SocioEconomic Mathematical Epidemiology: Developing Mathematical Modelling Theory (24w5286)

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1 Overview of the Field

The COVID-19 pandemic taught us that human behaviour makes a big difference to the way an epidemic progresses in a population. If people are willing and able to adopt behaviours that are protective to themselves and society, such as getting vaccinated or physically distancing themselves, then disease spread slows down and fewer people get sick. As soon as people relax these behaviours, the epidemic can take off again. We also saw that behaviours can change over time, with or without government-imposed regulations. For example, the first pandemic restrictions in Canada were widely accepted, but as the pandemic wore on people got tired of ”putting life on hold.”

Throughout the pandemic, mathematicians were working hard to predict how the epidemic would evolve given the best information available about the transmissibility of the virus, and the extent to which people would willingly adopt protective behaviours. While mathematicians have an excellent understanding of disease spread when behaviours are static, our understanding of opinion dynamics is much more elementary. Researchers in the social sciences, however, have been working hard to try and understand the way opinions and behaviours evolve in a human population, and so the time is ripe to bring mathematicians and social scientists together. The social scientists have theories that help explain human behaviour in qualitative ways, while mathematical models are powerful tools for developing predictions that can be tested in experiments or used to guide policy. At this workshop, mathematicians learned from social scientists how emotions and internal biases drive the way human opinions change over time, and then discussed how to translate this knowledge into mathematical equations. This led to important discussions toward a new framework for disease-and-opinion-dynamics models that can form the basis of future epidemic modelling.

2 Recent Developments and Open Problems

Wednesday morning started wtih group discussions to generate questions surrounding modelling, behaviour and their intersection. Groups shared questions (see Table 1). These were categorized and disussion topics were determined that will inform a future publication:

1. How can we foster effective collaboration across social and mathematical sciences?

2. Model TO Data/Experiment/Intervention (How can models inform surveys, interventions, etc?)
3. Data (etc) TO Model (How can data etc inform models?)
4. What is behaviour (defined by social scientists)? What behaviours can we model (mathematicians)? What types of models do we need for different types of behaviour?

A	How can one most effectively foster collaboration across the social and mathematical sciences? Do we need a new journal? How do we move towards a common language What level of details from social scientists are needed in the models? What is the critical information needed for a model?
B	How do we represent “trust” and “undecided” behaviours in models? How to model community resilience? How can survey design/data types be informed by modellers’/behavioural scientsits’ needs/insights? How to communicate lack of certainty in science (probability distributions) to the general public? to policy makers? How to go from mechanistic description of individual interactions towards population description, e.g., IBM to differential equations (stochastic preferred) Integrate first and higher order sources of information into compact (F.B.) models. Is the worst in the future or the past? How do we integrate this question into behaviour change models? (F.B.) How can we bridge descriptive/top-down approaches to understanding the malleability of behaviour with mechanistic/intervention/bottom-up understandings of the malleability of behaviour? How can we identify and curate available data? What is the critical information needed for a model?
C	How do we distill the “big behaviour ball” into sufficiently parsimonious (given available data) models that we can advance our understanding of and ability to predict basic patterns? How can we operationalise survey data and philosophical theories into the models of behaviour? How can modellers be realistic about the nature of gathered data?
D	How to model community resilience? What are the most influential systemic barriers to accessing preventive health? What are the most successful efforts in overcoming systemic barriers? For those experiencing systemic barriers to preventive health resources, what do their trajectories of behaviour look like over time? Is multi-level modelling (individuals, organisations, societies) a tool that can be used to model different types of data?
E	Goal: Control an epidemic. Available controls: NPIs, vaccines, etc. What is the feasible reagion? (there’s 5% of the population that you will never reach) What is the cost of control or no control, in dollars and in political capital? What is the optimal approach? Is it ethical to help politicians get votes by modelling? How do we address the fact that anything we learn about behaviour can also be used by nefarious actors? How can you incorporate or model social constructs (religion, sects, politics, ..) with an epidemiological model?
Other	Is the use of an ABM justified, or would it be better to use a mean-field model? How can we pursue group-level modelling? We may end up with a theory that says the outcome is impossible to predict because of sensitive dependence on initial conditions (which side of the bed someone got up on in the morning). That’s useful, but how do we move from there? What are the useful theories, predictions that we can make?

	Is it premature to try and predict at this point? How do we (consistently) measure behaviour?

Table 1: Discussion Questions

3 Presentation Highlights

The workshop featured presentations from behavioural scientists, statisticians who work with behavioural data, and mathematicians who incorporate human behaviour in their models. There were many different perspectives offered from all three groups, and these made it clear that all of these perspectives inform each other and are important in developing good socioeconomic mathematical epidemiology. The workshop presenters are listed in Table 2 with their repsective titles and abstracts. A poster session highlighted extra projects by these researchers and included presenestaions by many of the junior workshop participants: Laura French Bourgeois, Teri Garstka, Betsy Varughese, Azadeh Aghaeeyan, Monica Cojocaru, Lindsey McConnell-Soong, Priscilla (Cindy) Greenwood, Md Mijanur Rahman, Grégoire Ranson, Chadi Saad-Roy, Elissa Schwartz, Madeline Ward.

Presenter	Title/Abstract
Megan Delahanty	Data don't speak: Epistemic trust and scientific controversy In cases where existing knowledge is limited and there are very significant consequences to the policy and/or personal decisions that must be made based on the current state of rapidly changing knowledge, we often hear appeals to "trust the science," "listen to the evidence,", or "let the data speak for themselves." These appeals implicitly rely on a view of science and of scientific objectivity according to which science is free from political, social, and moral values and controversies (the Value Free Ideal). This view, however, has been the subject of considerable criticism from philosophers of science over the past 20 years and is almost universally rejected in favour of an understanding of science that emphasizes the centrality of social processes.. Data do not speak for themselves but require interpretation. They do not serve as evidence outside of particular frameworks, about which scientists may disagree. And debate about those frameworks brings in considerations of values, directly or indirectly. Trusting the science, therefore, means placing epistemic trust in specific social processes, institutions, and scientists. In this talk, I will examine some of the complexities of building and maintaining the epistemic trust of various publics in science and medicine.
Dilshani Sarathchandra	Identity roots and ideologies driving attitudes towards controversial science This talk will examine the identities and ideologies that drive attitudes towards controversial scientific topics and practices. Using examples from COVID-19 and climate change, we will examine how these attitudes are shaped by religious and political beliefs, trust, media, personal experience, emotions etc. We will further examine how, for some, certain attitudes develop into core identities, generating the "us vs. them" dynamic of behavior. While it is difficult to change core identities, we will uncover some areas of common interest which can be capitalized on to develop public policy with wider support.
Iain Moyles	Behaviour in Models vs Behaviour Modelling We will provide a brief overview of how behaviour is used in disease modelling and distinguish it from modelling behaviour explicitly. We will emphasize the value and importance of mechanistic modelling in general and as it relates to behaviour. The unique complexities of behaviour to other fields will be explored and discussed.

