



Making transdisciplinarity work for complex systems: A dynamic model for blending diverse knowledges

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ARTICLE INFO

Keywords:

Transdisciplinarity
Complexity
Plural knowledges
Knowledge blending
Collaborative framework

ABSTRACT

The world is increasingly characterized by a paradigm of interconnectivity within a complex system, so that impact to any single element or location is likely to cause unanticipated, unequal, and disruptive impacts elsewhere. As society has become more complex, the intractable problems of our global community have also become complex, interconnected, dynamic and nonlinear. Potential solutions to complex global issues will not be identifiable through efforts associated with any single discipline. Boundary-spanning collaborations and collective action are required to create the necessary paradigm shifts. In response to this need, this paper presents a trans-disciplinary framework designed to blend different knowledges and resources via a non-hierarchical, self-organizing collaboration. This boundary-spanning process fosters the integration of diverse scholarly expertise, artistic expression and lived experiences to engage broad audiences in knowledge exchange. As illustration, a virtual art + science exhibition produced during the COVID-19 pandemic, **Long COVID: We Are Here!** is examined. The exhibition, co-created by six artists and six scientists, curated multiple voices, skills, talents and artefacts to explore perspectives of an emerging global health and social problem. This paper scrutinizes the design process, production, and outcomes of the exhibition as a model for engaging with complexity, at multiple scales; as a method of knowledge sharing and new knowledge creation, of disseminating empirical knowledge to a broad audience, and for enabling and catalyzing transformative and sustainable pathways for social change.

1. Introduction

The effects of war, poverty, resource scarcity, pathogens, extinctions, human migrations, extreme events, and social upheaval threaten and compound worldwide social, economic and ecological disasters on an unprecedented scale (Bennett et al., 2023; Gostin, 2022; Richardson et al., 2023; Scheffran, 2023; Westman et al., 2022). The world is increasingly recognized as an inherently complex system, where impact to a single element in any given location is likely to cause unanticipated, unequal, and disruptive cascading impacts. Power disparities around structural and procedural equity (e.g. health, education, employment, mobility, access to resources, political and social participation) are constantly being exhibited globally (Abimbola et al., 2021; Béland, He, & Ramesh, 2022).

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<https://doi.org/10.1016/j.futures.2024.103415>

Received 10 November 2023; Received in revised form 28 April 2024; Accepted 7 June 2024

Available online 13 June 2024

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Countervailing political forces increasingly amplify isolationist pressures, leaving society even less capable of solidarity or unified responses to global priorities (Priebe et al., 2023).

As the problems our global community faces have become interconnected, dynamic and nonlinear, in other words, complex, a growing body of research supports the potential of transdisciplinary collaborations for yielding cross-cutting alliances able to design innovative solutions able to address complex issues (Fraccascia, Giannoccaro, & Albino, 2018; P. Gibbs & McGregor, 2023; Rinaldi, 2023). However, elite knowledge remains heavily siloed within singular disciplines and sectors (Bento, Tagliabue, & Lorenzo, 2020). These limitations are amplified by a paucity of platforms, models, and detailed guidance for how to navigate the myriad challenges of working across discipline and sector lexicon, foci and ideologies (Gostin, 2022; Mobjörk, 2010). In this paper, transdisciplinarity is taken as providing a framework that transcends disciplinary boundaries to develop holistic and transformative solutions where the outcome extends beyond interdisciplinary approaches to create something completely new providing space for social transformations as well as governance ones (Defila & Di Giulio, 2015; Klenk & Meehan, 2017; Norström et al., 2020; Schneider et al., 2019).

Novel collaborative platforms that promote transdisciplinarity and offer great promise for the cross-pollination of ideas. Multi-sensory environments create opportunities for engagement of wide audiences and dissemination of powerful data driven narratives able to inspire transformative learning and social change (Blackwell, Wilson, Street, Boulton, & Knell, 2009; Cvitanovic, McDonald, & Hobday, 2016; McNeil, 2014). Fundamentally, transdisciplinarity enables the examination of complex systems and the consequences that these attributes pose to our knowledge of the world. This is because, as Cilliers & Nicolescu clearly state, that '*neither transdisciplinarity nor complexity are neutral: they involve an ethical dimension*' (Cilliers & Nicolescu, 2012, pg.717). This reality grounds transdisciplinarity. Co-creative approaches are resolving mechanisms that assist with problem conceptualization and resolution within increasingly complexity-driven landscapes (Kumar Giri, 2002; Lawrence, 2015; Russell, Wickson, & Carew, 2008). The implicit values, underlying assumptions, and norms that shape transdisciplinary knowledge generation and integration can be proactively used to identify possible futures able to guide the transformations of societies towards greater levels of sustainability (Gugerell, Radinger-Peer, & Penker, 2023; Renn, 2021).

To tackle the recognised limitations of siloed knowledge, this paper offers a novel collaborative framework for transdisciplinary knowledge exchange, alongside the story of the ensuing boundary-spanning exhibition, **Long COVID: We Are Here!**, as a method for knowledge dissemination. Long COVID will first be discussed through the lens of 21st century complexity, highlighting the need for robust problem-solving approaches able to address complex issues in the Anthropocene. Finally, implications for future research will be discussed. The transdisciplinary framework presented provides a design for the convening of diverse disciplinary perspectives, the exchange and blending of disparate knowledge sets including lived experiences, a methodology for collectively cross-learning processes and practices, and a way to disseminate the integrated knowledge such that a diverse audience is able to engage, and find their own space and identity in the outcomes.

2. Why do we need a new approach to problem-solving now?

2.1. 21st century complexity

We are living in the Anthropocene, an epoch reflecting the substantial impact human activity has had on the planet, especially to climate and ecosystems (Biermann et al., 2016; Olsson, Moore, Westley, & McCarthy, 2017). The sum of our economic, political and social systems, including contemporary elements, such as ubiquitous technology and interconnectivity, can be viewed in the context of globalization and the Anthropocene. We live in a hyperconnected, complex and fast-changing world where it is difficult to predict the consequences of our actions. The demanding conditions of our current global landscape are the antecedents to unprecedented challenges being faced by humanity, reflected in the UN Sustainable Development Goals (SDGs), goals established in 2015 (United Nations, 2015).

