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V. Kumar Murty
Jianhong Wu
Editors

Mathematics of Public Health

Proceedings of the Seminar on the Mathematical Modelling of COVID-19

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Preface

At noon on March 17, 2020, the doors of the Fields Institute closed as the coronavirus pandemic reached Toronto, and the Province of Ontario declared a state of emergency.

The Institute building on College Street may be considered the physical embodiment of the legacy of John Charles Fields. It is a wonderful sunlit space, lined with blackboards and covered in a fine film of chalk dust. It is the place where mathematical scientists from around the world congregate to exchange ideas. While there are many structured events, the most precious aspect of the Institute is in its ability to provide a physical environment to stimulate serendipitous meetings of minds in which creative thoughts, embedded in a string of symbols, diagrams, and formulae, are bounced around and collectively shaped into new discoveries.

About a month earlier, in mid-February, the Institute recognized the coming storm and started planning the role it might play in dealing with the virus. With barely a week's notice, the Institute summoned mathematical modelers from across Canada to convene in Toronto for a 2-day seminar and brainstorming session on February 14–15, 2020. During that session, the core group was formed, and soon afterwards, a proposal was submitted to the Canadian Institutes of Health Research (CIHR) for funding the work of the Task Force.

That proposal was successful, and the research activity of the group began in earnest. During the period of March 2020 to June 2021, the Task Force produced 46 seminars, publishing dozens of papers, participating in and running knowledge-sharing events for mathematicians and nonmathematicians alike, and supporting decision makers across the country to reduce the spread of COVID-19 by applying mathematical modeling to a host of public health problems.

Particularly noteworthy about this Task Force is that it had members from across Canada as well as the support of the mathematical science institutes, namely AARMS (the Atlantic Association for Research in Mathematical Sciences), CRM (Centre de Recherches Mathematiques), and PIMS (Pacific Institute for Mathematical Sciences) in addition to the Fields Institute itself. In addition, we also had the support of the Public Health Agency of Canada (PHAC), the Vaccine and Infectious Disease Organization (VIDO-Intervac), and the National Research Council (NRC).

A central feature of the research activity of the Task Force was the weekly COVID-19 Mathematical Modelling Seminar. The seminar brought together experts in mathematical modeling from across Canada and the world, presenting modeling methods as they related to the COVID-19 pandemic. While the primary aim of the seminar was to advance the work of the Canadian Mathematical Modelling of COVID-19 Task Force, we hoped that sharing the methods and mathematics that have proved useful in a particular geography might provide useful insights that could be applied elsewhere. This volume largely represents talks from that seminar.

The mathematics in this book can be used to support decision makers on critical issues such as projecting outbreak trajectories, evaluating public health interventions for infection prevention and control, and developing vaccines and decisions around vaccine optimization. Readers of this book will find chapters on

- Compartment modeling involving categories of susceptible, exposed, infected, and recovered (SEIR) as well as versions of compartment models which are more nuanced to include age stratification and other subdivisions
- Forecasting for personal protective equipment (PPE)
- Predicting COVID-19 deaths
- The impact of delays of contact tracing
- Heterogeneity in social distancing
- The challenge of providing daily COVID-19 forecasts
- Analytics of contagion
- Modeling point-of-care diagnostics of COVID-19
- Understanding unreported cases

Readers will have the opportunity to learn about current modeling methodologies for infectious diseases, and the mathematics behind them, and understand the important role that mathematics has to play during this crisis, in supporting governments and public health agencies.

Most researchers who have been grappling with issues related to the pandemic understand that the challenges that had to be dealt with evolved quite rapidly over the course of the past year, and in some sense, they continue to evolve. In the early months, data was in short supply, but that changed very quickly, and there is now an abundance of data from around the world. At the same time, specific regions had, and still have, data silos, and accessing that data was a nontrivial matter which was addressed in some specific cases only through the leadership shown by policy makers and decision makers. Data access remains an issue for those who are thinking about the future of public health preparedness and resilience. Mathematical scientists have shown that access to good data can provide a formidable tool in dealing with public health crises.

The availability of data at a speed and a scale that we did not have in the past naturally led to a keen interest in turning this data to knowledge and to actionable science. With polymerase chain reaction (PCR) tests giving rapid results for infections and cell phones providing data on people's mobility (more accurate than human recall), financial data on spending, and digital government data that records information like employment status, we are challenged to quickly and accurately calculate the spread of the disease and observe its impact on people's lives. What will happen to rates of infection if we open the border? What will happen if we reopen schools? How will we cope with flu and COVID-19? How do we optimize testing or make sure that testing is equitable? Who will get the vaccine? These are complex questions that require an assortment of tools including mathematical modeling.

While the pandemic forced us to temporarily close our physical space, the problems we were trying to solve gave birth to new virtual collaborations. As everyone worked on these complex problems presented by COVID-19, mathematicians found themselves alongside epidemiologists and public health experts applying mathematical tools in novel ways, where clear gaps between knowledge creation and translation existed. The immediacy of these problems did not allow the luxury of time to polish and discuss as in pre-COVID times.

Virtual environments have made it possible for us to work quickly, to all be in the same room without the obstacles of travel and room bookings, and to include those who could not come to the meeting because of other commitments, career responsibilities, and mobility or health issues. While we definitely want to return to our beautiful physical Institute, this new, virtual world is also quite beautiful and a "new frontier of math," one which also is "strengthening collaboration, innovation, and learning in mathematics and across a broad range of disciplines" beyond what is possible at 222 College Street. If meeting in physical space enables the possibility of serendipitous collaboration, meeting in virtual space enables introduction to an expanded world of researchers with new ideas and new approaches. Effectively utilizing both kinds of space will be crucial for the successful functioning of the Institute in the future.

And we bring these prefatory remarks to a close on this optimistic note. While there has been much suffering around the world as a result of the pandemic, perhaps it has also opened our minds to the possibility of broader and deeper collaboration through the combined use of virtual and in-person interactions.

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