Editorial

Welcome to this Special Issue of *Mathematics Today* devoted to all things related to pandemics. A pandemic is an epidemic due to an infectious disease that affects multiple countries or regions. We are presently experiencing a major global pandemic in the form of SARS-CoV-2, with mathematics being used throughout the pandemic response.

Daniel Bernoulli (1700–1782)

Infectious disease epidemics have interested mathematicians for centuries. In 1766, Daniel Bernoulli published a seminal paper ‘An attempt at a new analysis of the mortality caused by smallpox and of the advantages of inoculation to prevent it’ [1] in which he developed a model to estimate life expectancy with and without smallpox.

Life in the 18th century was pretty risky, and even without smallpox, less than half of the population could expect to live past the age of 25. Bernoulli modelled the fraction of yearly age groups who never had smallpox by assuming that up to the age of 25 the risk of catching smallpox, 1 in n people, and the case fatality rate, 1 in m cases, were independent of age. The model, written in terms of an ordinary differential equation, parameterised by n and m, admits an explicit solution in the form of a logistic curve. With this equation at hand, an educated guess of 1 in 8 for the risk of catching smallpox every year, and a mortality rate of 12%, Bernoulli uses Edmond Halley’s mortality tables to compute how many people (out of the total number of deaths) died of smallpox at every year of age from birth to 25.

The conclusion, summarised in four columns, compares the mortality data with how many lives could be saved if smallpox was eradicated: out of a cohort of 1300, only 565 reached the age of 25 according to the mortality tables; without smallpox, another 79 people reached the age of 25 (see Table 1). The value of Bernoulli’s contribution lies in a clever choice of what quantities to model to build a compelling public health argument.

Age	With smallpox	Without smallpox	Difference
0	1300	1300	0
1	1000	1017.1	17.1
24	572	651.7	79.7
25	565	644.3	79.3

Table 1: Bernoulli’s analysis of smallpox (from [1, Table 2]).

In this Special Issue, we have a collection of articles that highlight how mathematical modelling contributed to tackling a breadth of questions related to SARS-CoV-2, the pandemic and interventions aimed at mitigating its impact. We stress that what is presented represents only a small selection of important topics. There are several other topics that all warrant ongoing consideration and that we must learn from; for example, impact across the world and differential impact by ethnicity.

In a pandemic public health emergency, decision makers are often assisted by multiple mathematical models. In the UK, scientific advice on statistics such as the effective reproduction number and growth rate has been informed by combining results from multiple epidemiological models. While consulting many models can help resolve some uncertainties, the decision-making process can be complicated when model outputs disagree on the recommended course of action.

In these circumstances, what is a reasonable method for resolving differences in model recommendations? One approach is to combine model-generated rankings of interventions by applying vote-processing rules, which Will Probert from the University of Oxford and his collaborators present with example applications to foot-and-mouth disease and Ebola (see page 147). The article by Veronica Bowman (Defence Science and Technology Laboratory) outlines how results from epidemiological models can be combined, why combination is important and how the mathematics community can use this as a starting point to improve future advice. The article also describes how statistics can be visualised to make them easier to understand (see page 164).

Another example of how mathematics can be crucially important in pandemic-response, and indeed in public health more broadly, is with respect to the efficient use of interventions. During the Covid-19 pandemic, pooled testing methods were used extensively by several UK institutions, and even more extensively in some other countries for example Israel, India and China. David Ellis at the University of Bristol discusses how different pooled testing methods can be used to test for infectious diseases such as syphilis and Covid-19 (see page 160).

As the outbreak progressed there was a swell in research seeking to quantify the risks in close-contact settings, such as schools and universities. One such example is reported by Jasmina Panovska-Griffiths (University of Oxford), with the use of an agent-based model, named Covasim, that allowed modelling of SARS-CoV-2 transmission between individuals across different layers of society. It outlines how Covasim was applied over the period January 2020 to April 2021 and its use in studying questions on the reopening of schools (see page 156). The contribution by Emma Fairbanks from the Swiss Tropical and Public Health Institute showcases how multiple statistical and modelling analyses provided new understanding on SARS-CoV-2 infectious disease outbreaks in UK university students during September to December 2020, and how subsequent models were adapted to give advice to mitigate further outbreaks upon the return of students to universities in January 2021 (see page 151).

Although mathematical models of infection transmission at the population level have been instrumental in controlling the spread of infection by recommending lockdown and self-isolation measures, they do not help infected individuals to increase their chances of survival. It is important to therefore use models that can allow for the study of the progression of an infection within individuals. Farzad Fatehi from the University of York shows how these models can help analyse disease progression in the presence of various treatments, leading the way to optimal therapeutic strategies (see page 168).

The Covid-19 pandemic led to educational institutions across the sector needing to adapt to continue to facilitate learning remotely during national lockdowns, whilst supporting students face-to-face in order to maintain essential services. Even when restrictions were eased, the need for social distancing, regular testing and isolation meant that returning to pre-pandemic strategies was not an option for many institutions.

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Despite the challenges the pandemic presented, a silver lining can be taken from the lessons learned, and the innovations made. Thomas Hobson (University of Lincoln) spoke to practitioners from across a range of settings, discussing the impact of the pandemic on the teaching and learning of mathematics (see page 172). Another teaching perspective is given by Emma Davies, a former IMA scholar, whose reflections provide a window into the challenges faced in teaching mathematics through remote learning, the mixed feelings as pupils returned to in-person learning and the anticipated long-standing implications the pandemic will have for teaching practice (see page 141).

It is recognised that models can never exactly replicate reality and therefore no individual model can give a perfect description of the future. However, as demonstrated by the range of questions investigated within the articles of this Special Issue, having multiple independent modelling approaches allows for a consensus view to arise through a robust discussion comparing and challenging the different models' results. Ultimately, having viewpoints and expertise from multiple groups enriches discussions and can help unweave the web of uncertainty.

Infectious diseases will pose us persistent challenges. Mathematical modelling has been, and continues to be, a key tool contributing to efforts that seek the betterment of public health.

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Pandemics Special Issue Guest Editors

References

1 Bernoulli, D. and Blower, S. (2004) An attempt at a new analysis of the mortality caused by smallpox and of the advantages of inoculation to prevent it, *Rev. Med. Virol.*, vol. 14, pp. 275–288.