The world is increasingly characterized by a paradigm of digital interconnectivity within a complex system. Emergent crises occur more rapidly and overlap with one another, enabling wicked cascades that cannot be addressed by singular or discipline perspectives. Specialization of information has given rise to a large body of elite knowledge which allows for adequate response to complicated problems; however, falls short for finding solutions to complex problems. Complex problems are not linear and thus are not adequately addressed by singular sets of knowledge (Abramo, D'Angelo, & Di Costa, 2018). Hyper-specialization also precludes cross-fertilization of ideas and knowledge integration, obscuring the fundamental truth that we are all connected (Dorst, 2017). The more siloed our knowledge becomes, the less connected and integrated the information will be with other scientific endeavours and the community at large. The accelerated proliferation of digital information and global connectivity further propels hyper-specialization and the output of specialized knowledge. Elite knowledge has become accessible to fewer and fewer people, who find themselves unable to understand or apply the elite jargon, methods and results of any given field (McNeil, 2014). Real world context can be lost with specialization (Zafeirakopoulos & Bijl-Brouwer, 2018). Moreover, specialization makes it difficult for us to address the big picture, and the fundamentals set out in the SDGs. Revolutionary ideas and innovations will come from synthesised understanding of the broader picture and making boundary-spanning leaps, not just from eking out incremental advances in esoteric subfields (Bateman, 2015). By zooming out and refocusing our lens, we can see how the case study of Long COVID acts as a metaphor for the new realities of today's world. COVID-19 has both spotlighted and amplified our 21st century paradigm.

2.2. The problem of Long COVID

The emergence of the COVID-19 pandemic has been attributed to multiple pandemic drivers including globalization, zoonotic

pathogens, anthropogenic climate change and urbanization (Gostin, 2022). The spread of the SARS-CoV-2 virus and the subsequent severity of the pandemic was compounded by insufficient pandemic preparation (OECD, 2022; The Lancet, 2020), impeding the success of traditional institutional responses. Governments and international health organizations have not been built to be nimble in response to global crisis management. While it has been estimated that the probability of novel disease outbreaks, such as COVID-19, will likely grow three-fold in the next few decades (Marani, Katul, Pan, & Parolari, 2021), a successful crisis management strategy remains elusive as such planning will require a coordinated international response, clear and consistent communications, transparency in decision making and international solidarity related to health policies and protocols (OECD, 2022).

Applying a complexity lens to the COVID-19 pandemic stresses the dynamic nature of causality as well as the emergent and difficult to predict behaviour in networks that can adapt to a changing environment. Wernli et al. (2022) describe the emergence and global spread of SARS-CoV-2 as resulting from multilevel and multiscale interactions between host, pathogen, and other factors at the human, animal, and environment interface including incessant land use changes, accelerating population statistics, continual genetic evolution at the pathogen level, and a human-flora-fauna interaction producing zoonotic spill. Further, global travel resulted in the rapid transmission of SARS-CoV-2 across the world, with factors as diverse as population health status, quality of institutions, and political leadership and philosophy affecting how countries mounted responses (Wernli et al., 2022). Finally, socioeconomic inequities and political and social determinants of health, within and between populations, created differences in how the virus played out. Moreover, the COVID-19 pandemic exhibited a typical non-proportional and path-dependent behaviour of non-linear systems.

In the weeks following the first wave of COVID-19, post-acute sequelae of SARS-CoV-2 infection (PASC), or Long COVID, emerged. Long COVID is a post-viral syndrome impacting nearly every organ system including respiratory system disorders, nervous system and neurocognitive disorders, mental health disorders, metabolic disorders, cardiovascular disorders, gastrointestinal disorders, musculoskeletal pain, and anaemia (Al-Aly, Xie, & Bowe, 2021; Davis et al., 2021). While most people recovered from SARS-CoV-2, within 2–4 weeks, others experienced a lengthened recovery period characterized by newly emergent and/or lingering symptoms. The initial lack of Long COVID syndrome recognition led to an absence of baseline data collection, so prevalence rates have been difficult to determine. Further, the conveyance of empirical information about COVID-19 during the pandemic was impeded due to the spread of misinformation, especially via social media (Viswanath, Lee, & Pinnamaneni, 2020). Prashar (2023), described the social disruption of Long COVID to public services, economies and population health at community and population level, with as many as 91.8 % of long COVID sufferers experiencing at least 35 weeks of symptoms and with permanent organ damage having been observed in young, low-risk individuals even with mild and moderate COVID-19 infections. Prasher further described policy movement towards an ‘endemic COVID’ approach was likely to result in a new surge of long COVID in the general population, amplifying the public health burden, spanning multiple countries, healthcare systems and communities, especially for those with unequal access to care (Prashar, 2023).

Long COVID exemplifies a wicked social issue as a global health issue, with highly interactive complexity, with interdependent social, economic and public health implications. It cannot be understood or addressed via a single disciplinary knowledge set. There remains a paucity of knowledge about the issue, there are interdependencies of people, disciplines and sectors as well as interactions with other complex problems, and all individual actions to address it will have uncertain effects, as it cannot be tackled from a siloed perspective (Schiefloe, 2020). As such, Long COVID offered an exemplar to test a knowledge exchange and dissemination process that had been devised to explore complex problems that require transdisciplinary collaboration. The project this paper describes began with a personal crisis. Artist-scientist and lead author of this paper, Jerome was infected with COVID-19 on March 5, 2020, during the first wave of the pandemic. After an intense acute infection Jerome experienced a range of enduring Long COVID symptoms, spanning multiple bodily systems. Like other “long haulers,” Jerome found little available information or medical care and frequently had their symptoms dismissed, questioned or attributed to psychological processes. Jerome was shunted from one specialist to another with each specialist (e.g. cardiology) making referrals to new specialists (e.g. pulmonology) until the circle was completed by being referred back to their original specialist. The hyper-specialization of western medicine forestalled the integrated, holistic care that a full-body, multi-system disease process requires. Specialists were unprepared to address the complexity of Long COVID. The post-viral syndrome reflects a systemic pathology unable to be addressed by a single specialism. Long COVID requires integrated, holistic solutions. Traditional problem solving fell short.