Chris Bauch	Simple, wrong and useful modelling in behavioural epidemiology Distilling sociological, economic, and psychological theories into mathematical models requires simplifying assumptions that can change the original meaning of the theory. On the other hand, this process can also highlight similarities and create a common framework for thinking about human behaviour modelling. I will summarize how several representations of social dynamics in coupled behaviour-disease dynamics—the rational actor model, social learning, and social contagion—are limiting cases of the same framework. For this and other reasons, I will also argue a role for phenomenological models in behavioural epidemiology.
Hugo Martin	Less effective but individually less costly prophylactic measures can reduce disease prevalence in a simple epidemic model accounting for human behaviour We study a simple SIS epidemic model accounting for human behaviour. Individuals can decide at each instant of time whether or not they adopt prophylactic (hereafter protection) measures such as mask wearing or social distancing. These measures decrease susceptibility and/or transmission. We consider a situation in which individuals are unaware of their current health status (infected or not), but can perceive disease prevalence at the population level. This assumption fits situations in which tests are not widely available. Thus, personnal decisions depend first on disease prevalence, as a proxy for the risk of being infected or infecting others, and second on the fraction of the population complying to the protection measure, which people can observe in their every day life. Human behaviour is assumed to be driven by imitation dynamics (Bauch, 2005; Poletti et al., 2009). When the disease does not naturally die out, the model has three types of endemic equilibria: no-protection, mixed-protection, and full-protection. Which endemic equilibrium is stable depends on the parameter values. We assume that the efficiency of the protection measure is positively correlated to its individual cost. Increasing the efficiency of the protection measure and therefore its individual cost can make the system switch from full protection to mixed-protection. This way, increasing the efficiency of a protection measure may increase disease prevalence at equilibrium. In other words, disease prevalence is minimized for intermediate efficiency, and individual cost, of the prophylactic measure. The rational is that when the prophylactic measure is too effective and therefore costly, part of the population free-rides on the effort of others and drops protection, resulting in increased prevalence. Altogether, our results show that the interplay between epidemiology and human behaviour may lead to counterintuitive but nevertheless intelligible outcomes, that should be anticipated when designing public health policies. This work is shared with François Castella and Frédéric Hamelin. References: Bauch, C. T. (2005). Imitation dynamics predict vaccinating behaviour. Proceedings of the Royal Society B: Biological Sciences, 272 (1573), 1669-1675. Poletti , P. et al. (2009) Spontaneous behavioural changes in response to epidemics. Journal of Theoretical Biology, 260

Rob Deardon	Feedback mechanisms in epidemic models: Is your population alarmed? One of the many difficulties in modelling epidemic spread is that caused by behavioural change in the underlying population. This can be a major issue in public health since, as we have seen during the COVID-19 pandemic, behaviour in the population can change drastically as infection levels vary, both due to government mandates and personal decisions. Such changes in the underlying population result in major changes in transmission dynamics of the disease, making the modelling challenging. However, these issues also arise in agriculture and public health, as changes in farming practice are also often observed as disease prevalence changes. We propose a model formulation wherein time-varying transmission is captured by the level of alarm in the population and specified as a function of recent epidemic history. The alarm function itself can also vary dynamically, allowing for phenomena such as "lockdown fatigue". The model is set in a data-augmented Bayesian framework as epidemic data are often only partially observed, and we can utilize prior information to help with parameter identifiability. We investigate the identifiability of the population alarm across a wide range of scenarios, using both parametric functions and non-parametric Gaussian process and splines. The benefit and utility of the proposed approach is illustrated through applications of COVID-19 and Ebola disease.
Teri Garstka	Modeling Community Resilience: Is Network Analysis the Most Effective Method? Community resilience is a dynamic process that describes a network of adaptive capacities that impact human society and allow it to adapt after adversity and take advantage of opportunities (Garstka & Kennedy, 2023; Norris et al, 2007). Better methods for quantifying or modeling resilience in an ecosystem allow for a more precise understanding of what influences outcomes at the population-level. Results from a study of multiple community ecosystems and health outcomes using network analysis are presented. How might measurement of complex adaptative systems being improved to better predict dynamic change or incorporate more signals of resilience or vulnerability?
Deborah Woodman	Making Meaning from both Quantitative and Qualitative Research – The Opiate and Mental Health Challenges in a Small Northern Ontario City This presentation will explore what information we have from both quantitative and qualitative research on the issue of opiates and mental health. As people living in Canada, we are aware that Canada is in the grips of an opiate crisis. The Algoma District (where I live) has seen alarming rates of opioid deaths at 50 deaths per 100,000 - well above the Ontario provincial average of 19.7/100,000. Bigras et al. (2021) have demonstrated that front-line workers in social services are uniquely positioned to reflect on the stresses of their work and how best to support people who are struggling with substance use. This presentation reviews both the publicly available quantitative information about the situation and preliminary findings of qualitative research undertaken with local front-line social service workers and volunteers about factors driving the crisis. By exploring both what the numbers make clear and what we hear from frontline workers we will be able to see what is missing from the picture. For instance, we will explore what the barriers are that prevent people from accessing services, and how we often leave this out of our data collection. The goal of this discussion is to give us ideas about what to research and how to research. I aim to give researchers, policy makers and stakeholders a fuller picture so that we can create new solutions for issues that are harming many in our society.

Lindsey McConnell-Soong	Reflections from the Extension Collaborative on Immunization Teaching and Engagement (EXCITE): Understanding vaccine attitudes in rural and/or medically underserved populations. In 2021, the Extension Collaborative on Immunization Teaching and Engagement was created in response to the COVID-19 pandemic. To date, the work of nationwide teams has reached over 21 million people, delivered 1,198 vaccine clinics, and administered 26,497 immunizations. University of Idaho Extension has participated in five rounds of funded EXCITE projects addressing immunization education and access for rural and/or medically underserved populations. This presentation will offer a summary of behavioral determinants that were considered influential on vaccine attitudes and uptake in rural, low-resourced, Hispanic, and/or agricultural families.
Dan Coombs	A Bayesian approach to combining behavioural surveys with clinical data in the context of HIV epidemiology We wanted to estimate the likely impact of a program to increase HIV testing rates among members of high-risk groups. To do this, we constructed an epidemic model, and then sought to estimate its parameters from data. The available data consisted of potentially unreliable sexual health survey data along with firm clinical diagnosis data, both drawn from a population of gay, bisexual and other men who have sex with men in Vancouver, BC. I will briefly summarize how a Bayesian analysis allowed us to achieve our modelling goals. This was all joint work with Michael Irvine, Warren Michelow, Bernhard Konrad and Mark Gilbert.
Laurent Pujo-Menjouet	Forecasting the Effect of Pre-Exposure Prophylaxis (PrEP) on HIV Propagation: do political and economical decisions help to regulate the disease? The HIV/AIDS epidemic is still active worldwide with no existing definitive cure. Based on the WHO recommendations stated in 2014, a treatment, called Pre-Exposure Prophylaxis (PrEP), has been used in the world, and more particularly in France since 2016, to prevent HIV infections. We propose a new compartmental epidemiological model with a limited protection time offered by this new treatment. We describe the PrEP compartment with an age-structure hyperbolic equation and introduce a differential equation on the parameter that governs the PrEP starting process. This leads us to a nonlinear differential–difference system with discrete delay. After a local stability analysis, we prove the global behavior of the system. Finally, we illustrate the solutions with numerical simulations based on the data of the French Men who have Sex with Men (MSM) population. We show that the choice of a logistic time dynamics combined with our Hill-function-like model leads to a perfect data fit. These results enable us to forecast the evolution of the HIV epidemics in France if the populations keep using PrEP.
Bouchra Nasri	Behavioural modelling: linking data collection and modelling techniques Understanding the dynamics of health emergencies is essential for effective public health intervention. Human behavior and coping capacities can influence the health crisis. However, these aspects can also be influenced by socio-economic conditions, community interventions, trust, information sources, etc. The integration of these interconnected variables into modeling remains limited due to lack of data or development of modeling approaches. Therefore, in this presentation, I will give some examples of data we have collected or analyzed over the years, as well as some mathematical and data-driven modeling strategies and their limitations.

