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EDITORIAL

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COVID-19 – how a pandemic reveals that *everything is connected to everything else*

The *emergence* of a coronavirus (SARS-CoV-2) with novel characteristics that made it highly infectious and particularly dangerous for an older age group and people with multiple morbidities brought our complex adaptive system (CAS) "society"—the economy, health systems, and individuals—to a virtual standstill. The COVID-19 pandemic—caused by SARS-Co-2—is a typical *wicked problem*[1]—we did not see it coming, we experience its effects, and it challenges our entrained ways of thinking and acting.

In our view, it is a classic example that demonstrates how suddenly changing dynamics can destabilize a system and tip it into an unstable state. COVID-19—rather than something else—turned out to be what we colloquially call *the last straw that broke the camel's back* or, put in system dynamics terms, what pushed our societal systems over a tipping point. When a system suddenly tips over, the linkages between most of its agents break, and a chaotic situation ensues. Chaotic states entail a high degree of uncertainty, a state in which previously proven interventions no longer maintain the status quo.

The uncertainties triggered by COVID-19 have not only shown the fragility of health and national systems but also highlighted the intrinsic and tacit dynamics underpinning them. Most notable are the markedly different responses at the policy and community level. China drastically clamped down on all societal activities and rapidly built large new hospitals to deal with those fallen ill. Iceland rapidly tested every potential case. Sweden implemented limited social distancing measures. Italy hospitalized many mild cases in an environment of limited hospital resources, and the United States, for several weeks, denied that there is a significant problem. Each of these approaches has its own dynamics affecting individuals, communities, health systems, the economy, and the nation as a whole—*new patterns emerge* that become understandable with increasing knowledge (Figure 1). However, the long-term outcomes and effects on the system as a whole will only become evident over the next months and years.[2]

1 | CAS ARE IN CONSTANT FLUX

CASs contain many different agents that interact in non-linear dynamic ways. They are open systems that constantly interact with their environment. Within given constraints, the self-organizing properties of a CAS makes it resilient to most perturbations to any of its constituent parts. Nevertheless, a CAS may become *unexpectedly* unstable triggered by a small—often unforeseen/unforeseeable—event. The emerging dynamics then shift the system to a *new*—stable or unstable—*state*, where the relationships and the interactions between the systems' agents have permanently changed within the context of a different set of constraints.[3]

When system perturbations result in unexpected outcomes, we become aware of the ever-present uncertainties in our lives. These experiences easily result in over-exaggerated fear, which in turn results in ad hoc responses that invariably perpetuate and/or exacerbate the underlying system dysfunctions.

2 | THE EMOTIONAL RESPONSE TO UNEXPECTED COMPLEXITY

In general, we are not good at seeing and comprehending the complexities in issues, and we have great difficulties in managing their underlying dynamics into the future. The human brain has not evolved to keep all components of a problem in mind and to appreciate their changing dynamics more than two or three steps ahead.[4] At the physiological level, the experiences of failing to manage a complex problem creates cognitive dissonance and emotional distress—we experience anxiety and physical symptoms such as palpitations, sweating, and tremors.

Having to solve problems with high levels of unknowns often results in interventions that are ad hoc focussed on what appears to be the most obvious without considering the wider consequences. Dörner's studies[4] in the 1980s demonstrated how people of all walks of life handle unexpected contextual problems. Most of us succumb to the *logic of failure*; we over-respond and, when realizing the consequences, promptly react with an over-response in the opposite direction and so forth. Few among us use the approach of first closely analysing the problem, second responding by introducing small interventions, and finally taking time to observe what happens. In dynamic systems, the *true effects* of an action are only evident after a time delay. One has to observe and evaluate a CAS' feedback to guide responses; invariably infrequent small *tweaks*—rather than rapid and dramatic actions—achieve a stabilization of the situation and ultimately provide the necessary space for a (re)solution to emerge.

