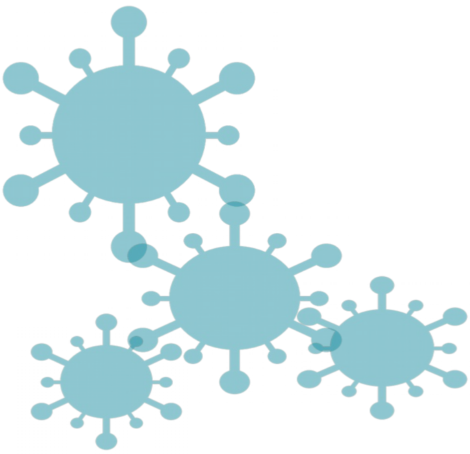

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Priyanka Roy Chowdhury
Elisabet Fonalleras Nadal

Gerardus Julius Lancee
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Oscar Miles

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