Monica Cojocaru	Behaviour, decision making and efficacy of NPI, vaccination measures in the ON pandemic In this work, we propose a modeling framework that gives insight to public policy compliance and efficacy for complex One Health issues, and apply it to a case study on non-pharmaceutical interventions (NPIs) compliance in Ontario during the COVID-19 pandemic. Using a stepwise multivariate linear regression analysis, we determine monthly comfort levels with both staying-home and mask-wearing, as well as determine significant indicator variables of each. These comfort values are then used within a decision-making model to determine average estimated compliance to each NPI in Ontario from March 2020 to January 2022. Using $SEILR$ and $SEILRV_{1,2,3}$ compartmental models, we fit our simulations to real incidence data to determine the efficacy of staying-home and mask-wearing policies over time. Finally, we explore the applicability of our model to One Health policies, benefits of using the One Health approach, limitations of our work and discuss possible avenues for future work. Joint work with: Rhiannon Loster (UoG & Public Health), Ed Thommes (Sanofi & UoG), Sarah Smook (Astra-Zeneca, UoG graduate) and David Lyver (Quintalink - UoG graduate)
Eric Foxall	Representation of coupled opinion/infection models via opinion distribution and effective transmission rate When modelling opinion-dependent spread of infection, the presence of both multiple opinion states and epidemiological compartments can make direct analysis unwieldy. Conceptual understanding of the dynamics can often be improved by representing each compartment through its total size, opinion distribution, and effective parameters. To illustrate this idea, we discuss an example with multiple opinion states among susceptible individuals, and explore insights that can be gained by first assuming time scale separation, then weakening this assumption.
Azadeh Aghaeeyan	Vaccination Decisions: Revealing the Proportions of Decision-Making Types If vaccines are to be promoted, it is important to understand the factors behind individuals' attitudes and final behaviour toward vaccination. Motivated by the considerable variation in individuals' reliance on social learning, we developed a mechanistic model that incorporates two decision-making types: myopic rationalists and success-based learners. By fitting the model to COVID-19 vaccine uptake data, we estimated their proportions across US states and Canadian provinces. In this talk, I will address the study's limitations and discuss our proposed solutions.
Eric Lacourse	Understanding the use of mixture models with cross-sectional and longitudinal data During the past 25 years, the methodological literature on mixture models has expanded and it is now extensively used in practice to capture unobserved heterogeneity of specific parameters in the population. We use a pedagogical review presenting different mixture models and their relationships to each other. We first present the results of a Latent Transition Analysis of political behaviors. Secondly, we will present the results of a Latent Transition Mixture Model that combines Latent Class Analysis to identify profiles based on an important number of risk factors, Latent Class Growth Analysis to identify longitudinal profiles of a behavior, and their interaction in predicting some distal outcomes. We will present these prototypic mixture models in a unified format, based on familiar probability laws, common assumptions, and interpretation. Each mixture model can be divided into a within class model and a between class model. The within class model accounts for the data-generating mechanism for persons in class K. The between class model helps define the probability that a person will be in a class vs. another. Co-authors: Félix Laliberté, Mathieu Pelletier-Dumas, Jean-Marc Lina and Roxane de la Sablonnière
Jean-Marc Lina	From structural equation modeling to Kalman

Matheiu Caron-Diotte	Missing Responses in Modeling Social Behaviour Missing data is inherent in the study of social phenomena, and can introduce bias and result in diminished statistical power. However, missingness can also be an indication of interesting dynamics. For instance, some individuals might be dissatisfied about the efficacy of a treatment and thus abandon a study. Other individuals could be unreachable because of an unstable social and political context. This communication is aimed to argue that mathematical modelling of social behaviour must take into account missingness in order to deepen the understanding of the phenomenons under study. To this end, we will outline the theory behind missing data, present on some of its causes, and provide pointers on the introduction of missingness into the mathematical modelling of social behaviour. Co-authors: Mathieu Caron-Diotte, Mathieu Pelletier-Dumas, Éric Lacourse, Anna Dorfman, Dietlind Stolle, Jean-Marc Lina, and Roxane de la Sablonnière
Matheiu Pelletier-Dumas	Navigating the Complex Dynamic of Compliance to Public Policy During a Dramatic Social Change: Insights from Three Canadian Studies The United Nations anticipates that over 500 dramatic social changes (DSC) like the COVID-19 pandemic will occur by 2030 (i.e., climate catastrophes). DSC requires the implementation of public policies aimed at shaping collective behavior, and in particular compliance. Understanding the adaptation process to DSCs entails complex methodologies and analyses that consider the dynamic nature of DSC. However, to date, most research has focused on cross-sectional "static" designs. We aim at answering this limit by exploring compliance with public policies during the COVID-19 pandemic. Specifically, we use a comprehensive investigation spanning three studies that involves a representative sample of Canadian citizens (N=3617) who participated in a 12-wave longitudinal study (April 2020 to April 2022). All studies use LGCA (i.e., trajectory analysis) to account for the dynamic aspect of the pandemic. Study 1 seeks to identify longitudinal patterns of compliance behaviour with preventive measures during the first year of the pandemic and their relation with factors like used sources of information and level of understanding. Study 2 uses different indicators (e.g., trust in the Prime Minister) to predict transitions in memberships to varying patterns of compliance across time. Finally, Study 3 furthers our understanding of transition patterns during a different moment of the COVID-19 pandemic (July 2020 to March 2021). By delving into dynamic processes, this investigation offers valuable insights for understanding how individuals react to the public policies put in place to face the DSCs of today and of those anticipated in the coming decades. Co-authors: Sahar Ramazan Ali, Éric Lacourse, Jean-Marc Lina, Jacques Bélair, Dietlind Stolle, and Roxane de la Sablonnière
Simon Bacon	Modelling behaviour change using theory - an example from the COVID-19 pandemic There are now a number of ways in which behaviour and behaviour change can be modelled. One of the most popular is the Capability-Opportunity-Motivation: Behaviour (COM-B) model. This provides an excellent structure to be able to understand behaviours. COVID-19 was, and still is, a disease which requires a specific set of behaviours to occur to reduce its spread and impact. As an example of the kind of work we do at the Montreal Behavioural Medicine Centre (www.mbmc-cmcm.ca), we applied the COM-B to an ongoing COVID-19 study, the iCARE study (www.iCAREStudy.com), which has collected over 170,000 responses since the start of the pandemic, to explore the drivers of various pandemic behaviours, e.g., mask wearing, vaccine uptake, and physical distancing. Mapping the data collected onto the COM-B provides concrete information on how to better structure public health interventions to fight future pandemics. However, there are notable challenges in analysing this kind of data, e.g., changes in trends overtime, accounting for impacts of multiple concurrent behaviours, etc., which would benefit from more advanced statistical techniques.