3 | BALANCING THE NEED TO KNOW WITH THE NEED TO ACT

COVID-19 is a wicked problem[1]—there are many known unknowns, unknown knowns, and unknown unknowns. We yet do not know

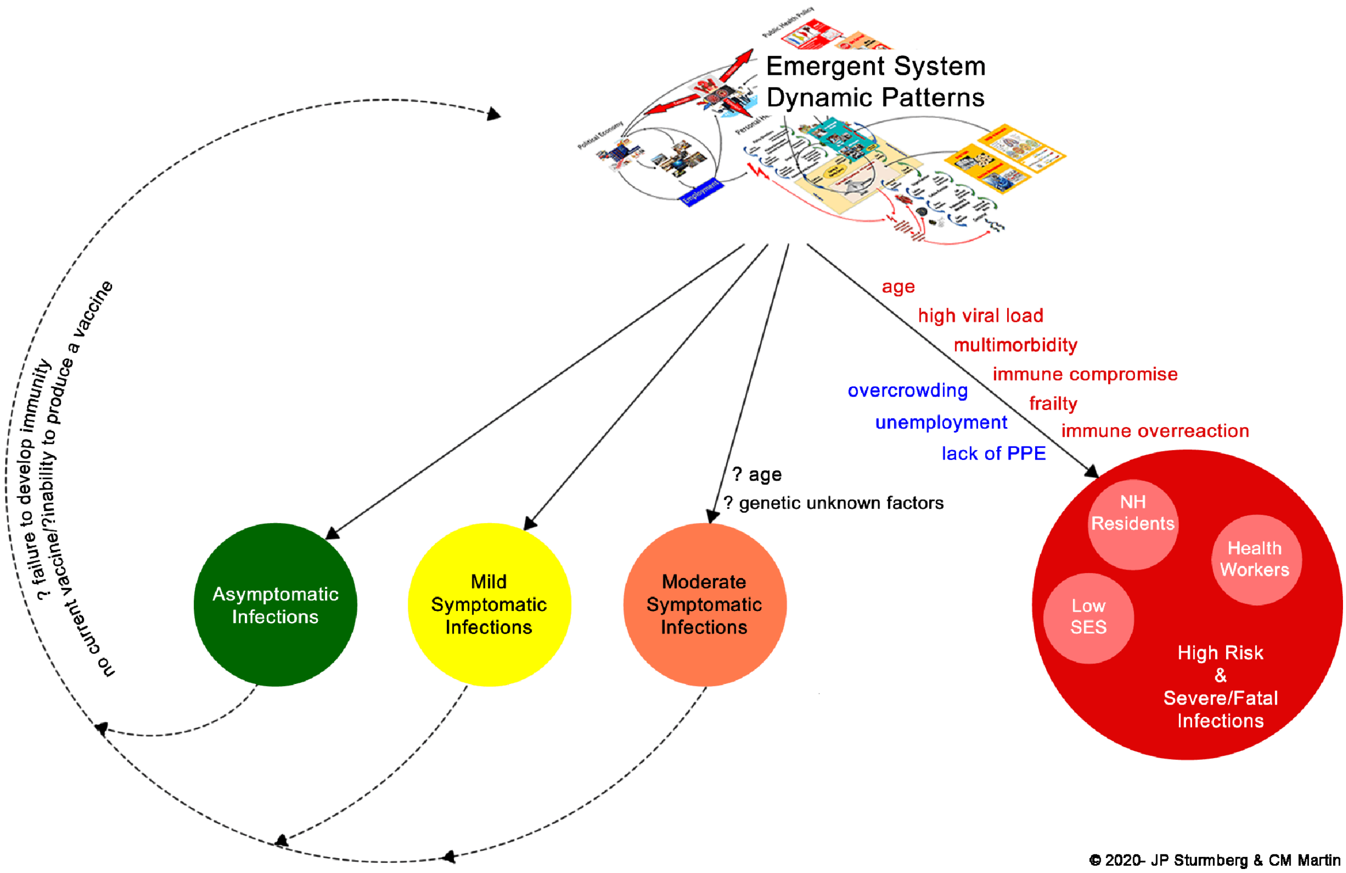

FIGURE 1 Emergent patterns resulting from the system dynamics triggered by COVID-19. While we as yet have no clear understanding of the mechanisms of COVID-19 on people, some common features emerged for those developing severe disease and high fatality outcomes. Moderate severe disease may be associated with increasing age and potential, otherwise innocent, genetic factors. As the development of immunity to SARS-CoV-2 is uncertain, previously infected people may continue to spread the disease and/or remain susceptible to reinfection

enough about the virus (but we are painfully learning)—the true mode and speed of infectivity, its population dynamics, and treatment; we do not know enough about the risk to the population as a whole and on any subpopulation—age groups, behavioural risk takers, and those with pre-existing morbidities; we did not have ready-to-go pandemic plans—who is in charge, what are proven population control measures, what advice to provide for protection to people and health professionals and public health services, and what are potentially effective treatments.

