The Council for the Mathematical Sciences

*The mathematical sciences*

# Small grant scheme

Since January 2021, the mathematical sciences small grant scheme has supported over 80 original research projects from over 40 institutions across the country, half of which are still underway.

Via a streamlined application and review process, this investment has enabled the exploration of new ideas from across the discipline in a diverse range of different areas.

Here we describe six of these innovative projects.

1

# Leveraging modern data to prevent crime

## Modelling the dependencies and synergies between different types of data is valuable for improving the accuracy of predictions in a wide range of scenarios, such as severe weather events.

Based at the University of Plymouth, Dr Luciana Dalla Valle is developing cutting-edge statistical methods to combine more traditional data sources with the large amount of unstructured data available from social media to enable greater understanding and insight.

The initial application of her statistical models will be to pinpoint where minor crimes are most likely to occur in the city of Plymouth. Working in partnership with the Devon and Cornwall Police, she will integrate official police records with more informal crime information discussed on different social media platforms. The output will be easy-to-interpret maps which indicate high risk areas, so that earlier and more targeted interventions can be made. Her feasibility study can then be used as a basis to apply for further support to extend the tools developed to other areas in the UK, and to other application areas.

*"This grant enables me to develop a new stream of research, exploring the untapped potential of integrating different data."*

# 2 Understanding resilience using probabilistic graph theory

Vital to the health of the mathematical sciences discipline and the UK's international standing, is the support of fundamental research. One such project is in the area of probabilistic graph theory, led by Professor Stefanie Gerke, at the Royal Holloway University of London and Professor Paul Balister at the University of Oxford.

Networks, for example, the internet, transport networks, social networks, and electrical grids, are omnipresent in our everyday lives. They can be described mathematically using graph theory. Frequently, identifying the shortest path on a network, which might, for example, represent the cheapest or most direct route, is very useful, and this can be calculated using existing methods. These methods can also be used to estimate the length of a shortest path in a typical network, that is, a network in which the connections have a random length. However, if this route is unavailable, for instance due to an accident or failure, then the next best options are required, and estimating this length in a typical network is a much more challenging problem.

Using techniques from probability theory, Professors Gerke and Balister are developing new approaches to precisely estimate the second, and subsequent, shortest paths, for any network, enabling a better understanding of their robustness and resilience. In addition, as part of their grant, they have also run an annual outreach event to inspire the next generation of mathematical scientists, engaging with over 250 sixth form students and their teachers.


*"Schemes such as this Small Grants programme, which support dedicated research time and enable the exchange of ideas, are exactly what is needed to accelerate advances in the mathematical sciences."*

# Developing mathematical models to personalise COVID-19 treatment

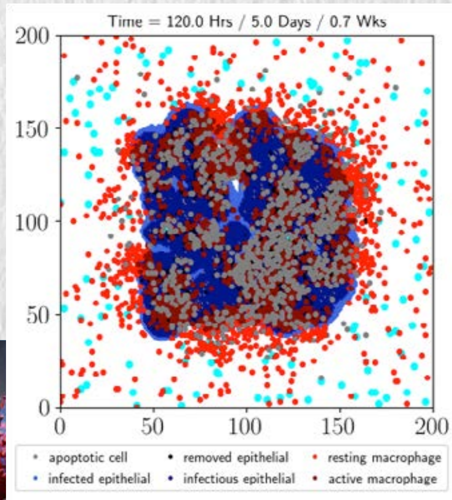
There is currently little understanding of why some people are more severely affected by COVID-19 than others.