Elissa Schwartz	Epidemic control and vaccine hesitancy: What vaccine efficacy levels are needed? Throughout the last two centuries, vaccines have been helpful in mitigating numerous epidemic diseases. However, vaccine hesitancy has been identified as a substantial obstacle in healthcare management. We examined the epidemiological dynamics of an emerging infection under vaccination using an SVEIR model with differential morbidity. We mathematically analyzed the model, derived R0, and provided a complete analysis of the bifurcation at R0 = 1. Sensitivity analysis and numerical simulations were used to quantify the tradeoffs between vaccine efficacy and vaccine hesitancy on reducing the disease burden. Our results indicated that if the percentage of the population hesitant about taking the vaccine is 10%, then a vaccine with 94% efficacy is required to reduce the peak of infections by 40%. If 60% of the population is reluctant about being vaccinated, then even a perfect vaccine will not be able to reduce the peak of infections by 40%.
Rebecca Tyson	The role of committed minorities in climate change action It is well-established that human activity is driving extreme weather patterns, and that these extreme events influence human behaviour. However, few models allow for human behaviours and the climate to dynamically interact. The models presented in this talk expand on previous work and serve as an initial framework to extend current models by using a dynamic social-climate feedback loop. First, we introduce a social model to determine the conditions under which a committed minority can overturn a pre-established social convention. Second, we modify an existing climate model to include climatic variability. Lastly, we formulate a social-climate feedback loop to study the interplay between human behaviour and the climate. Our results demonstrate that the social-climate feedback loop may be important in accurately predicting future temperatures, in contrast to the standard approach where human behaviour is considered fixed. Additionally, we find that a committed minority plays a vital role in shifting public opinion towards climate action and that the time at which the social convention of climate inaction is overturned has a large impact on future temperatures.
Brian Beckage	A framework for putting human behavior into socio-ecological models Problems in environmental sustainability, climate change, and spread of contagious disease involve biophysical, economic, and human social and behavioral systems that dynamically interact. We present a framework for modeling human social and behavioral systems through the processes of contagion and cognition with perceived risk as the state variable determining the human response. We briefly present examples from epidemiology, solar geoengineering, and anthropogenic climate change. Co-authors: Katherine LaCasse, Rhode Island College Louis J. Gross, University of Tennessee, Knoxville Karim Chichakly, ISEE Systems Sarah Constantino, Stanford University Travis Franck, Tufts University Sara Metcalf, University at Buffalo Fran Moore, UC Davis Kaitlin Raimi, University of Michigan Dale Rothman, George Mason University Daniele Visioni, Cornell University

Louis Gross	Modeling Cognitive Processes for Human Risk Perception: A Climate Change Example The vast majority of climate models designed to project future global temperature trajectories ignore feedbacks between human behavioral and social system responses and the climate system. Prior research on models linking climate models to human behavior provide evidence that these linkages can significantly modify future trajectories compared to climate models based only on natural system processes. We will describe our efforts to model the interactions of climate systems and human social systems, focusing particularly on risk perception. We will describe how we model human risk perception and associated changes in attitudes as driven by the experience of climate change, for example, from extreme climate events and economic damages, and how this perceived risk motivates willingness to pay for abatement of greenhouse gas emissions and support for 'green' policies. This presentation will focus on methods to model cognition, personal experience and memory processing. This is modeled as a balance between sensing and forgetting extreme climate events that allows for habituation, salience, biased assimilation and recency and considers how these factors might vary across a heterogeneous population. Co-authors: Brian Beckage (University of Vermont), Karim Chichakly (isee systems), Sarah Constantino (Northeastern University), Travis Franck (Tufts University), Katherine LaCasse (Rhode Island College), Sara Metcalf (University at Buffalo), Dale Rothman (George Mason University)
Jane Heffernan	Exploring Behaviours
Priscilla Greenwood	How to use stochastic dynamics in social behaviour
Diana Cardenas	Dramatic Social Change and Threatened Identities: An Algorithm to Understand Socio-psychological Processes $\uparrow$ COVID-19, wars, and natural disasters exemplify dramatic social changes (DSC), characterized by rapid shifts, disruption in social structures and behaviors, and threats to social identity. While existing models like ViEWS and MASON RebeLand attempt to forecast such events, they fall short by focusing narrowly on specific contexts and types of social change without taking a proper look on individual experiences such as identity threats. To address these gaps, we developed a new typology of social change from an extensive review of over 300 selected papers. This typology identifies four social states: stability, incremental social change, DSC, and collective inertia. Utilizing this framework, we created the Social Change Algorithm (SCA), a predictive tool now undergoing validation and simulation. The SCA forecasts shifts between social states by analyzing patterns and probabilities using a Bayesian model, aiming to improve decision-making in response to events like pandemics. Initial studies have modeled transitions due to coups d'état and elections and have first applied the algorithm to assess the impact of COVID-19 in North America. The SCA, however, requires further theoretical refinement, including the integration of collective memory, to enhance its utility for decision-makers. Co-authors: Jean-Marc Lina, Jacques Bélair, and Roxane de la Sablonnière

Laura French Bourgeois	In the name of freedom: Using machine learning to identify the factors that influence psychological reactance during the COVID-19 pandemic The public health measures imposed to curb the spread of the COVID-19 virus created strong opposition among part of the population. The literature points to psychological reactance as a main factor explaining non-compliance with the public health measures, as it prompts individuals to want to restore the freedom that they felt they have lost. While demographic, personal, and contextual factors have been identified as influencing the level of reactance, previous studies have not explored a comprehensive model that includes all these factors together to develop a broad profile of reactant individuals. Using a representative sample of Canadians (N=3617) and machine learning, the present study employs a regression with Lasso regularization to develop a predictive model assessing the most important factors (old and new) related to psychological reactance during the COVID-19 pandemic. Out of the 158 factors considered, the Lasso regularization retained the 34 most important ones. The results reveal that confidence towards scientists, political orientation, and loneliness are among the strongest factors related to psychological reactance. These findings contribute to a better understanding of the complex interplay of factors influencing psychological reactance and can inform public health strategies to enhance compliance with health measures. Co-authors: Matthew Fernandez, Sophie Sydoriak, Mathieu Pelletier-Dumas, Eric Lacourse & Roxane de la Sablonnière
Katherine Reynolds	Does COVID-19 herald a new era for the psychology of behaviour change? All the major challenges humanity faces - climate adaptation, social cohesion, technology adoption, healthy lifestyles depend on behaviour change. A silver lining of COVID-19 may be an awareness of the importance of behaviour change and the contribution of psychology. Different countries engaged with psychology and social psychology in different ways and adopted different 'theories' of the human subject and behaviour change (e.g., with an individual approach there was an emphasis on attitudes, risk perception, behavioural fatigue, loneliness and mental health, crowd fear and panic, incentivisation). In some areas there was an increased and novel openness towards group-based processes (social identity and group norms, collective responsibility, aid and solidarity, leadership and social influence). Internally within the field debates emerged about whether psychology was ready for "prime time" and the crisis of generalisability. In this presentation the focus will be on how COVID-19 offers a disciplinary opportunity to advance social psychology. Post-crisis it is important to consider questions such as What have we learned? What are the implications for other imminent crises and human challenges? and where are the gaps in knowledge and advances that are needed in theory and research?
Bert Baumgaertner	Standards of Evidence and Deference to Experts A standard of evidence is a transition from collecting information to acting on that information. In this brief talk I argue for two claims. First, evidentiary standards are heterogenous because they depend on context, domain, and social conventions. Here I will present some results from empirical work about people's evidence gathering behavior when they are asked to assess a causal claim, such as the effectiveness of an anti-viral nasal spray in preventing contraction of COVID. Second, deference to experts is itself subject to standards of evidence, but little is known about how people update their assessments of the reliability or trustworthiness of sources. Consequently, models should capture this uncertainty.

Chenangnon Tovissode	The Relative Impact of Social Influence Cost and Benefit of Prophylaxis on Epidemic Severity Coupling social influence-based opinion model with disease dynamics knows a growing interest to understanding feedback loops between the distribution of opinions on costly prophylactic behaviors and disease evolution. Recent research has examined how the occurrence of multiple epidemic waves depends on the influence cost of prophylaxis and the rate of opinion changes relative to disease propagation. Building on these results, we combine an attitude spectrum based on a double-prophylaxis with an SIR disease dynamic model that accounts for important disease states from the COVID-19 pandemic context. In this model, attitude changes are governed by the effective rate of mutual influence which is determined by the perceived risk of becoming infected. Under this framework, the distribution of opinions in disease-free conditions depends on the influence cost of prophylaxis. We explore how epidemic severity measures such as epidemic peak and final size, and the occurrence of multiple epidemic waves are related to the disease-free influence cost of prophylaxis and the influence benefit of adherence to prophylactic behaviors during an epidemic.
Jacques Belair	Knowledge as an infection: a model for variable compliance with NPIs In the deployment of non-pharmaceutical interventions (NPIs) for the control of infectious disease propagation, the level of compliance in the target population is crucial for their success. We present deterministic compartmental models in which subgroups of the population have variable degrees of i. information about the NPIs and ii. compliance with the NPIs. We explore the dynamical consequences of movements between the corresponding subgroups.
Julien Arino	A few naive experiments in phenomenological modelling of media-induced behavioural changes

Table 2: Presenters, abstracts and titles

There was also a lively poster session with about 20 posters on various topics, both on the behavioural side and on the mathematics side. The collision of two such distinct fields, behavioural sciences (which is extremely broad, with workshop participants ranging from philosophy to public health) and mathematics, led to a deep and creative questioning of mathematical assumptions and approaches.

