S20

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SCIENCE

Executive Summary

The primary conclusion of the 2020 Science 20 (S20), representing the National Academies of Science of G20 nations, is that issues of planet and people must be viewed holistically and with full appreciation of their complexity and interconnectedness. This lesson was learned from a systematic examination of emerging critical global transitions in health, environment, and technology, punctuated by a real-time example of a globally disruptive event, the COVID-19 pandemic. This viral pandemic laid bare the health, economic, social, and educational vulnerabilities of societies and exposed the lack of foresight that resulted in ill-equipped responses on multiple fronts.

The world's leading economies, represented by the G20 countries, must have the foresight to alleviate the system-level economic and social disruptions that will be brought by the next pandemic and other future Critical Transitions. As such the G20 Academies of Sciences recommend the following actions:

1. Advance existing pandemic preparedness towards an internationally collaborative framework to monitor and respond rapidly to emerging diseases and handle future pandemics.
2. Promote advanced therapy and precision medicine research to enhance personalized care, with a view to concurrently improve technology, cost, and accessibility.
3. Deploy policies and interventions to address the challenges arising from demographic shifts.
4. Develop an integrated and efficient closed-loop systems approach to natural resource extraction, distribution, consumption, disposal, and recycling.
5. Promote circular design of materials and energy systems through advancing the 3Rs (Reduce, Reuse, Recycle) plus Renewables aimed at net zero carbon emission.
6. Bridge the emerging digital divide to ensure that all people on the planet have access and capability to use digital technologies and the internet, while ensuring privacy, resilience, and security of digital networks and devices.
7. Improve the sustainability of the digital infrastructure, including end-user devices, and improve opportunities for smart city technologies to contribute towards a cleaner environment.
8. Adopt a multi-disciplinary approach to plan for a human-centric, digitally enabled society of the future, in which the digital infrastructure is fully embedded in the entire social, educational, political, business, and cultural landscape.
9. Support foresight research that is based on robust science, repeatable methods, and open sharing, and incorporates recent advances in complex systems analysis.
10. Establish a platform upon which to implement and foster international collaboration and to build trust in foresight research and activities.

Critical Transitions : Abrupt Shifts in the State of Ecosystems

In 2008, the world experienced a global financial crisis, a critical transition that warranted the G20 discussions to be elevated to include G20 leaders[1]. Twelve years later, we are faced with another critical transition of far-reaching impact in COVID-19. These transitions are abrupt shifts in the state of our ecosystems[2] and become critical when they have global or far reaching impacts. The global impacts of these Critical Transitions could be negative and avoidable, negative and unavoidable, or positive and desired. Several Critical Transitions have been identified across health, environment, and digital sectors, and are now occurring at an unprecedented pace and magnitude. The world's leading economies, represented by the G20 countries, must have the capacity to alleviate system-level economic and societal disruptions that can happen during and from such Critical Transitions. The science and engineering community must help governments identify impending risks and opportunities, but they must also provide evidence-based advice to policymakers to explore the "solution space" for addressing these risks or optimizing the opportunities.

COVID-19 is the latest in a long line of infectious disease outbreaks that have increased both in frequency and diversity over the past several decades, a period coinciding with population doubling, urbanization, globalization, and climate change[3]. Repeated outbreaks and prolonged pandemics will probably become more common in the future and will demand sustained and data-driven foresight research. Holistic approaches, such as 'One Health', must be contextually understood as complementary to the basic provision of access to healthcare and to broad support for the United Nations Sustainable Development Goals (SDGs). Another health and socio-economic related Critical Transition is due to the significant demographic shifts many countries are facing due to changing birth rates, aging populations, migration, and urbanization. Aging represents a significant demographic shift affecting many developed nations. The potential implications include increased vulnerability to infectious diseases, rising healthcare expenditures, and increased demands for healthcare services for the elderly including mental health. Furthermore, the way healthcare is practiced is going through a transition. Conventional therapeutic approaches face several challenges, mainly related to their lack of specificity and associated toxicity. Multiple approaches have recently emerged to overcome these limitations such as multi-omics technology, tailored cellular therapy, specific immunotherapy, gene therapy, and nanomedicine. However, inadequacy of talent, institutions, regulations, and funding have hampered progress in these areas. While the COVID-19 pandemic has accelerated the application of telehealth and other digital health applications, it has also revealed serious gaps in digital infrastructures and digital literacy especially among vulnerable populations. This is further exacerbated by the lack of uniform regulatory and legislative structures as well as the absence of real-time data sharing mechanisms that also maintain data privacy and security.