3. VUCA and complex problems

The term ‘VUCA’, first used by the American military, lays out a framework for understanding the unpredictable nature of the global landscape (Bennis & Nanus, 1985). VUCA’s four elements, of ‘volatility’ ‘uncertainty’ ‘complexity’ and ‘ambiguity’, reflect the nature of interconnectivity within a complex system, and point to the consequences of our global predicament. Complexity is the key aspect of VUCA, differentiated from a complicated system and complicated problems. In a complicated system, past behaviour predicts future behaviour. In contrast, a complex system cannot be disassembled, the parts cannot be individually analysed, and insight into its past behaviour will not predict future behaviour. Further, a small localized change in a complex system can have large effects elsewhere: i.e. Chaos Theory.

To address complexity, a shift is required, from single ‘cause and effect’ thinking and problem solving, to the creation of solutions that apprehend multiple causes and effects (von Stamm, 2017). Four factors can be delineated for how we might embrace this shift: 1- Concurrent action amongst diverse disciplines, to match the conditions and opportunities in the moment; 2- Collaboration, rather than customary linear and sequential approaches; 3- Co-creation that focuses on the way we work as well as the products and services we create; and, 4- Caring, a sense of responsibility as well as agency to act to improve the state of our planet. ‘Caring’ includes a deep respect of, and appreciation for, diversity. Thus, we reflect the importance of diversity, and the particular manifestation of

transdisciplinarity, as the enabling factor for thriving in complexity (Fig. 1).

Compartmentalization of information hinders opportunities for interconnection that are needed for dialogue and to facilitate collaborations (Zafeirakopoulos & Bijl-Brouwer, 2018). Explanations as to why transdisciplinarity offers an answer to complex problems can be found in several frameworks including from cybernetics. Ashby’s Law of Requisite Variety suggests that, for an appropriate solution to be found, the level of complexity inherent in a task (or problem or challenge) should be matched by the complexity reflected in the response (Ashby, 1991; Tabilo Alvarez & Ramirez-Correa, 2023). Issues of complexity demand boundary spanning between individuals and disciplines, in order to forge meaningful new partnerships, inspire creative knowledge exchange, to share and blend scientific information in novel ways and co-evolve complex solutions. Page (2011) highlights the different role that diversity plays in complex systems compared to equilibrium systems stating that “In complex adaptive systems, diversity makes fundamental contributions to system performance.” (Page, 2011, pg. 14). While complexity has increased dramatically, the organizations, organizational structures and approaches to solving problems have not evolved at the same speed. Embracing and nurturing transdisciplinarity is key. To solve our grand societal challenges, collaborative, transdisciplinary approaches are required, able to bring together myriad disciplines and perspectives, define problems empirically, determine concurrent methodologies, and work to understand complex issues from a common vantage point and with unified goals (National Academies of Sciences Engineering and Medicine, 2018). Knowledge that spills over at the intersection of multiple fields, disciplines and cultures can be absorbed from novel points of view to create greater opportunities for serendipity, creativity and innovation.

4. How to create a successful transdisciplinary project

Transdisciplinarity is largely recognized as a key method for collaborative research to advance science in dealing with grand challenges but the reality reveals a gap between transdisciplinary research collaboration and knowledge translation in the real world (Archibald, Lawless, de Plaza, & Kitson, 2023; Chappell & Muglia, 2023). Chappell & Muglia (2024) also assert the need to foster a community that centres diverse perspectives and ways of knowing. By defining models able to create knowledge exchange across science, the humanities and the arts we can engage researchers in non-traditional ways that amplify creativity, play, and truly transdisciplinary work. Such new methodologies will foster cultural change needed in the scientific community, fuelling discoveries and innovations able to resolve complex societal issues. In this third section, the Relational Space framework for transdisciplinary collaboration is detailed, then illustrated through the story of **Long COVID: We Are Here!**

4.1. Project origination

In September, 2020, Relational Space (RS), a New York based non-profit gallery, posted an open call for an exhibition, **Long COVID: We are here!** The origins of this project were a combination of personal experience, identification of an urgent, emergent issue, and a sponsoring organization with a visionary, transdisciplinary mission able to take on the effort. As noted in our case study, Jerome, the Founding Director of RS, had become disabled as the result of Long COVID and thus cognizant of the multitude of others grappling with the syndrome, with limited information and care. Since this health crisis was not yet recognized by the medical community or healthcare policy makers, awareness of the patient experience and grass-roots activism was needed to raise visibility, encourage nascent research regarding the disease course, promote treatments, identify the need for training amongst physicians and initiate a call to action by government agencies. An open call for scientist and artist participants was established with selections reflecting a diversity of disciplines, professional contributions, and personal stakes in exploring this issue.

Work on this effort began in the lock-down phase of COVID, about seven months after the pandemic was declared. The exhibition

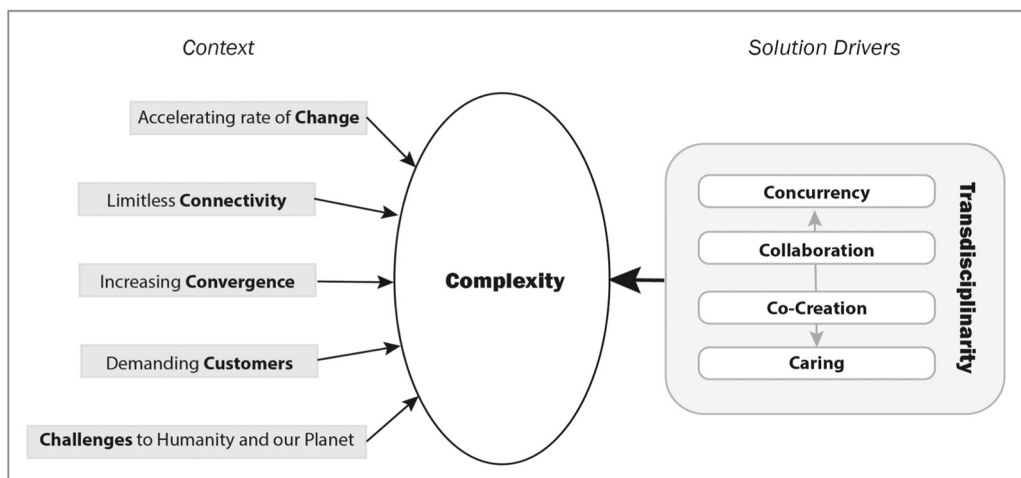


Fig. 1. The context of complexity: drivers and accelerators of transdisciplinarity (von Stamm, 2017).