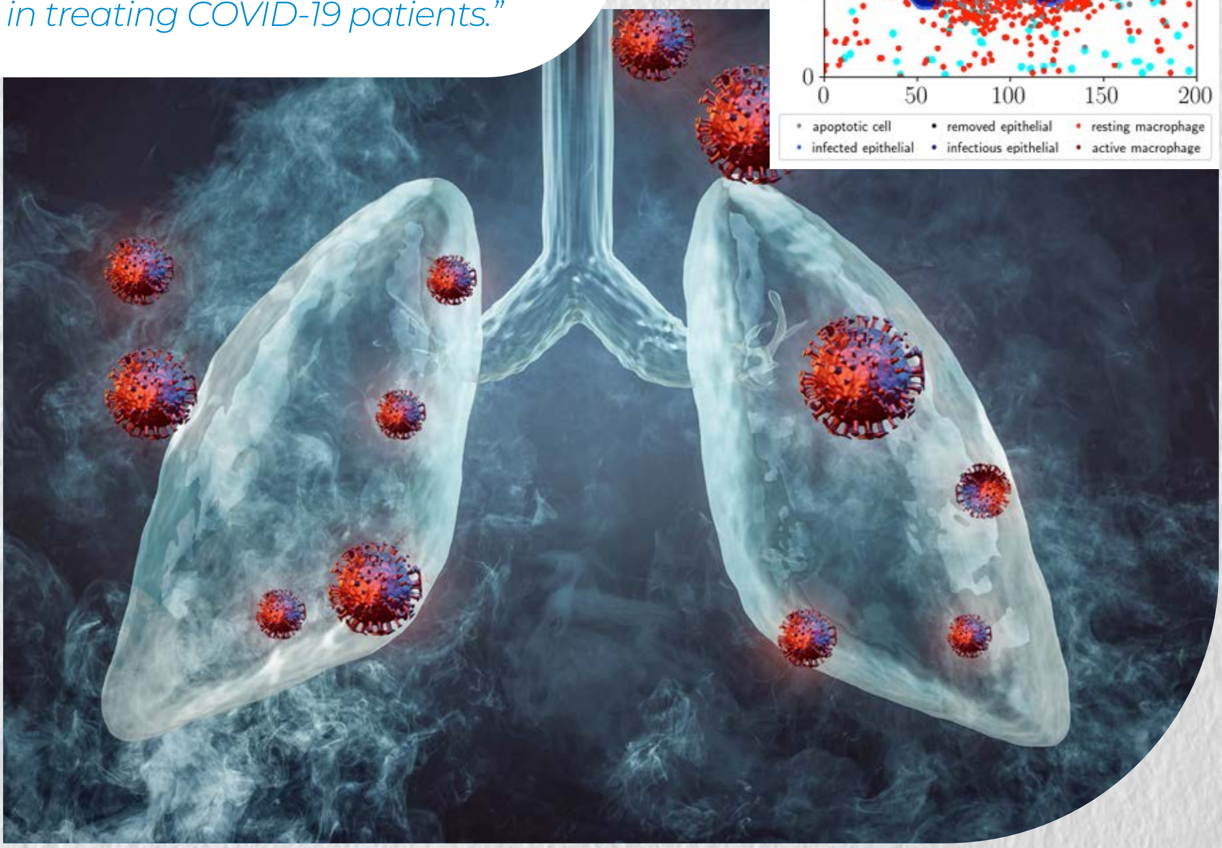
Dr Ruth Bowness and Dr Christopher Rowlatt from the University of Bath, in collaboration with clinicians, immunologists, and virologists, has been using a combination of differential equation and individual-based models to investigate. Initially funded by the Chief Scientific Office, their multidisciplinary team has developed a robust mathematical framework to describe how COVID-19 affects patients' lungs.

Through this EPSRC small grant, their innovative mathematical framework will be used to better understand the variety of responses to the disease, as well as why some people are more infectious than others. Their work will help identify high-risk individuals, and why they are more likely to become infected. They will then go on to conduct clinically-relevant simulations to test the efficacy of different treatments, in particular for those who are critically unwell.

For more details on what mathematical models can tell us about how infectious diseases affect our body see the animation Dr Bowness commissioned as part of a Newton Gateway / RAMP Innovation Award.

*"Thanks to the EPSRC Small Grant we can make the most of the robust mathematical framework my team and I have developed. Our goal is to enable a more personalised approach in treating COVID-19 patients."*



# Combining mathematical modelling and control theory to inform design

From LCD screen manufacturing to lubrication systems to printing, thin liquid films are ubiquitous in industry. Independent of its application, the ability to control the shape of these liquid films, for example to ensure defect-free coatings or optimise contact area, is crucial. Drs Radu Cimpeanu and Susana Gomes from the University of Warwick brought together techniques from mathematical modelling, asymptotic analysis, control theory, and computational fluid dynamics to develop a novel framework which can be used as an exploratory tool to inform design choices.

Leveraging additional funding from other sources, the framework they developed comprises partial differential equation-based evolution equations which are capable of describing often highly-non linear fluid flow.

Their hierarchical modelling technique, which provides access to multiple approximation levels for these complex f fluid flows and their subtle interplay, offers significant advantages over more traditional computationally-intensive direct numerical simulations, including speed, cost, and efficiency. Their approach is sufficiently robust and versatile to be used to inform and optimise a variety of next-generation technological applications.