The disruptions caused by the COVID-19 pandemic seem to have temporarily slowed many environmental impacts caused by human activity. Yet, we continue to damage the environment by following the traditional linear economic model based on 'take-make-consume-throw away' practices. This has created a situation where we are using our natural resources unsustainably and generating enormous waste. The traditional linear economic model and associated downsides could be mitigated through a circular economy that is based on 'reduce, reuse, repair, refurbish, and recycle', while maintaining focus on economic development that includes green jobs. However, technological challenges and insufficient incentives for upscaling and adoption have been barriers to the swift transition to circular economic designs. Moving towards a more circular economy would seamlessly complement existing global climate and environmental efforts to deliver opportunities including reduced pressures on the environment, enhanced security of the supply of raw materials, and increased numbers of jobs. These will further contribute to the attainment of multiple SDGs. Increasing greenhouse gas emissions are driving a critical transition of climate change and consequent damage to land and marine ecosystems, which in turn pose threats to human health and lives. Efforts to reduce emissions and enable carbon circularity will support global commitments for responsible development while also reducing environmental pressures from hyper growth and urbanization. Limited awareness of available approaches and of opportunities to reduce emissions and to adopt carbon circularity continues along with a lack of economic and regulatory incentives to drive change. The need for such change is central to attaining SDGs related to making cities resilient and sustainable, combating climate change and its impacts, and conserving oceans and marine resources.

The COVID-19 pandemic has underscored the divide in our society between those who have capability and access to digital technology, especially the internet and services enabled by it, and those with limited or no access. The present pandemic has further reinforced the notion that internet accessibility must be considered a basic or fundamental right of every citizen. Furthermore, the existing telecom infrastructure is vulnerable to disruptions by Critical Transitions such as climatic disasters, cyberattacks, and pandemics. Despite the strong need for resilience, most nations are economically and politically constrained from investing in the network redundancy that provides resilience. These vulnerabilities in connectivity and data are shaking trust in digital technology. This mistrust has been compounded recently by the emergence of deep fakes, misinformation, and fake news. We are witnessing a changing societal landscape across multiple domains. Digital technology is disrupting traditional industries and giving rise to novel ones. In turn, this disruption is changing the professional landscape via job elimination and outsourcing and is particularly affecting vulnerable groups including women. Geopolitical factors, involuntary human migration, and climate change are resulting in increased urbanization. By 2050, two-thirds of the world's population are expected to live in urban areas, causing a heavy load on cities' operations and resources. While smart city technologies could offset this, we are not able to harness their full potential due to the lack of interoperability between competing proprietary technologies. Furthermore, global digital infrastructure and the associated billions of end-user devices consume vast amounts of energy and significantly contribute to global greenhouse gas emissions. More needs to be done in helping to reduce energy consumption and e-waste.

Foresight: Connecting the Dots

The current pandemic crisis has highlighted that Critical Transitions can have far-reaching impacts across the globe and that global challenges transcend societal, economic, political, and technological domains. The growing complexity and interconnectedness of systems make it increasingly difficult for policymakers to understand the impact of their decisions as they navigate the Critical Transitions we will face. The pathway to better government, policy, and action should be built on a whole-system approach.

"*Foresight is a purposeful process of developing knowledge about the future of a given unit or system of actors, which is aimed at action in the form of public or private policy making, strategizing and planning*[4]*.*" Yet, the on-going COVID-19 pandemic clearly shows that pandemic foresight was and still is a challenge requiring the convergence of medical, public health, socio-economic, and complementary disciplines. Up to this point in history, exercises for navigating the future have largely been conducted by policy analysts in think tanks, corporations, multilateral organizations, and governments. Science has been an *ad hoc* resource for most foresight studies. However, profound global challenges and Critical Transitions require insightful leadership and vision to transform these traditional foresight exercises through evidence-based foresight research.

Foresight research would propel the science and engineering community into a needed central role to develop deeper, more accurate, and more comprehensive foresight methods to drive effective policymaking. There is a need for foresight research that can connect the dots, allowing the assessment of the impact and unintended consequences of decision options and leading to visionary actions at an international level.