was informed by empirical research on post-viral syndromes and Myalgic Encephalomyelitis/ Chronic Fatigue Syndrome (ME/CFS), as well as the lived experience of Long COVID patients. While the model originally set forth a collaborative design for the co-curation of an in-person exhibition, the participants pivoted to produce a virtual exhibition within a virtual reality (VR) environment able to accommodate public lock-down status. **Long COVID: We Are Here!** represents a transdisciplinary, arts-sciences collaboration generated from a data-driven narrative with an immersive, multi-sensory exhibition endpoint. Linking evidence-based knowledge with art installations engages, educates and mobilizes people around salient issues, such as Long COVID, pointing the way to changes in attitudes, behaviour, culture and policy (Jerome, 2019). The final result was an accessible and powerfully moving exhibition that invited the public to learn about a poorly understood syndrome, increased visibility for an under-recognized health movement, and promoted social action via an innovative methodology.

4.2. Process design

RS developed a model collaboration blueprint for addressing complex social issues, from a multi-disciplinary perspective, via facilitated sessions. An aggressive six-month timeframe was established and a process design was mapped out, built on a series of six phases:

1. **Planning phase:** The transdisciplinary project narrative was created, including aims and timeline, and funding was secured. All necessary documentation was developed including presentation materials, timelines, entry forms, a submission system and documents outlining project values, expectations, technical specifications and collaboration instructions.
2. **Inviting phase:** A call for artists and scientists was initiated, designed to identify a diverse mix of disciplinary expertise and talent. The invitation was shared broadly via mass mailings, social media, and personal networks. Collaboration platforms were finalized and all shared documents were posted there for reference.
3. **Founding phase:** Multi-disciplinary art and science participants were selected for the project. The model calls for each participant to bring 3-4 elements to the group, that is, expertise, artefacts, skill sets and other knowledges. Each participant received biographical information about all participants and guidance regarding how to choose elements for sharing. Session guidelines and shared values were disseminated to participants along with the narrative, a timeline, instructions for technology use, expectations and collaboration etiquette.
4. **Building phase:** The participants were brought together to collaborate in a series of three facilitated, synchronous video-conferencing sessions. Collaboration was also established between sessions, via a hub for asynchronous sharing and collaboration. The goal for the Building phase was knowledge spillover amongst the diverse participants. The collaborative process prioritized a non-hierarchical and self-organizing approach. Individual elements were brought to the group and shared. Participants were then broken into dyads and small groups for the sharing of expertise, knowledge sets and ideas. In these environments, participants were encouraged to blend their individual elements in novel ways to create brand new elements, thus creating the opportunity for discussion, collaboration and knowledge spillover. In the final collaborative session, participants returned to the overall group in order to synthesize individual and blended elements into themes and specific actions, and to weave the entirety into a co-evolved design into a production for a virtual exhibit, able to convey the narrative in the most compelling, interactive and engaging way.
5. **Installing:** Once the details of the co-curation were decided, a review of production parameters was refined related to virtuality, timeline and resources to determine how the virtual co-curation production would be achieved. Participants were able to help define production elements including design, marketing and event installation.
6. **The Loop:** At the conclusion of the installation, there was a period of reflection on the exhibition outcomes, process and the co-evolution experience in order to allow for collected shared learnings and personal meaning making to inform the next iteration of this process.

4.3. Process execution

After determining project resources, a narrative was written for an open call. The narrative described the intent of the collaborative exhibition and provided a shared context for the participants' consideration. The narrative established:

Long COVID - We Are Here! is a fearless exploration into the long-hauler experience with four concurrent goals. It aims to raise awareness about the impact of this disabling post-viral epidemic; open doors for the research/medical community already strained by the COVID-19 pandemic and compel the establishment of an international, funded research agenda; advocate for a global repository of articles, resources, therapeutics and treatment strategies; and urge widespread physician training related to Long COVID. Further, **Long COVID: We Are Here!** unites in solidarity with other debilitating and frequently dismissed syndromes such as (ME/CFS) for increased visibility and support.

The selection process yielded a panel of 12 artists, activists and scientists to collaborate, co-evolve and co-curate **Long COVID - We Are Here!** Five of the twelve invited participants were actively suffering from Long COVID throughout the collaborative process. One participant suffered from ME/CFS; one counselled people whose loved ones had died from COVID; one collected the stories of many Long COVID sufferers, via interviews, as part of her work as a journalist; and one participant had a close friend who was suffering from Long COVID. Some participants had personal and professional experiences advocating for people with stigmatized and deprioritized health conditions. All participants were committed to sharing these experiences to raise awareness about Long COVID. Upon selection, each participant was provided with the narrative, and other documents outlining goals, expectations, collaboration values,

methodology, installation parameters and participant bias.

The process design phases were shared with participants to ensure comfort in moving smoothly through the sessions. The model utilized three 90-minute collaborative sessions for knowledge exchange and the blending of expertise, talent and skill-sets between participants. Two platforms were utilized for the collaboration: a synchronous video-conferencing platform (Zoom); and an asynchronous hub (Basecamp) for participants to achieve between sessions work, and as a communal space for sheltering reference documents and session notes. The model reflects a sophisticated knowledge sharing process (Fig. 2). The process was fundamentally non-hierarchical and decentralized, where all participants' voices and contributions were held as equally valuable. Further, the process was both highly structured and, simultaneously, self-organizing. The structured aspect of the model was achieved via the 'elements' contributed by each participant; and, through the imposition of strict time limits throughout sessions. Within this structure, the content of discussions was completely self-organizing, that is, individuals were empowered to determine the flow of conversation, and to make curatorial decisions regarding the final exhibition.

Each participant submitted 3–5 'elements' to be shared with the other participants during the first session. Elements were defined as artefacts, pieces of expertise, data, skills and other ideas for knowledge sharing. An elaborated document was provided for greater clarity of elements, with respective examples. Elements are the means by which participants were able to bring focused and specific ideas to the collaboration. Each participant was positioned for the rest of the participants as an expert, that is, a person with extensive content knowledge and ability based on their own research and/or experience in a particular field. Time was spent on having them get to know each other as individuals, and as dyads and double dyads, for the purpose of creating a sense of mutual respect and interdependency. This method reinforced the collaboration value that each participant's voice would be heard in an equal manner.