4 Scientific Progress Made

The workshop was formatted in such a way as to maximize the rapid establishment of social connections between the participants, and the opportunities for focussed discussion on topics emerging from the presentations and the diverse perspectives in the group. We thus started the workshop with a "speed dating" session. All of the talks were held on the first two days, which meant that the participants rapidly became acquainted with the expertise of the other participants, while there were still several days left for productive discussions. This format also meant that participants encountered a wide range of diverse perspectives in a short period of time, maximizing the likelihood for cross-disciplinary conversations. The second day closed with a lively evening poster session.

The remaining time was devoted to small and large group discussions with regular reporting back to the full group, and extensive documentation of the groups' discussions in a common document. The group discussions were always animated and productive, and the "reporting back" presentations to the full group highly informative. We had lots of good discussions and outlined a paper that the full group is going to produce. Our work is summarized in the following photos taken of discussion boards.

Group 1 How can we foster effective collaboration across social and mathematical sciences?

Simon Bacon, Mathieu Caron-Diotte, Eric Foxall, Teri Garstka, Louis Gross, Mathieu Pelletier-Dumas, and Rebecca Claire Tyson

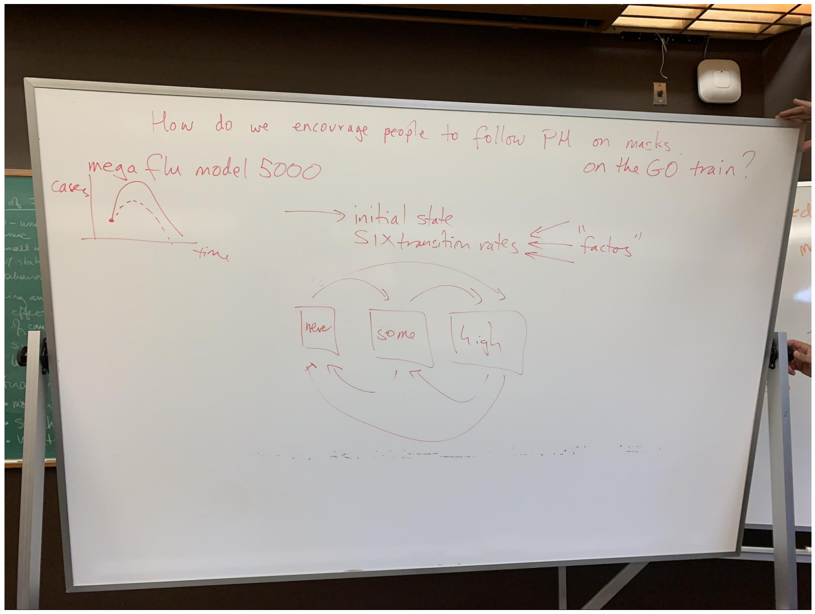
Brief Summary

Fostering collaboration between mathematicians and behavioural scientists has the potential to enrich both disciplines and produce significant benefits in terms of theories, methods, and concrete outcomes. Interdisciplinary collaboration has the potential to be exciting, stimulate new ideas, provide opportunities to learn new things and to challenge preconceived notions. The participants in this group aimed at identifying how to foster effective collaboration across social and mathematical sciences. Existing mechanisms promoting interdisciplinary collaborations (collaborative projects, grants, interdisciplinary centres, centre-funded working groups) have been discussed. It was also deemed important to establish a common language between mathematicians and behavioural scientists. Furthermore, using the knowledge gathered in the science of team science field could also prove useful in fostering collaboration, such as including a mentor and at least one fully interdisciplinary researcher in a team to guide and help researchers from both sides to connect. Factors such as low incentives for researchers to enter interdisciplinary collaborations, and the perceived low support of journals and agencies towards interdisciplinary work were identified as hindering the development of such projects. The definition of a successful collaboration has also been discussed as being tied to the number of publications stemming from it, the number of interdisciplinary researchers trained, and the impact on policies. To promote interdisciplinary collaborations between mathematicians and behavioural scientists, the group proposes to publish a perspective paper on the subject of fostering effective collaboration and a review paper outlining examples of successful collaborations. The participants believe that it is imperative to create opportunities for interested, committed, and like-minded scientists to collide and let their collaboration grow organically over a long timeline.

Summary of the Meetings

Fostering collaboration between mathematicians and behavioural scientists has the potential to enrich both disciplines and produce significant benefits in terms of theories, methods, and concrete outcomes. In fact, when listening to talks from both mathematicians and behavioural scientists, one might realize that there can be many similarities in the subjects investigated in both disciplines. Because of the differences in objectives and methods, an increase in exchange and collaboration between mathematics and social sciences could indeed produce new avenues, as we can conceptualize them as being complementary. Interdisciplinary collaboration has the potential to be exciting, stimulate new ideas, provide opportunities to learn new things and to challenge preconceived notions. However, as with any interdisciplinary enterprise, this kind of collaboration has to be carefully planned and some conditions are necessary to ensure its effectiveness. The discussions held in this group were aimed to answer the question How can we foster effective collaboration across social and mathematical sciences? The existing mechanisms aimed at bringing mathematics and behavioural sciences have first been outlined. The Synthesis Centre Model (Sesync), in which working groups composed of researchers from different disciplines apply for funding to answer a particular research question and meet multiple times over two years. This has worked well in the ecological sciences. Other interdisciplinary centres, such as the Santa Fe Institute in New Mexico was also discussed as an institution that brings together people from different disciplines to arise collaboration. The current workshop held at the Banff International Research Station for Mathematical Innovation and Discovery, was also identified as an outlet for the discussion between mathematicians and behavioural scientists, as it arose from mathematicians/statisticians and behavioural scientists who started their own collaborations. Funding agencies, such as Howard Hughes Medical Institute and the Burroughs-Wellcome Fund also encourages interdisciplinary work with funding opportunities. These mechanisms encourage the establishment of networks of researchers interested in interdisciplinary works. From this initial discussion, existing mechanisms by which mathematicians and behavioural scientists can be brought together have been identified. Grants, interdisciplinary centres, and centre-funded working groups can be used as settings in which mathematicians and behavioural scientists can work to extend their collaborations. They provide structures for like-minded researchers from different disciplines to exchange, and money to support this collaboration and produce new research from it. These structures also allow the development of networks of researchers interested in interdisciplinary work, facilitating the organization of new collaborations and the exchange of ideas and advice. However, the participants believed that, although they are excellent avenues, there are other issues that need to be tackled. In fact, money and means help in establishing an effective collaboration, but they are not sufficient. The need for a common language was discussed as an important step in establishing a fruitful collaboration between mathematical and social sciences. In fact, because the methods of both fields are somewhat unknown to each other, communication is hindered. Establishing a common language might require more frequent interactions between the fields. Creating spaces for the discussion between mathematicians and social scientists might provide useful in learning each other's language, by exposing them gradually to the concepts and methods of their respective fields. In this sense, the minimal amount of information that is needed to be given by each field to better understand each other should also be found. Relying on actionable data from the science of team science might also provide some insights into how to foster an effective collaboration between mathematical and social sciences. This new field studies how to foster collaboration in science and thus could help in identifying the necessary conditions to successful interdisciplinary works between mathematics and behavioural sciences. For instance, relying on individuals who are interdisciplinary in their work to make the bridge between the fields can help in accelerating the collaboration between disciplines. Such individuals are already familiar with the language and methods of both fields and can thus ensure that messages from one side to another are clearly understood. The presence of mentors can also prove to be useful, as they can guide more junior members of an interdisciplinary team. One last consideration that has been discussed is how to define success. One more traditional way to define success in science would be to think in terms of publications. As such, a successful collaboration between a team of mathematicians and behavioural scientists could be measured by its publication output. Other ways to define success could be the number of persons trained to collaborate in interdisciplinary projects or the impacts of collaborative works on policies. Barriers to interdisciplinary collaborations have also been identified. For some researchers, there is little incentive to do interdisciplinary work if they are already successful in their field. Some can also have the impression that journals, tenure committees, and granting agencies, to name a few, tend to be less supportive of interdisciplinary work. As such, junior researchers can believe it is in their best interest to avoid interdisciplinary work before they are well established. As means of achieving the group's goal of thinking about how we can foster effective collaboration across social and mathematical sciences, the redaction of two papers had been discussed. First, a perspective paper detailing the importance of collaboration between mathematicians and social scientists and the direction such collaboration could take has been deemed as necessary. Second, a paper presenting a review of published interdisciplinary works in mathematics and social science could help in showing how mathematics and social sciences can be combined to work together. Outlining a clear direction and idea of how such collaborations can be done could promote the development of interdisciplinary works between these fields. In brief, the group aimed to answer the question How can we foster effective collaboration across social and mathematical sciences? In their discussions, participants answered this question by identifying existing mechanisms promoting interdisciplinary collaborations (collaborative projects, grants, interdisciplinary centres, centre-funded working groups), facilitators (funding, networks, establishment of a common language), and inhibitors (low incentives for entering interdisciplinary collaborations, journals and agencies less supportive of interdisciplinary work). The group also decided that a perspective and a review paper should be written to promote interdisciplinary collaborations between mathematicians and behavioural scientists. The participants believe that it is imperative to create opportunities for interested, committed, and like-minded scientists to collide and let their collaboration grow organically over a long timeline.