International cooperation and collaboration are needed for better foresight research. The pandemic has provided the central incentive to break silos for healthcare professionals, engineers, scientists, policy and decision-makers, and leaders worldwide. In fact, given the wide disparities among developed and developing nations in terms of research capabilities and financing, international collaboration on foresight scientific research, innovation, and funding is needed. International collaboration on foresight research naturally flows from the growing interconnectedness of the world and resonates with SDG 17, 'Revitalizing the global partnership for sustainable development'. Advancing foresight research and international collaboration in foresight activities holds the promise of fulfilling the potential of our best minds to avoid and mitigate future suffering and achieve greater health, stability, and prosperity.

The G20 Academies of Sciences seek to:

1. **Advance existing pandemic preparedness towards an internationally collaborative framework to monitor and respond rapidly to emerging diseases and handle future pandemics.**

Establish an international research agenda to study the superposition of pandemic scenarios on existing health conditions, lifestyles, health impacts from environmental changes such as climate change, and social interactions using contemporary research methods. Such research will build on and work with existing global efforts to strengthen the response to a pandemic or similar health emergencies. The impact and feedback from social and behavioral research, mental health, and frontline-community interactions must be considered. To enable the application of foresight, data must be collected, shared, and analyzed, with results transparently communicated in a manner that ensures peer review, continuous knowledge sharing, data assimilation, and continuous quality improvement.

2. **Promote advanced therapies and precision medicine research to enhance personalized care, with a view to concurrently improve technology, cost, and accessibility.**

Enhance the development of techniques such as multi-omics technology, tailored cellular therapy, specific immunotherapy, gene therapy, and nanomedicine to complement the traditional healthcare industry. Promote vertical integration of multidisciplinary basic, translational, clinical, and ethical outcomes research, cutting across silo-based activities and taking into account the need for facilitating trans-national mobility and accessibility of scientists and clinicians through better exchange policies. Patients must be empowered to actively participate and collaborate in health research programs. The agenda must also incorporate development of low-cost and high-precision digital health solutions, leveraging predictive models to profoundly understand pathogenesis, identify new drug targets, and develop more personalized diagnostic and therapeutic modalities. Investments in research and training programs are needed to enhance human capital to support the development of and access to innovative diagnostics and therapeutics including vaccines.

3. Deploy policies and interventions to address the challenges arising from demographic shifts.

Account for global demographic, ethnic, and socioeconomic differences in health-related data analyses to allow more accurate data interpretation and decision-making, especially among vulnerable populations and systems with growing inequities. Similarly, conduct a comparative analysis of epidemic data collected from different countries using an agreed framework and appropriate samples in population surveys to provide added value. Among older adults, mental health issues resulting from social isolation, as well as other challenges related to higher risk of contracting diseases, limited digital literacy, and inadequate access to testing and treatment must be addressed.

4. Develop an integrated and efficient closed-loop systems approach to natural resource extraction, distribution, consumption, disposal, and recycling.

Establish the required legal and economic structure to promote large-scale acceptance and application of closed-loop systems and use of recycled and recovered products by businesses and consumers. Steps to encourage the development and adoption of closed-loop systems, especially among key sectors such as mining, manufacturing, construction, services, agriculture, and urban dwellings, should be undertaken. This will in turn stimulate research, development, and use of innovative waste reduction technologies. The design of circular economy systems should create new jobs and encourage community participation at the local level to reduce the use of virgin materials and to promote responsible consumption. Develop educational materials and programs on the circular economy to be included at all educational levels to raise awareness and open career paths to innovation, startups, and jobs in all aspects of the circular economy. Leveraging advanced digital technologies such as IoT, AI, big data, and blockchain will improve the efficiency, resilience, and circularity of natural resource use as well as enhance synergies of circularity in energy, water, materials, and food. Progress towards circularity and waste minimization must use standardized circular economy indicators to support establishment of targets for transitioning towards the circular economy.

5. Promote circular design of materials and energy systems through advancing the 3Rs (Reduce, Reuse, Recycle) plus Renewables aimed at net zero carbon emission.

Promote renewable energy along with affordable and sustainable energy systems including storage, through market-based approaches and awareness programs, that will reduce societal dependence on fossil fuels. Conduct techno-economic feasibility studies and lifecycle assessment to determine the optimal mix of alternative energy technologies coupled with 3R related technologies in integrated societal systems that will best meet carbon neutrality goals. Assessment and promotion of emerging Carbon Capture, Utilization, and Storage (CCUS) technologies such as Bio-Energy Carbon Capture and Storage (BECCS), and conversion of CO_2 into products, including tests at test-bed sites, will be required to clarify their upscaling and implementation opportunities. Encouraging forest and marine ecology recovery and restoration as methods for carbon sequestration will simultaneously help restore biodiversity.