Elements represented technical knowledge and skills (manual and/or intellectual skills) including both explicit and tacit knowledge sets that provided a sensitivity to patterns of meaningful information. To determine elements, each participant was asked to think of their minds as a box of Lego pieces, where the Lego reflect their expertise, acquired over time, experience and study. The participant's task was then to consider the context (narrative) and determine which pieces in that box (elements) most related to this context. For example, a health journalist participant shared her interviews with Long COVID patients while an artist offered vivid photographic images. Every Element was uploaded and shared via a Basecamp, a project-management hub, with the understanding that each would be honoured as part of the final curation.

Careful facilitation of each session precluded the power imbalances that often characterizes transdisciplinary collaborations, such as when artist contributions are turned into a marketing window dressing for more serious scientist communications. Instead of allowing a few individuals to dominate the conversation in the sessions, the facilitator ensured equality in conversational turn-taking,

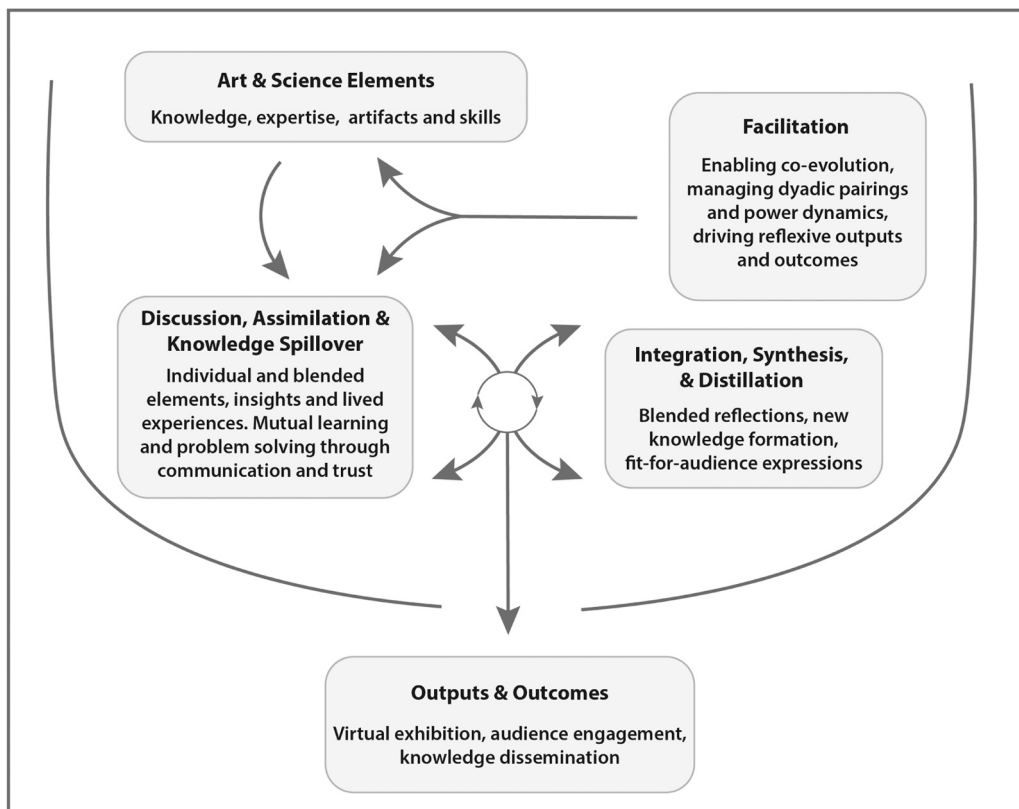


Fig. 2. Transdisciplinary Collaborative Model Design Centred on Care and Equity.

instructing each participant to use the same amount of time to share their insights. Throughout the process, the facilitator also emphasized listening to each other to make sure that all individual voices were heard, understood, and incorporated into the group's shared understanding. Another way that the facilitator prevented inequity was by insisting that all elements remained intact. This was sometimes challenging—for example, one participant complained that an element submitted by someone else “didn't make any sense” when working to try to organize it into a room with other elements. However, once it was restated that the expectation was that all of the original elements needed to be a part of the final exhibit, the team was able to figure out a successful way to incorporate the element that resulted in an insightful addition. These parameters reinforced the importance of blending multiple voices, skill sets, perspectives, and contexts when addressing complex problems. The facilitation of sessions included the consolidation of the information presented in sessions including elements, break-outs and Basecamp discussions. All material was consolidated between sessions and provided back to participants weekly in aggregate. Relevant information, ideas, comments and elements were boiled down and integrated so it was easier to move forward to the next step in the process.

First, the participants shared their individual elements with the overall group. Through a narrowed focus on defined elements, the design process precluded participants from crystallizing production ideas or jumping immediately to curation decisions. After elements were shared to the group of twelve, breakouts were conducted where participants were paired in transdisciplinary break-out dyads. One of the key guiding principles of this transdisciplinary collaboration was the blending of elements, and/or knowledge sets. Rather than assuming that the diversity of membership would automatically create optimal outcomes, this project actively facilitated the sharing and blending of knowledge between members. Conscious dyadic pairing of “science” participants with “artist” participants maximized opportunities for radical cross-pollination. Participants collaborated to blend their elements and create new elements that would also be included in the final co-curation. This collective fusion of new ideas through transdisciplinary break-outs went further in the second session, when dyads were combined into small groups, for compounded knowledge exchange and blending. In the third session, participants returned as a full group to share their new, composite elements and to integrate the elements into a synthesized exhibition design, working together to achieve a compelling and interactive vision for engagement. The immersive exhibition was produced within a virtual environment to accommodate the pandemic lockdowns, and included both visual and audio components.