Such problems are known as *VUCA problems*—they entail Volatility, Uncertainty, Complexity, and Ambiguity. Resolving such problems requires *VUCA leadership*—Vision, Understanding, Clarity, and Agility.[5] *VUCA problems* place health and political leaders in a difficult position as any decision will have difficult-to-foresee consequences. For example, imposing community-wide (self-) isolation entails that "almost all activities stop", destroying the economy and resulting in high unemployment, poverty, and increasing disease burden, while implementing strategies to slow down the spread of infection will not guarantee that we will not overwhelm health systems or stabilize the pandemic.

4 | INTERCONNECTEDNESS—NOT ALWAYS EVIDENT BUT ALWAYS PRESENT

As all parts of a CAS at every level of organization are connected to everything else, a change in any part of the system has reverberations across the system as a whole. Two processes control the dynamics of a CAS—*top-down causation* transfers information from higher system levels to lower ones, which constrains the work that lower system levels can do, that is, it limits the system's *bottom-up emergent* possibilities.[6] If top-down constraints are too tight, they can bring the system to a standstill. System stability also depends on the law of *requisite variety*, meaning that a system must have a sufficient repertoire of responses (capacity for self-organization) that is at least as nuanced (and numerous) as the problems arising within its environment.[7] If the possible ways of responding are fewer than what is demanded from the system, it will fail in its entirety.

Both these constraints feature in the COVID-19 crisis. Figure 2 brings these complexities and interdependencies into a single view. It demonstrates the *top-down causation* in CAS and particularly emphasizes to policy-makers the importance not to limit system constraints