*"The EPSRC Small Grant acted as the catalyst that enabled us to dedicate valuable collaborative research time towards a well-defined project and the setting of an exciting direction within an emerging area. The workshop we organised here at the Warwick Mathematics Institute at the end of the programme was a particular highlight: an excellent opportunity to connect with key nodes of our extended community and formulate larger scale plans from a leadership position, initiatives which have been of great benefit to us as early-career researchers."*

Credit: Anca Pora

5

# Using higher-order network analysis to model the spread of disease

## Mathematical models of the spread of disease are useful for predicting future disease levels and quantifying intervention strategies.

Traditional models tend to be "pairwise", and assume that the chance of catching a disease is directly proportional to the number of infected people we encounter. The University of Edinburgh's Professor Des Higham will build on preliminary work to construct an underpinning modelling and analysis framework to represent the much more realistic case of where people interact in groups, not just pairs.

Working in collaboration with SME Brainnwave, who have been collecting publicly-available data about interactions in Edinburgh, he will use techniques from higher-order network analysis to track the status of individuals as a disease randomly propagates through the population. One output of his project will be an easy-to-use software tool for exploring the effects of large-scale "what-if" scenarios, such as school closures or public-transport restrictions. This graphical tool will be made available on the web for use by policymakers and public-health professionals.

*"This grant has given me the opportunity to develop new theory and to strengthen a pathway to impact by collaborating with external partners."*

# Maths drives material design

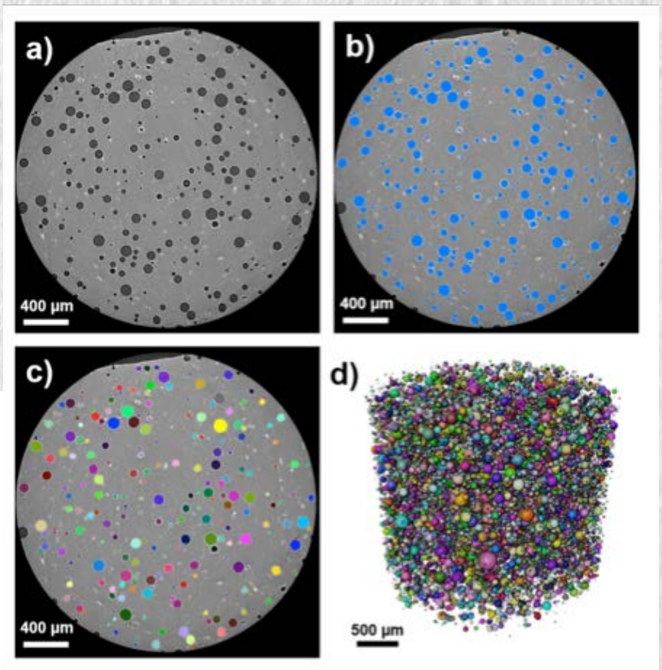
A composite material combines two distinct materials with different physical and/or chemical properties to optimise it for a particular job, for example to make it stronger or lighter than it would be on its own.

These materials are used for a variety of applications, including vehicles, buildings, medical devices, and sports equipment, primarily due to their favourable strength-to-weight ratios, durability, and flexibility. Inclusions – which are small particles or holes embedded within the material – are used to further enhance the physical performance of a material, for example stiffness, toughness, or conductivity.

However, inclusions can result in cracks at the interfaces where the stress is high, with potentially catastrophic consequences.

In this project, Professor William Parnell investigated the concept of “*Neutral Inclusions*” (NIs), where inclusions are specially coated to reduce the stress concentration to about three times that of the loading. The focus of the project was to develop mathematical techniques to design these and associated coated inclusions that can manipulate local stress fields around such objects in different ways. Using methods from continuum mechanics and nonlinear elasticity, his interdisciplinary team of mathematicians and material scientists designed and subsequently fabricated such coated inclusions using novel 3D printing techniques. This project brought together fundamental mathematics and novel experiments in order to demonstrate the potential use of such coated inclusions in advanced materials applications.

X-ray computerised tomography images of the microstructure of a syntactic foam. These complex composites are used in a variety of different applications.




*“This grant not only accelerated my interdisciplinary research, it has enabled the career development of my talented postdocs. Dr Matthew Curd secured a new postdoc position in the Department of Materials. Dr Zeshan Yousaf (funded by my EPSRC fellowship), who contributed to the project, subsequently joined the Graphene Engineering Innovation Centre, which helps companies develop and launch new technologies, products and processes that exploit the remarkable properties of graphene and other 2D materials.”*