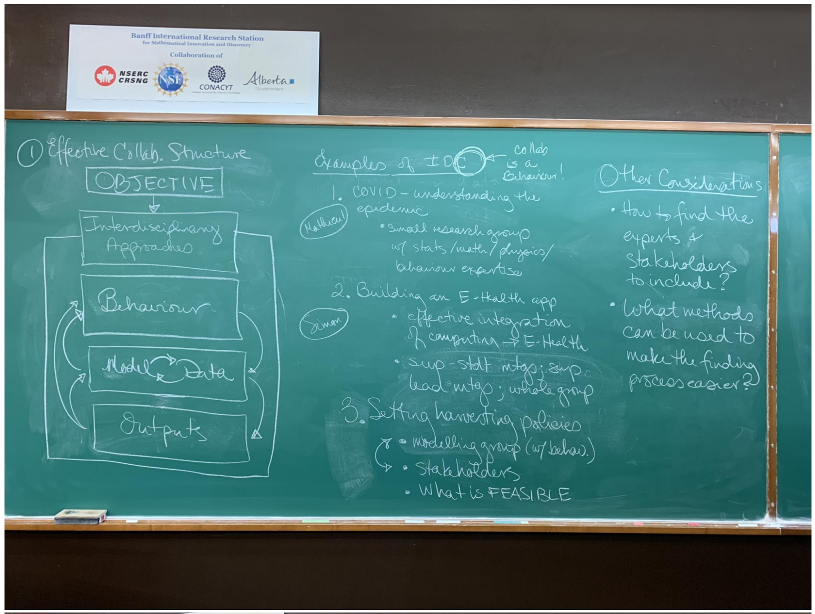
Group 2 created a case study in which mathematical models exist already based on previous models we then discussed how the mathematical models would have high uncertainty and require data as well as expertise from behavioural scientists to better inform it. We agreed that this is not the ideal scenario as social scientists and mathematical modelers work together from the beginning to create the models. Our case study will ilustrate when models are the beginning of the project, as well as the limits of this approach.

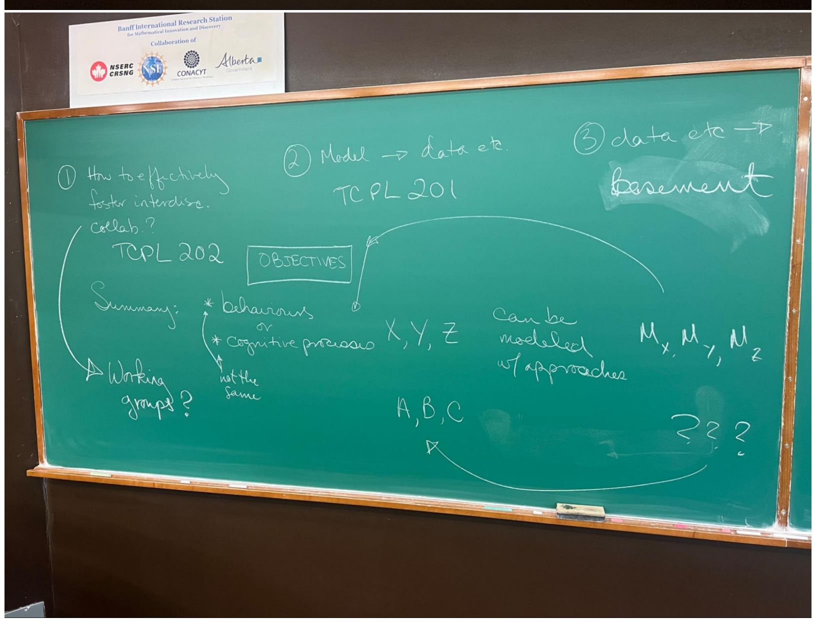


Discussion Group 3: Data to Model

Our group focused on how data from social sciences can inform mathematical models. During day 1 discussions our group spent half the discussions gaining common ground related to knowledge and language. Common language examples included definitions of models (mathematical and statistical), and parameters having subtle differences across disciplines. We discussed differences between statistical and mathematical models, when each would be used, types of models, and modelling assumptions. We further addressed what should be considered "data" (e.g., distributions and statistical relationships, as opposed to expert knowledge and theoretical models), and when social sciences data and knowledge should be integrated into the mathematical modelling process. There were discussions about the importance of understanding human behaviour in terms of its heterogeneity. We also discussed: 1) the iterative nature of the question and that the process goes both ways i.e., data to model and model to data, 2) how important it is to know what information is needed within a model based on a specific question, which would require collaboration across disciplines, and 3) the development of AI tools to help bring people closer between qualitative and quantitative knowledge.