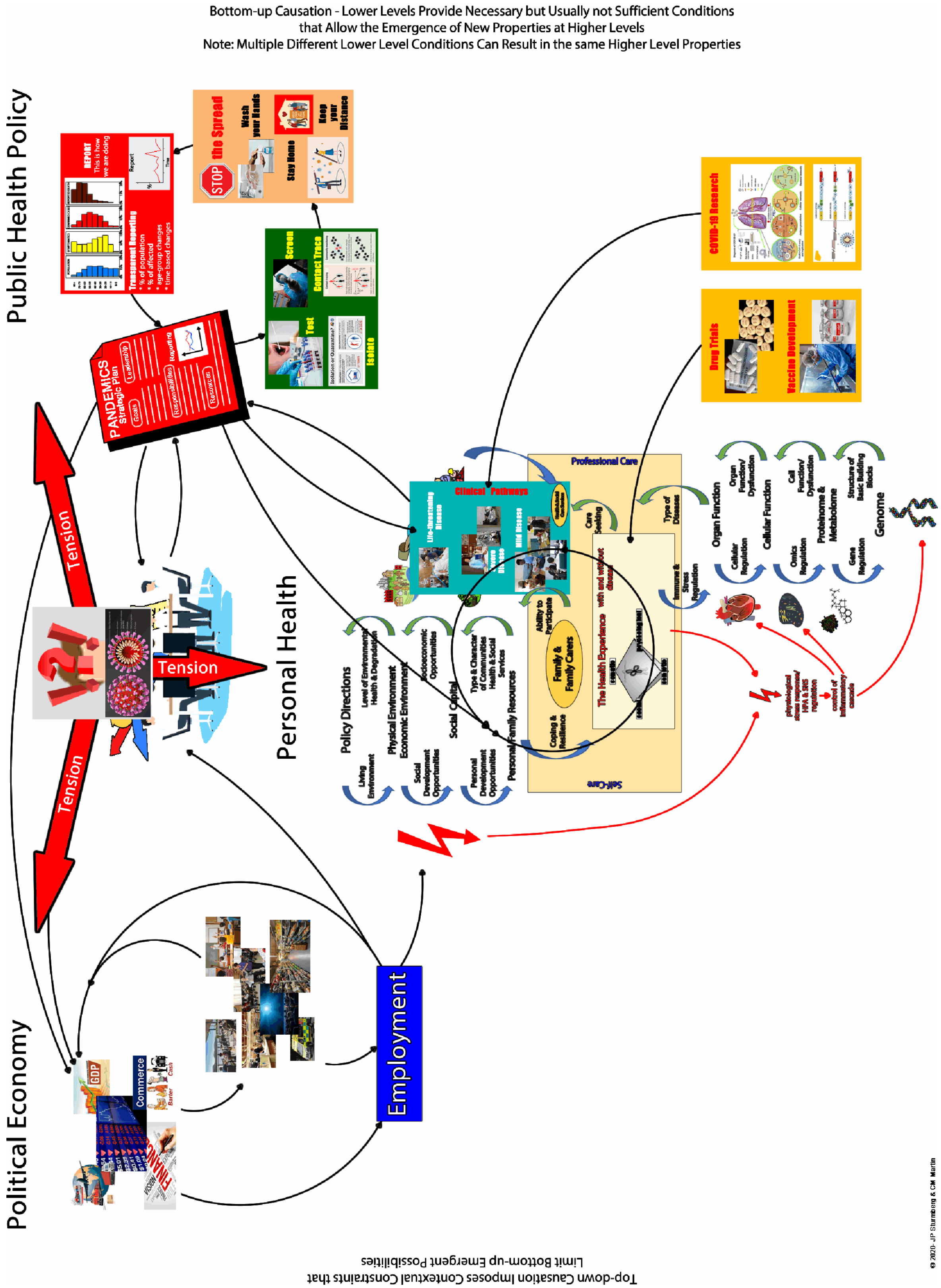

FIGURE 2 A complex adaptive system appreciation of the COVID-19 crisis. The virus triggered unexpected and competing challenges at the policy level with direct and indirect effects on public health policy, the political economy, and individuals (the red tension arrows). Each of these domains has its own circular feedback loops—all link back to the policy level. Ongoing research into the disease, its treatment, and prevention potentially provides "external input" into the systems, which may modify doctors' disease management and alter patients' health outcomes. As described elsewhere,[8] individual health arises at the interface between the environmental and biological domains and is—at times—supported by health care interventions. The detrimental effects of the COVID-19 pandemic on the economy, besides that of the disease fears, increases the dysregulation of the physiological stress responses that, in turn, result in the dysregulation of upstream metabolic pathways, which have long-term health consequences far beyond the direct effects of the pandemic

to such a degree that the agents at other levels cannot do *the work that needs to be done*. It also points to the lack of *requisite variety* at multiple levels, which ultimately limit the system's options to self-organize back to its prior stable state. These deficiencies can be identified at all three key system levels—policy, service delivery, and biology.

While this representation is obviously a simplification, it is useful as it helps to maintain the all-important focus on the *system as a whole*.[9] All systems require a *central focus*—for a health system, it ought to be the person.[10] Health ultimately emerges from hierarchical network interactions between the external environment and internal physiology.[8] Hence, it is the task of health professions at the health service level—the interface between policy and biology—to manage the *complex task* of integrating the various dimensions of a person's biomedical and social care needs.[11]

4.1 | The health service level

Primary care services are the first contact point between a sick person and the formal health system. Health professionals have to assess the person and make decisions about further actions; in the case of COVID-19: Does this person require investigations; does this person require isolation, and do his contacts need to be identified, screened and/or isolated; and does this person require hospitalization because of the severity of symptoms?

Secondary and tertiary care services have to manage the disease-specific features of COVID-19 but are limited by their services' resource constraints, such as the number of hospital beds, ICU beds, and ventilators and the number of qualified staff to provide specialized care.

4.2 | The policy level

Pandemic planning should provide *ready-to-go* policy, principles and high-level strategic plans that provide an *epidemiology informed* framework to guide population-based actions, allow health professionals to locally adapt overarching policy decisions, and ensure required resources are in place. In return, health professionals need to have systems to reliably provide accurate data about the spread of the disease, disease burden, resource utilization, and staffing needs to inform policy decision makers. These data must be contextual—they always need to have a *meaningful denominator*, such as whole/affected population size or socio-economic/age demography, and acknowledge cluster sizes and rates of spread in different environments to enable meaningful comparisons and aid informed decision making.[12] Most importantly, all observations must be communicated in a transparent fashion to ensure maximum adherence to guidelines and directives aimed to achieve pandemic control.

4.3 | The biomedical level

COVID-19 creates many biomedical research challenges addressing genomic, cell, organ, and whole-of-person level questions. An understanding of the virus and its disease mechanisms is necessary to provide clinicians with the best evidence-informed treatment options.[13] At the same time, these basic understandings are the necessary stepping stones to develop disease-specific drugs to cure the disease, as well as a vaccine to stop the pandemic and prevent future recurrences.