Once the three sessions of the Building phase were complete, participants were invited to continue as collaborators and advisors in the Install phase, the completion of the virtual exhibit. Although they had already fulfilled their commitment to the project, some participants continued to play active roles during Installation, such as the person who designed the website with the virtual reality immersive experience. While it might be expected that the artists might dominate during this phase, the participants who continued to meet regularly with the facilitator represented a mix of both artists and scientists and they contributed technical assistance, content creation, and design guidance. Throughout this process, all of the members of the team received updates on the progress, saw and tweaked initial designs, and provided feedback on the final exhibit. Marketing for the launch of the event included the participants and the activation of their own social networks in support of the project. Based on the group's vision of the exhibit layout as representing both the body and the journey of a Long Hauler, the exhibit, <https://longcovidwearerehere.org/>, was constructed as a virtual reality interactive exploration in which a visitor moves in and out of rooms that could be part of the experience of someone with Long COVID. Visitors chose their own path through the experience, deciding which art and information to unlock as they imagine themselves on the journey—such as spending time waiting in a hospital lobby to see their doctor, while learning data about Long COVID symptoms from an illustrated poster on the wall or understanding the emotions of the illness by listening to recordings of patient's testimonies. The construction of the VR map was designed to highlight the complexity, uncertainty, and ambiguity of the participants' understandings and perspectives of Long COVID. In one darkened bedroom, a moving soliloquy “*I Am Unseen in My Bed*” is joined with ceramic art “*Impossible Drinking Vessels*” and a documentary-style video testimonial “*Jodie's Heart*” describing total exhaustion and despair. The analogy of rolling a die and spinning a wheel are used to reinforce this sense of chance and not knowing what to expect. The moving images, scenes, videos, recorded voices of Long Haulers, data visualizations, works of art, and interactive immersive activities within the exhibit challenged visitors to engage with and make meaning from these experiences.

In the final phase – the Loop – participants and RS reflected on the outcomes of the **Long COVID: We Are Here!** exhibit, as well as the learnings it generated. The original aim of the project was to raise awareness about the devastating impact of COVID-19's post-viral damage with the goals of opening doors for new research, advocating for an open source repository of articles, resources therapeutics and treatment, and urging widespread physician training. Upon reflection, it seemed clear that the primary impact of the exhibit was in the arena of raising awareness. First, the many people who visited the exhibit learned about the experience of Long COVID and the urgent health crisis it reflected. A virtual Reflection Book was created as part of the exhibition, available at the conclusion of the virtual experience, where visitors were able to comment and provide personal insights related to their experience. Many commented how their emotional reaction to the inequities of the experiences of Long Haulers moved them in ways they hadn't expected. Others stated that they were leaving the exhibit motivated to take action. Visitors were encouraged to share what they had learned with others and raise awareness about this critical issue. A secondary element of impact was in beginning to curate a repository of helpful Long COVID articles. Visitors were able to access resources and scholarship in the Reading Room and blog articles on the website that allowed them to continue learning. After the exhibition was launched, a small grant was acquired allowing the exhibition to build a website, create a live presentation with a walk-through of the VR exhibition, and present a follow-up panel of Long COVID medical experts. This production was recorded and posted on YouTube as an enduring artefact.

4.4. Collaboration model features

The phased process design provided a model for collaboration, intentionally shaping the divergence and convergence of ideas, knowledge and expression. We can enumerate several elements that enabled and amplified the success of this project.

4.4.1. Shared values

The following were established as shared collaboration values and communicated as part of the onboarding process that welcomed participants into the project. The values were reviewed during the first session, helping to create a reinforcing, virtuous circle that allowed the project to continuously build momentum.

- • Trust is a belief in one another's character, ability, integrity, familiarity and/or ethics. Trust in the facilitator, each other and the process built a sense of safety, promoted efficacy and agency and facilitated openness, risk-taking and generosity of spirit.
- • Respect refers to a willingness to show consideration of and appreciation for respective knowledge sets, expertise and points of view. Showing respect included showing up, being on-time, being responsible for group participation, and being kind, humble, non-judgemental, reliable, inclusive, and contributing richly. Respect within groups increased productivity, knowledge sharing and understanding.
- • Non-hierarchical refers to the fluid organizational approach of the collaborative design, with complex interrelationships and an absence of strict hierarchies. The non-hierarchical structure allowed participants greater empowerment and creativity in the exchange of ideas as well as increased fluidity in collaborative processes and relationships.
- • Knowledge exchange is rooted in the value that each person can learn from everyone else. Knowledge is expertise or understanding, and/or technique, creation, process and/or method. Knowledge collaboration created an exchange of diverse information that empowered each other to explore, listen and create.
- • Self-organizing is a value that allows for maximum flexibility within collaborative sessions and in the final, co-curated exhibition. By allowing the group to identify elements and collaborative styles, enumerate production details and design and prioritize tasks and management, teamwork, motivation, accountability, sense of ownership and trust were amplified.
- • Narrative, or telling stories, is a fundamental way that humans understand the world. The sharing of personal stories and lived experience as well as empirical knowledge helped to create a shared vision and culture and provided opportunities to acknowledge one another's efforts and contributions.
- • Communication or the transmitting of information, is the key for collaborative success. The degree of effective communication led to the group's ability to collaborate well, work together, and reach common goals efficiently. This communication was mediated via technology such as Zoom and Basecamp.
- • Problem Solving recognizes that the essence of collaboration is to build on and value each other's ideas and expertise through shared identification of goals, negotiated solutions and outcomes, inclusion and relationship management. Collaborative problem solving generated more and better solutions than individuals and the synthesis of these ideas heightened the potential for collaborative success.

4.4.2. Shared vision

The provision of a singular narrative for **Long COVID: We Are Here!** provided clarity for the collaborative process and, ultimately, the exhibition itself. Collaborations that are grounded in shared vision mobilize expertise and promote participation, creativity and accountability, increasing the likelihood of synergy and effectiveness (Somboonpakorn & Kantabutra, 2014). The first step was the provision of a written narrative to participants during the on-boarding process. The narrative was expanded in later stages and co-evolved over time. By creating a strong communal focus and an organic sense of shared purpose, everyone became singularly aligned and thus more nimble, enabling greater adaptation and innovation, while maintaining consistency of goals. A shared purpose was critical to engaging busy experts who were perhaps already at maximum capacity given the global pandemic. Each session opened and closed with a dedication that focused on Long COVID and reminded participants of their shared purpose. Participants focused on creating a collaboration to serve an audience who had urgent unmet clinical needs.