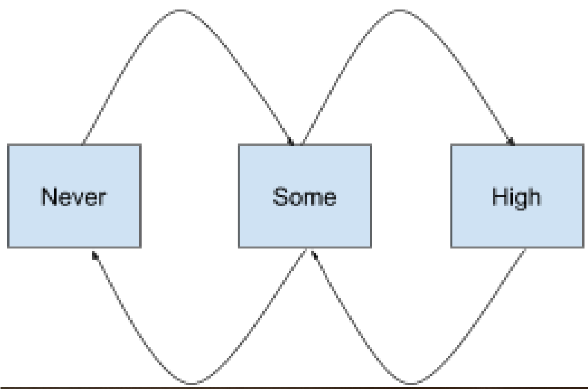
On the second day, the group started with a mathematical model that was offered by a group member and allowed to brainstorm what types of data can inform mathematical models. The model focused on how masking impacts respiratory infections and incorporated a cost parameter affecting mask-wearing. This model allowed for further discussions on definitions and assumptions related to model stratifications and parameters. During these discussions, the evolution of the model structure occurred. For instance, since the model assumed a homogeneous population, we discussed how the socio-economic status could change the perceived cost of wearing a mask and therefore risk of being infected by the virus. Although the data may not be available to determine if this stratification is a reasonable assumption, through collaboration there are opportunities to then gather and analyze this information. Through this process we outlined some possible lessons learned: 1) Who is part of the discussion, 2) What are the definitions, 3) Do we have the data and research on the subject, and 4) Revisit the model structure. Overall, we should start with the research question followed by discussions around definitions, assumptions, and the type of data (if it exists) to support this work.

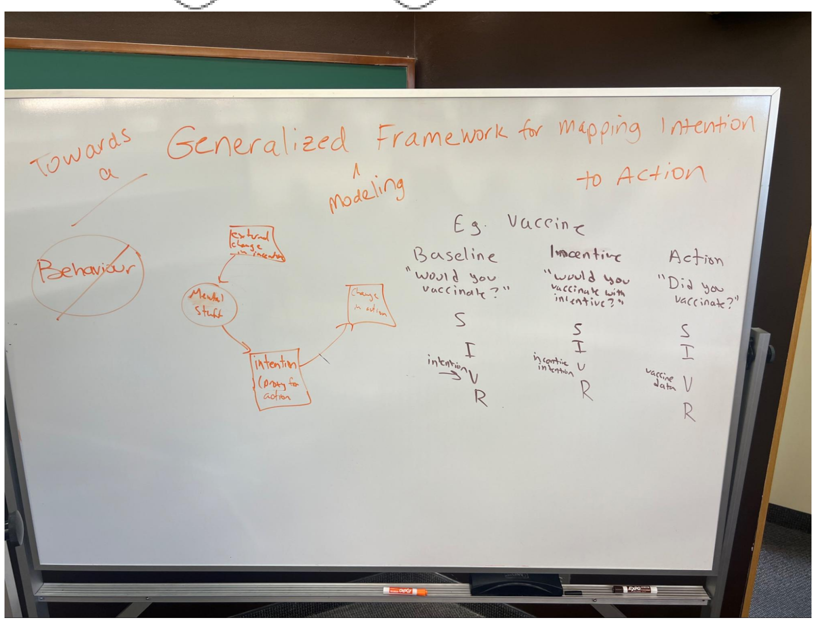


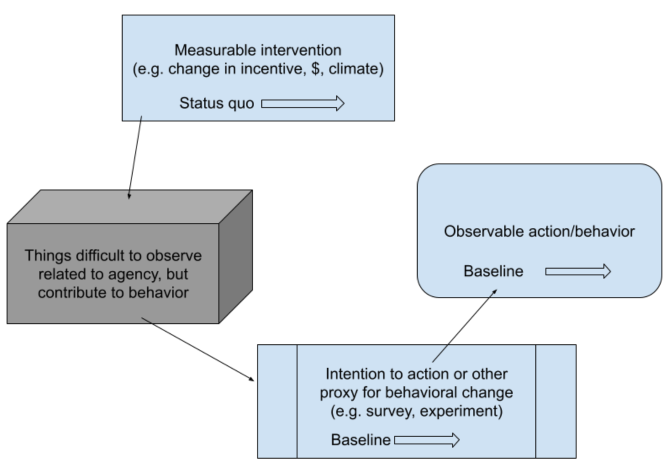


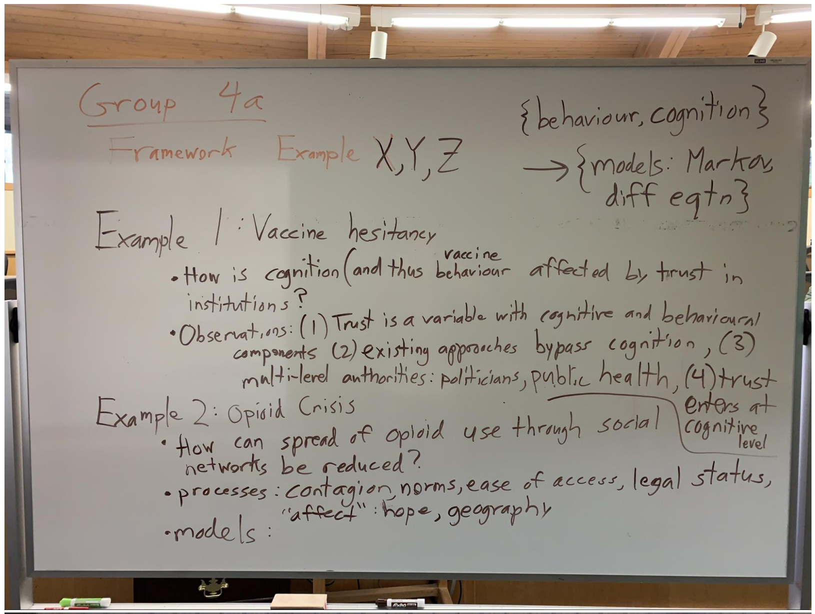
Discussion Group 4: Modelling behaviour Modelling adaptation and threats increasingly incorporates behaviour. However, the word "behaviour" can have several interpretations and interacting with several other societal and socioeconomical factors. Behavioural factors can consider individual behaviours and societal behaviours which include dispositions, actions, intentions, motivations, incentives, habits, beliefs, desires, values, hesitancies, etc. All the more challenging is that most of the concepts resist operationalization and observability. This complexity makes its inclusion in models nuanced as the scale of factors and model detail need to be reconciled. At the same time, we have good reason to invoke concepts like opinions and intentions because they help explain changes in the "behaviour" of interest. In our brainstorming paper, we outline a framework for connecting salient considerations when coupling mathematical models to statistical models. In particular, we aim to build a framework for modellers and behavioural scientists interested in intention-behaviour gaps. We divide these considerations into four boxes, roughly labelled as: Incentive, Hidden Cognitive Processes, Stated Intention, and Action. Examples of Incentive may include both financial and non-financial payoff promises that are external to an agent. Hidden Cognitive Processes may include a vast number of difficult-to-observe factors, primarily psychological in nature. Stated Intentions are observable and often include measurable parameters quantified from survey responses. Importantly, these are thought of as proxies for the fourth box: Action. Items under Action are both measurable and directly related to the process of consideration. As an example of the application of this process to infectious disease we consider the intention and action of receiving a vaccine.