5 | SENSEMAKING IN AN ENVIRONMENT OF COMPLEX DYNAMICS, POLARITIES, AND INTERDEPENDENCIES

The uncertainties created by COVID-19 require analysis that provides the deep understanding needed to formulate and implement necessary interventions. The Cynefin framework[14] provides a conceptual map to make sense of a complex world. It shows four ways of knowing, each characterized by the strength of the relationships between observable phaenomena—the *known*, where cause and effect (C&E) are perceivable and predictable; the *knowable*, where C&E are separated over time and space; the *complex*, where C&E are only perceivable in retrospect and do not repeat; and the *chaotic*, where no C&E relationships are perceivable. COVID-19 has tipped the health and political systems into the chaotic domain. Two possible responses can shift a systems out of this domain—by enforcing order into the *known* domain or by implementing actions that allow for the emergent self-organization of a more stable state moving into the *complex* domain. The complex domain is the space where the *best-adapted decisions* to manage rapidly emerging problems arise—informed by the knowledge generated in all other domains (Figure 3). However, certain responses can legitimately operate in known and knowable domains based on context.[15]

Understanding the multifaceted dynamics of the COVID-19 pandemic requires interdisciplinary and transdisciplinary approaches.[16] As outlined above, there are many contradictions and tensions within the policy community; they are unavoidable, but people must ultimately make sense of the multiple dynamics in and between the different biological, social, environmental, and politico-economic domains.[17]

Sensemaking (or sense-making) is the process of people giving meaning to their experiences. At the collective level, *a transdisciplinary process* involving, among others, mathematics, biology, philosophy, sociology and cognitive science, communication studies, and complexity sciences offers the best way to understand the COVID-19 pandemic. While these discourses cannot deliver certainty,[18] they offer the best change to allow the emergence of *best adapted solutions* that can ultimately resolve such problems.[16]

One approach to reaching *best adapted solutions* involves *mapping* out the problem to visualize its agents and their interdependencies. Mapping is the basis for multi-stakeholder *modelling* of a problem; it allows the testing out of many different possible interventions and the comparison of their *potential* outcomes on the system as a whole.[19] However, modelling is not a panacea. As Rosen pointed out, model outputs only reflect an *anticipation* of a future state of a system.[20]

Models are a mental representation of reality; they are not reality itself.[9] Models are never entirely valid but are useful if they can "recreate" a reasonably accurate "current state" of the system based on available