6. **Bridge the emerging digital divide to ensure that all people on the planet have access and capability to use digital technologies and the internet, while ensuring privacy, resilience, and security of digital networks and devices.**

Develop strategies to encourage funding of the digital infrastructure and development of communications technologies and devices suited for deployment and use in poor communities and remote locations with limited infrastructure. Inclusive education and literacy programs are required for all to ensure digital education opportunities, especially among women, minority groups and disadvantaged communities. Leverage the scientific community in digital infrastructure planning to upgrade current systems for improved resilience and increased network traffic demands. Dedicate more resources to promote data science for the public good, research and development for robust and resilient AI algorithms, stronger cryptographic protocols, and expanded regulations to prevent threats from random failures and malicious cyber-attacks.

7. **Improve the sustainability of the digital infrastructure, including end-user devices, and improve opportunities for smart city technologies to contribute towards a cleaner environment.**

Accelerate initiatives aimed at reducing the environmental impact of digital technologies, including designing for energy efficiency, developing less intensive computational methods, and using renewable energy sources in place of non-renewables. Develop standardized tools and frameworks to maximize efficacy in the use of digital technologies and maximize their useful lifetime to reduce e-waste. Design smart cities and smart communities to be inclusive, optimize resource sharing, embrace interoperability, and reduce the emission of greenhouse gases and other pollutants. Promote collaboration and knowledge-sharing of best practices and experiences among policymakers, industry, community stakeholders, and the scientific community. Enhance public awareness of the environmental impact associated with use of digital technologies.

8. **Adopt a multi-disciplinary approach to plan for a human-centric, digitally enabled society of the future, in which the digital infrastructure is fully embedded in the entire social, educational, political, business, and cultural landscape.**

Strengthen focus on multidisciplinary education and research, interlinking science and engineering, social sciences, the humanities, and ethics, and enhancing the quality of digital education for all. Initiate a broad scientific and public discourse related to the societal and health impacts of digital technologies and engage in public education based on scientific evidence. Support the development of technologies and human-managed processes that allow for rapid detection and blocking of deep fakes, fake news, and disinformation, and empower users to identify and handle false and misleading information. Increase investment in research and development of trustworthy and explainable AI in high-stakes domains such as finance and healthcare and develop methodologies and protocols for the incorporation of ethical behavior into robots and related autonomous technologies.

9. Support foresight research that is based on robust science, repeatable methods, and open sharing, and incorporates recent advances in complex systems analysis.

Transform foresight research given recent major advances in network and complexity science, AI, machine learning, big data analytics, and advanced computing (e.g. quantum computing). Ensure that foresight research is based on robust science and repeatable methods that are openly shared. Such research would involve the intersection, interaction, and/or combination of scientific and engineering methods, technologies, trends and drivers, as well as the contexts in which these are embedded. Such enhancement would strengthen the reliability of foresight research and would promote trust in the use of and outcomes from these applications.

10. Establish a platform upon which to implement and foster international collaboration and to build trust in foresight research and activities.

Encourage international organizations (such as the UN) to establish a global clearinghouse and knowledge-sharing platform, as well as a global scientific advisory body to strengthen scientific foresight research, to foster international collaboration and collective exchange of foresight reports, data, best practices, and information on foresight initiatives conducted around the world. This will complement and leverage existing (mostly) regional foresight efforts by encouraging international dialogue on the need for foresight research and capabilities to understand the complexity and interconnectivity of global systems. Challenges that are global in nature often involve different pathways in different regional, national, or local contexts, and effective intervention options are also likely to vary according to context. International cooperation must foster acceptance and tolerance of various cultures and social norms. Global cooperation offers a rich collaborative space for developing appropriate methods that use cutting-edge developments in network and complexity sciences, AI, and big data with the goal of promoting foresight research. Such efforts should also help to develop protocols, technologies, and regulations to ease data sharing, both locally and cross-border, to allow open access to data among relevant stakeholders. These efforts should also help to prioritize programs that heighten the awareness of foresight to the broader society and policymakers and to establish strategies for communicating different futures to diverse audiences.

References

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