4.4.3. Trust-based relationships & mutuality

Successful collaboration was supported by prioritizing trust-based relationships, establishing communal values, and a recognizing a set of practical mechanisms to enable members to dynamically explore and iteratively blend ideas and perspectives in the co-evolution of breakthrough ideas (Barker Scott & Manning, 2022). This project fostered successful collaboration by ensuring key conditions of trust-based relationships were met (Schnugg & Song, 2020), including the introduction of shared collaboration values as guidance, fostering of a quiet mind thorough session dedications; promoting introspection and sharing; encouraging humour and respect, and not focusing directly on solutions too early by a refocusing on elements.

In each of the three sessions, mutuality was emphasized. Mutuality is a relational approach to collaborations focused on forming connections that support mutual benefit, purpose and vision (Walsh, Bartunek, & Lacey, 1998). Mutual empathy and knowledge exchange are inherent in the Relational Space collaboration model, recognizing that reciprocal and dynamic processes are actively able to promote respect, build better understanding of all points of view and create relational empowerment. When one of the dyads had a conflict that seemed to have been primed by a power imbalance, the relationship was repaired and their work together was advanced by referring to the shared collaboration values and also by helping each person better understand the value of the other's art/science element to achieve the shared vision.

4.4.4. Caring: active dedication to healing

Throughout the **Long COVID: We Are Here!** process, caring amongst participants was stressed. A third of the participants were sick with Long COVID and experiencing considerable symptomology. In keeping with the recognition of connection and regeneration, the collaborative work continuously centred the wellbeing of the group. This commitment to caring heightened the sense of dedication,

balanced work with personal needs, and acknowledged limits and healthy boundaries. This focus ran parallel to an awareness that we were helping the world understand the importance of caring for Long Haulers. Caring was made explicit in the invitation to participate, the preliminary working agreements, and reminders that were included during working sessions.

4.4.5. Facilitation

Within this model, the role of an academically trained facilitator is indispensable. Working across disciplines with diverse voices can result in misunderstandings, mismatch of goals, and conflicting assumptions. Therefore, within this project, the facilitator acted as a champion, rallying the group and flexibly promoting the project's shared narrative and goals; as well as, bringing the participants together initially and being the glue for holding the group together along the way. Within the sessions, the facilitator acted as a neutral guide, providing clarification about process issues (e.g. elements, aims, session foci), ensuring all voices equal opportunities for participation, maintaining positivity and actively listening in order to enable the group to progress the discussion. Further, the facilitator provided structure, refocused group members to the specific task at hand and inspired relationship-building. Behind the scenes, the facilitator worked with a coordinator to ensure timings, technological integrity and the management of group dynamics. Between sessions, the facilitator consolidated elements, ideas, discussion points and postings into single-page, easy reference sheets distributed to participants for the subsequent session. Further, between meetings the facilitator provided individual participant support, as needed, and moreover, managed the emotional culture of the group. This was necessary as participants could get stuck or feel they didn't know how best to contribute. The facilitation goal was never to define the outcome or influence the result, but to help the group blend ideas, maintain clarity as their discussions progressed, and conceive a united exhibition design vision.

4.4.6. A method for holding uncertainty

While uncertainty is stressful, it is inherent in complex problems. It is also a highly motivating trigger for delineating actions that might lead to solutions. **Long COVID: We Are Here!** was created from a system that embraced uncertainty, thus allowing for the creation, exchange and dissemination of knowledge in agile ways. Agility requires flexibility, creativity and the ability to pivot quickly, enabling proactive responses to manage challenges and adapt swiftly (Ghosh, Barman, & Ulugov, 2021). Long COVID was a largely unknown and widely misunderstood disease process. Science had yet to catch up to the pressing needs of those suffering from Long COVID. Uncertainty is always more stressful than predictable negative consequences (de Berker et al., 2016), so holding space for this ambiguity provided value for the participants and the visitors who eventually viewed the exhibition.

Virtual spaces (Zoom and Basecamp) were established for the project to "hold" the collaboration; and, were used throughout the process in both a scheduled and ad hoc manner. While participants were familiar with Zoom, several struggled with using Basecamp, even after receiving technical assistance. The facilitator did have to step in to help load some documents and shared resources into the virtual space so that the rest of the participants could have equity of access to key materials. Despite this need for extra support, the virtual spaces were the forum for the in between session work that successfully blended elements and reflections. Holding uncertainty involves creating the conditions for inclusive conversations, and boundary spanning, always believing that the collaborations would yield a meaningful co-curation.

4.4.7. Boundary spanning

A high degree of stakeholder diversity was a core component of this project's collaborative success. The Invite and Founding phases were designed to bring very different people to the table able to provide distinctive points of view about Long COVID. Scholarly papers and art works were chosen based on the **Long-COVID: We Are Here!** narrative. The open call produced a diverse pool of trans-disciplinary participants. There are many ways of knowing, including empirical knowledge but also non-empirical knowledge such as sense perception, memory, imagination, emotion and intuition. People learn, understand and generate knowledge in different ways according to their experiences, perspectives, and culture, amongst others (Paterson et al., 2020). The model for **Long COVID: We Are Here!** allowed for knowledge sharing from cognitive, affective and expressive points of view as well as the provision of opportunities for blending perspectives able to promote new knowledge and novel problem-solving.

When members of a diverse team are able to, proactively, take the perspectives of others, they become curious about their thinking and practices, and this in turn enhances information sharing and increases the team's creativity (Du Chatenier, Versteegen, Biemans, Mulder, & Omta, 2009; Edmondson, Casciaro, & Jang, 2019). The RS model allowed for the blending of knowledge sets and iterative, collective ground-truthing. For example, a participant might report a clinical fact about Long COVID and a person with lived experience of Long COVID was able to augment, provide a correction or express another point of view. In this way, the group co-evolved a more holistic knowledge and in turn, an exhibit that engaged the public with multiple experiences of knowing. **Long COVID: We Are Here!** forged cross-cutting collaborations and spawned a release of expertise, ideas and expressions about Long COVID, from diverse expertise and points of view, including artists, scientists, activists and other thought leaders. Collaboration across multiple sectors and disciplines yields synergistic knowledge, greater than the sum of the parts. Within and across sessions, both divergent and convergent thinking were prompted at task specific times.