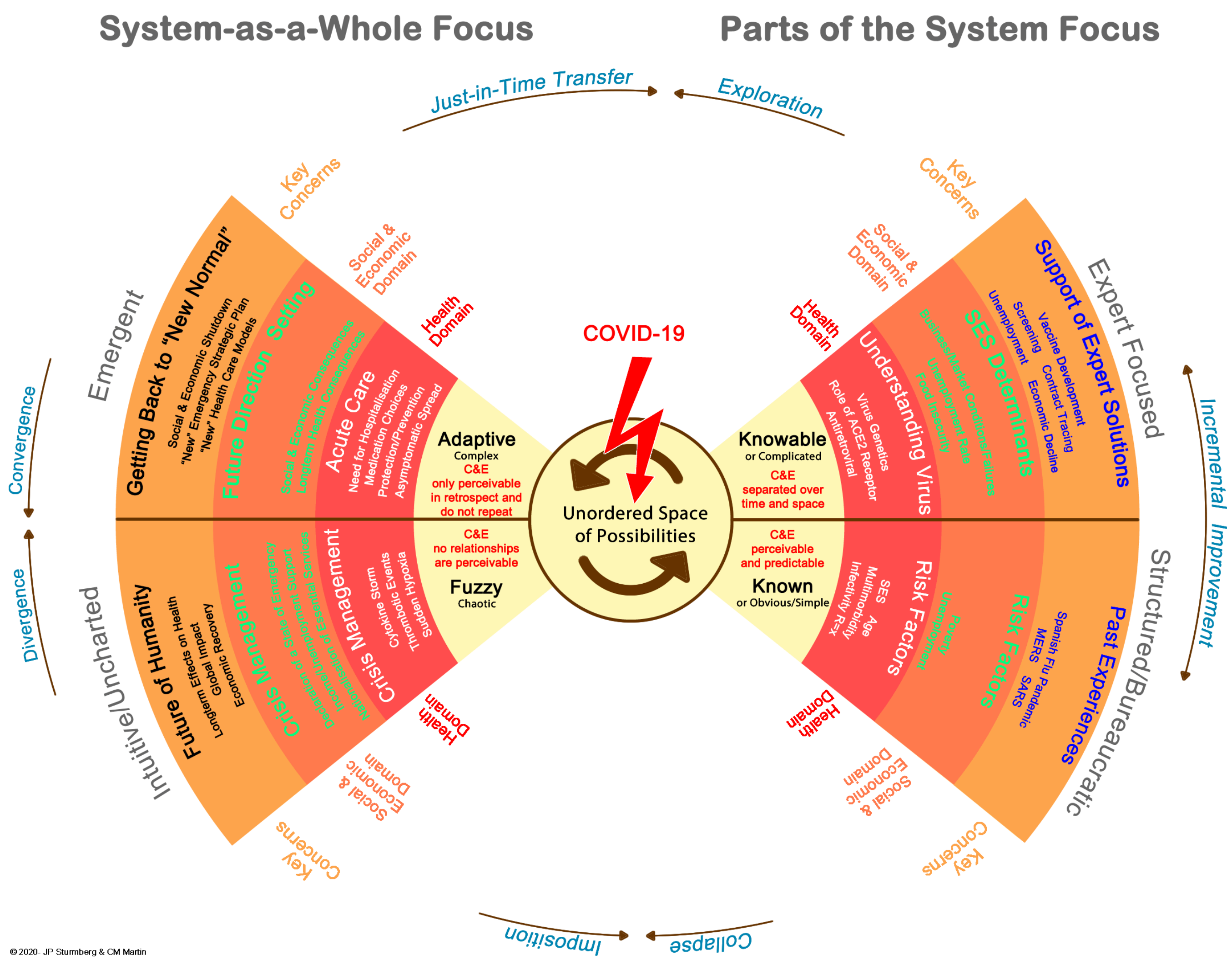

FIGURE 3 - Sensemaking dynamics of complex adaptive problems (Adapted from Martin[15]). This Cynefin-based model outlines the issues arising from the COVID-19 pandemic in relation to different knowledge domains. It provides a starting point to design an anticipatory system model. Each knowledge domain has its own dynamics and strength and weaknesses in understanding the pandemic as a whole. Note the nature of the strategies required to move from one domain to its neighbouring ones. This understanding is crucial as it has major implications for decision makers (for more detail on the Cynefin model, see Kurtz and Snowden[14])

data. If data about the nature of a problem are sparse, like at this point in time of the COVID-19 pandemic, many *anticipated* model outcomes entail high degrees of *uncertainty* or are frankly misleading. Anticipatory modelling can fail if a model is not fit for purpose or outdated, uses incorrect coding of agents' state variables that determine its dynamics, neglects to take account of interactions with other systems, or is frankly based on the wrong paradigm (Stockman—personal communication).

In time, *real-world feedback* will provide more complete data about the dynamic behaviours of the pandemic, which will result in refined models that *better anticipate* the future—desirable or undesirable—outcomes. Well-designed contextual models can provide fairly accurate projections of the *to-be-expected real-world outcomes* of the pandemic on the health system, social activities, and the economy. However, non-modelled interactions can have significant unintended consequences, for example, the focus on surge capacity of ICU for COVID-19 patients can reduce resources for other services and lead to greater morbidity and mortality of aged care residents or those affected by multiple morbidities.

5.1 | Polarities and interdependencies of the COVID-19 pandemic

Various interests aim to focus the debate and actions on different aspects of the pandemic. While all of them have their merits, it requires strong leadership to guide everyone through the crisis. Some of the dynamic tensions arising from issues include:

- Host resilience and responses
  - Patient factors—age, years of life left, frailty, multi-morbidity (compromised body systems), impact of common medications such as ACE-inhibitors, polypharmacy.