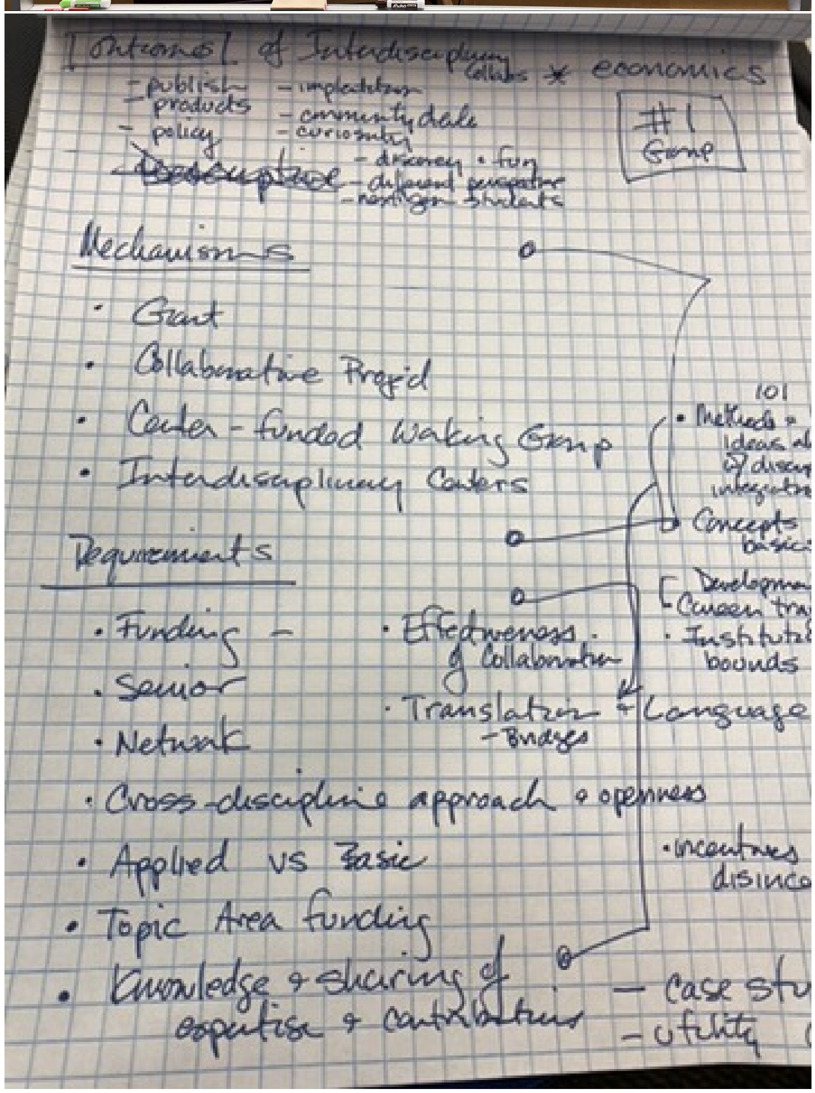
Initial state
Four transition rates <- "factors"

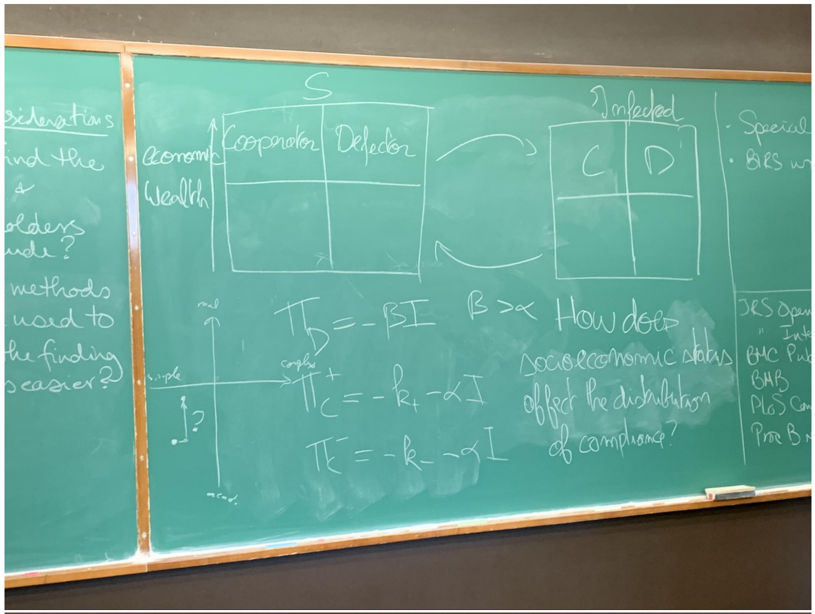


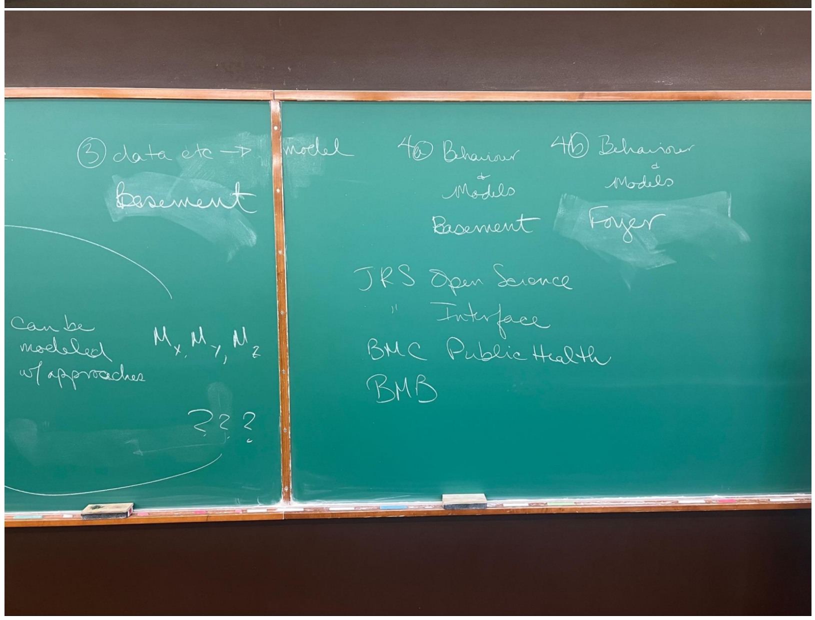





Group 4a
Framework Example X,Y,Z
{behaviour, cognition}
→ {models: Markov, diff eqtn}
Example 1: Vaccine hesitancy
• How is cognition (and thus vaccine behaviour affected by trust in institutions?
• Observations: (1) Trust is a variable with cognitive and behavioural components (2) existing approaches bypass cognition, (3) multi-level authorities: politicians, public health, (4) trust enters at cognitive level
Example 2: Opioid Crisis
• How can spread of opioid use through social networks be reduced?
• processes: contagion, norms, ease of access, legal status, "affect": hope, geography
• models:


economics
- publish
products
- policy
- curiosity
- fun
- different perspective
#1 Group
Mechanisms
• Grant
• Collaborative Project
• Interdisciplinary Centers
Requirements
• Funding
• Senior
• Network
• Effectiveness of Collaboration
• Translation & Language
- Bridges
• Concepts
• Institute bounds
• Cross-discipline approach & openness
• Applied vs Basic
• incentives
• Topic Area funding
• Knowledge & sharing of expertise & contributions
- case stu
- utility





5 Outcome of the Meeting

There are plans for two minisymposia in the same topic area as the workshop, one at the Canadian Applied and Industrial Mathematics Society Annual Meeting (July 28-Aug 1, 2024, Montreal) and the other at the Society for Mathematical Biology Annual Meeting (July 13-18, 2024, Edmonton), which will be an opportunity for various research groups from this workshop to get together again. These two minisymposia, in combination with this workshop, may lead to a special issue in, for example, the Bulletin of Mathematical Biology. One of the subgroups intends to apply for a BIRS Focussed Research Group to continue their work.

There are specific and well-laid out plans for two papers produced by the entire group, one a perspectives paper and the other a review paper. Both will demonstrate the need for mathematicians to work with behavioural scientists on any applied problem that involves humans at some level, especially if there are policy implications.

At least two of the smaller sub-groups have starting writing separate papers and have plans to meet monthly to keep the projects moving forward. In addition, at least a dozen new smaller (2-4 individuals) research collaborations were also initiated as a result of the workshop, and at least one new formal mentorship relationship between a senior and junior faculty participant.

The significant time allowed for larger and smaller group discussions on key topics identified by the full group was extremely successful in generating new ideas, new collaborations, and new manuscripts. We intend to keep meeting monthly to keep the conversation going.