5. Why art + science exhibitions?

Collaborations between artists and scientists provide an especially good fit for the exchange of ideas and for new knowledge generation (Segarra, Natalizio, Falkenberg, Pulford, & Holmes, 2018). It is time to move beyond the inclusion of non-science disciplines as 'add-ons', with art in the service of science. The arts are able to do more than accomplish outreach and communication of scientific goals (Paterson et al., 2020). Arts-science partnerships are well positioned to address the 'often messy details' (Horlick-Jones

& Sime, 2004) of social, cultural and political issues, in order to explore a plurality of ideas rather than a narrow end-goal with singular linear progress (L. Gibbs, 2013). A diverse constellation of art and science participants is also able to promote new forms of artistic inspiration and expression. Knowledge exchange between the Arts and Sciences have been posited as providing learning that is disciplinary distinct, inquiry-oriented, multifaceted, entangled and disciplinary transcendent with an emphasis on fostering cross-disciplinary thinkers that can deal with tomorrow's complex problems (Areljung, 2023). Rinaldi (2023) has pointed to the necessity of including different ways of knowing in transdisciplinary and co-creative approaches to resolve complex problems, pointing to science-art collaborations that seek to incorporate meta-rational, intuitive approaches such as the understandings derived from aesthetic and lived experiences. These additional ways of knowing are able to incorporate the aesthetic, to engage diverse publics, and to embody practice. Further, persuasive stories, especially those conveyed through multisensory and participatory engagement, are a powerful means for communicating complex information and further, assist in the retention of new information (Rinaldi, 2023; Rios & Negrete, 2013).

Ordinary knowledge exchange generally fails to elicit new knowledge, which instead requires a willingness to integrate novel knowledge into the individual's knowledge structure (Gugereil et al., 2023). Non-traditional collaborations, grounded in empiricism but integrating other ways of knowing have substantial opportunity for diverse engagement and bringing about novel thinking of artists and scientists in ways that encourage out of the box thinking (Leimbach & Armstrong, 2018). Art and science collaborations are increasingly being seen as a vital pillar of knowledge production as catalysts for scientific development and social change towards sustainability (Poliseli & Caniglia, 2024) and for the integration of multiple perspectives on problems and possible solutions across the boundaries of science, the humanities, arts and society. Poliseli & Caniglia (2024) conclude that arts and science collaborations are able to foster a more nuanced understanding of the differences and similarities of different knowledge systems. These opportunities allow for the development of cross-disciplinary understandings so as to embody the active ways in which people make sense of their worlds (Horlick-Jones & Sime, 2004). Transdisciplinary research across the sciences and creative practice offers exploration of novel areas of knowledge, previously not recognized between disciplines but depends on engaging in hands-on practices and shared cognitive activities beyond the comfort-zone of traditional research methodologies (Groth, Pevere, Niinimäki, & Kääriäinen, 2020).

Cobb, Nyhan, and Reifler (2013) state that the presentation of information, visually, increases the accuracy of people's beliefs about charged issues. Images, and multi-sensory information, tend to be processed differently than words. When information can get through at visceral level, new perspectives can be considered that might otherwise be rejected (Cobb et al., 2013). Combining the arts with science brings together different processing systems of the brain. It moves people past their particular perspectives and differences to an affective experience of common humanity so we can work together toward mutually beneficial solutions. Nothing is interesting to an audience unless they can recognize something in it. Whether presenting science or art, anchoring new information to things that people already know is the best way to get people to relate to and care about it (Brennan, 2018; Longtin, Wisner, & Organ, 2022).

6. Conclusion and future directions

Complex problems are, by definition, poorly defined. Generating solutions for ill-defined problems requires more than reductionism and single disciplinary exploration. What is required is a crosscutting mindset that integrates knowledge from different expertise and domains (Fraccascia et al., 2018; Gugereil et al., 2023). In this paper, we have explored complexity, transdisciplinary collaboration and the blending of diverse knowledge sets via a novel collaborative model. The framework yielded a co-curated, immersive virtual exhibition informed by multiple disciplinary perspectives and varied ways of knowing, integrating empirical evidence and lived experience with creative expression and explicit/tacit knowledge sets. **Long COVID: We Are Here!** translated a complex problem into an accessible, multi-faceted experience able to help people better understand the syndrome on a cognitive, emotional and social plane. There are a number of other factors that have been shown to be essential for successful collaboration and co-creation: openness, empathy, agency, self-efficacy and interactive learning (Barker Scott & Manning, 2022). Moreover, engagement was inclusive, equal and respectful, and shined a light on a global health crisis from multiple perspectives, to bring awareness to a global health crisis and promote social change. This approach fostered a more nuanced understanding of the differences and similarities of different knowledge systems.

There is currently a broad appetite for experiential and immersive productions. Immersive installations enlist our senses to create a context and a space of absorption. Evidence-based immersive installations that address complex social issues, utilizing evidence-based narratives, provide a compelling means for knowledge dissemination able to promote empathy and pro-social transformational learning. Further research is encouraged wherein varied social issues are approached via this methodology. There is an enormous need for strategies able to address topics that tend to be intensified by partisan divides. The Relational Space model engages the public with artistic expression, blended with empirical data, in a way that mediates complexity and partisan jargon. By using a creative lens to explore our most pressing global issues, this model provides a vehicle for self-reflection and learning, that brings people together both physically and emotionally, able to create a more nuanced and unified social understanding of issues.

Funding

Relational Space was awarded a City Artist Corps Grant presented by The New York Foundation for the Arts (NYFA) and the NYC Dept. of Cultural Affairs (DCLA), with support from the Mayor's office of Media and Entertainment (MOME) as well as Queen's Theater.

CRediT authorship contribution statement

Shona Paterson: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Conceptualization. **Leigh Jerome:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Conceptualization. **Kirsten Richert:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Conceptualization. **Bettina von Stamm:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Acknowledgements

The authors wish to thank all of the Long COVID: We Are Here! participants for their knowledge, insight, expertise and generosity throughout the co-curation process as well as contributions to the exhibition and this paper. The authors would also like to thank the Long COVID experts for their support, engagement and care before, during, and after the development of this work. In addition, the authors would like to thank the reviewers for their thoughtful and constructive comments on this manuscript.

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