  - Social determinants—poverty, social isolation and support, housing, food security.
  - Community susceptibility—herd immunity, individual and group vulnerabilities, ongoing infectivity, reinfection
  - Disease dynamics—acute respiratory distress syndrome, cytokine storm, acute organ failure, recovery and long-term sequelae
- Exposure intensity—asymptomatic shedding, exposure from health care workers, value of face masks and PPE types, potential of vaccination, building ventilation systems
- Virus characteristics and the unknown unknowns—viral genome, invasion, multiplication, persistence, seasonality, and mutations
- Interventions
  - social distancing
  - screening and contact tracing, testing for immunity
  - clinical drug trials for treatment and prophylaxis, for example, remdesivir, chloroquine, azithromycin, or nasal sprays
  - vaccine development
- Intrinsic factors—individual and public health motivations, anxieties and fears, social distancing
- Health services—private vs public funding, health service resourcing, ethics of rationing
- Resource security
  - interruption of supply chains affecting delivery and distribution of, for example, personal protective equipment, respirators, or medications
  - interruption to manufacturing
  - food security
- Political economy—political theories and mindsets, focus on growing GDP, trade, employment and business collapse, poverty

5.2 | Approaches to managing polarities and interdependencies

Managing polarities and interdependencies requires neutral spaces for negotiation, discourse, and conflict resolution. Prerequisites are the acknowledgement of difference in values, respect for different perspectives, and a clear focus on the real-world experiences of those involved. It requires communication and leadership skills to facilitate the necessary *adaptive work*[21] of knowledge translation amongst stakeholders. Specifically, it means facilitating the synthesis of data to information, information to knowledge, and knowledge to practical wisdom (refer to Figure 2).[22]

6 | KEY CHALLENGES—A COMPLEXITY SCIENCE PERSPECTIVE

COVID-19 offers a unique opportunity to reflect on two common catchphrases pertinent to a systemic understanding of our world: *nothing happens in isolation*, and *context is everything*. The challenges posed by the handling of the pandemic should also force us to reflect on our *"Thinking about our own thinking – without any kind of instruction –* [as it] *can make us better problem solvers."*[4]

What can we take away at this stage of the journey?[23] Dynamic interactions always keep social systems in a state close to instability (or dys-equilibrium). If political and economic constraints on our societal system are too tight and lack the necessary redundancies, the system cannot adapt to the disruptions of a pandemic like COVID-19.[24] Health systems, and particularly their public health divisions, have been constrained by the neglect of pandemic risk planning and inadequate resourcing. Health services are constrained by a lack of surge capacity.[25] The lack of consistent population health surveillance and health-related information systems minimize the ability to collect and utilize vital clinical and public health data in their proper context.[12] Inconsistent or non-transparent communication hinders the collective deliberation needed to make decisions in an environment of uncertainty and competing demands.[26] The long-term consequences of the hit-and-miss efforts in this crisis often remain unrecognized and thereby perpetuate socio-economic disadvantage and health inequities for future generations.[27]

7 | THE WAY FORWARD

We all face the challenge of adapting to the inevitable "new norms" of the emergent new societal systems characterized by different structures and dynamics. The "new norms" should emerge from our shared values and our humanitarian ability of sensemaking, which will take us forward on this quest.

What we—collectively—need is a better and more widespread understanding of the sciences of CAS—they are *wholes* that cannot be understood by the nature and behaviour of its constituent parts; they are self-organizing and emergent in light of challenges and changing contexts. We also need to acknowledge and mediate our "natural tendencies" to respond to unexpected complex problems in ad hoc—knee-jerk—ways. These understandings enable different approaches to manage the chaos of this (and other) unexpected crises. In addition, it, one, supports a far more nuanced communication approach to convey the scientific insights into the virus and its dynamics and, two, dampens the heightened anxieties associated with the uncertainties inherent in the unknowns of this continually emerging pandemic.

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Joachim P. Sturmberg MBBS, MFM, PhD, DORACOG, FRACGP[1,2]
Carmel M. Martin MBBS, MSc, PhD, MRCGP, FRACGP, FAFPHM[3]

[1]*School of Medicine and Public Health, Faculty of Health and Medicine, University of Newcastle, Callaghan, New South Wales, Australia*
[2]*International Society for Systems and Complexity Sciences for Health, Waitsfield, VT, USA*
[3]*Department of Medicine, Nursing and Allied Health Monash University, Clayton, Victoria, Australia*

Correspondence

Joachim P. Sturmberg, School of Medicine and Public Health, Faculty of Health and Medicine, University of Newcastle, Callaghan, New South Wales, Australia.

Email: jp.sturmberg@gmail.com

ORCID

Joachim P. Sturmberg https://orcid.org/0000-0002-2219-6281

Carmel M. Martin https://orcid.org/0000-0001-8174-7859

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