Mathematics enables today's most exciting and urgent technological developments, including energy, artificial intelligence, driverless cars, the development of quantum computers, and tackling climate change.

This briefing, from Protect Pure Maths (PPM), outlines the contribution of mathematics to society and the UK economy ahead of Sir Stephen Timms MP's Westminster Hall debate on 15th November 2022. It also highlights challenges faced by the mathematical sciences community and the areas where mathematics requires support and certainty from the Government.

This includes a call for an urgent commitment to deliver the promised £300m of additional funding for research in mathematical sciences in full.

THE CONTRIBUTIONS AND APPLICATIONS OF MATHEMATICS

> *"How many people know that maths is used to design the dust filters in their vacuum cleaners, and that the same maths has been used to develop filters to remove arsenic from groundwater in the Ganges-Brahmputra delta, impacting hundreds of thousands of people?*
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> *Many people probably are aware of the role played by maths in digital security, but how many know of its vital role in the manufacture of smart screens?"*
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> ***Professor Alison Etheridge OBE FRS***
> ***Chair, Council for Mathematical Sciences***

The mathematical sciences have a huge impact on the whole economy and public life. Deloitte has estimated that the mathematical sciences add more than £200bn to the UK economy, and there is a significant salary premium for advanced maths skills, calculated at £8,000.00[1]. The mathematical sciences are of fundamental importance to the UK and will be fundamental to uncovering the answers to today's most pressing policy problems - the cost of living crisis, energy security, NHS backlogs, and national security.

The maths we learn at school is largely about certainty, such as 7 x 9 equalling 63. But maths also provides the tools for quantifying uncertainty - underpinning decisions at all levels including personal, national, and international - and related to medicine, finance, the environment, and more. An understanding of uncertainty is crucial for making decisions about how to deploy limited resources, from hospital beds to bandwidth in the telecommunications industry.

Even with increasing computing power and more sophisticated technology, maths guides scientists in knowing what to look for and where. These advances often stem from a culture of curiosity driven research that has been nurtured over decades. Sir Roger Penrose showed that the theory of general relativity inevitably led to singularities in the 1960s, many decades before physicists were able to observe what we now call black holes. He had to wait until 2020 to share the Nobel Prize.

[1] Lightcast 2022

Current examples include:

- **COVID modelling:** The UK maths community came together during the pandemic as a working group to inform policy makers about covid measures. Reports from the Virtual Forum for Knowledge Exchange in the Mathematical Sciences, convened by the Newton Institute, include *COVID-19 Safety in Large Events, Test Trace and Isolate for epidemic control and Aortic Stenosis Post-COVID-19: a Mathematical Model on Waiting Lists and Mortality* and presented to SAGE meetings.
- **Energy supply:** Professor Chris Dent, Dr Amy Wilson and Dr Stan Zachary's research into energy generation and storage had a huge impact in improving energy supply. They used Extreme Value Theory to smooth data at extreme points and ensure that any estimates made are less sensitive to data fluctuations.
- **Climate change:** Mathematicians play a key role in our response to the challenges posted by climate change. Research by statisticians at Lancaster University has played a crucial role in building resilience to extreme flood events – the second largest natural hazard in the UK's National Risk Register of Civil Emergencies (after pandemics). The team's work on extreme value methods has produced a step-change in the quantification of spatial and multi-hazards for inland and coastal flood events, and is fundamental to government planning.
- **Auctions for carbon emissions:** Pure-mathematician-turned economist Elizabeth Baldwin has applied algebraic geometry, an important set of ideas in pure mathematics, to micro-economics and in particular to constructing effective auctions for carbon emissions. Her work has been used by the Bank of England.
- **Allocating scarce resource:** Operations Research (OR) is concerned with the application of advanced analytical methods to help make better decisions. Professor Bert De Reyck's research at UCL has an impressive track record of using O.R. to deliver improvements in transport and travel including supporting Single European Sky (SES) initiative, a scheme to integrate air traffic management across Europe. Models developed to track passenger flow have been augmented to use machine learnings to deliver real time systems that have been able to manage passenger flow through airports post COVID.
- **Health:** The mathematics field of topology studies how shapes behave when they are twisted, stretched and contracted without breaking. Topological Data Analysis brings ideas in this field with information from all sorts of different sectors to reveal hidden patterns in data sets, with application in healthcare, finance, voting and beyond. As an example, researchers were discovered a new group of breast cancers which can provide more effective treatments.
- **Improving clinical outcomes:** Researchers at the University of Dundee used mathematical sciences based computational geometry to develop an automatic diagnostic tool that determines the best treatment practices and time to operate on children born with clefts of lip and palate. The innovation minimises human error, improves efficiency, and significantly improves patient experience and outcomes.
- **Machine learning:** Machine-learning systems are already influencing several areas of clinical research. It can help with recruiting patients for clinical trials and allows researchers to reconstruct the underlying mechanisms of disease and help improve diagnostics.
- **Protecting digital archives:** Mathematicians and statisticians worked with the National Archives to build a tool to help understand the risks involved in digital preservation in

2020. The tool enabled the National Archives to develop a business case for a significant uplift in funding to protect digital archives.

- **Driving conservation policy:** Professor Andy White applies mathematics to understand and manage wildlife systems. Using mathematical modelling, Professor White discovered that red squirrels are being replaced by the invasive grey squirrels in England and Wales, in part due to the spread of the Squirrelpox Virus that is carried by grey squirrels and lethal to red squirrels. He has also used mathematics to design forest management plans to conserve and protect the remaining red squirrels in Scotland.
- **Digital technology and business:** The creation of digital twins - software models that closely resemble the real-life counterpart they're based on - allows us to harvest significant data analytics insights which are crucial to business. In 2020, the global digital twin market was valued at $3.1 billion and is expected to grow to more than $48 billion by 2026.
- **Justice:** Research from the University of Edinburgh has provided tools for quantifying the value of evidence provided in courts with strong impact on the administration of justice.
- **The Human Genome Project:** Eric Lander led the Human Genome Project. He was the first named author on the first paper announcing the genomic sequence. Lander trained and initially worked as a mathematician (he did his PhD in the Mathematics Department in Oxford). He has gone on to make foundationally important contributions to genome medicine and the treatment of disease. For example, he led on the development of a molecular taxonomy for cancers. He leads a joint Harvard-MIT institute and was listed as number 2 on the list of the top 150 innovators and ideas from MIT. His work is strongly influenced by his mathematical background.
- **PRiSM - Practice and Research in Science and Music:** PRiSM is a dedicated centre co-established at the Royal Northern College of Music by composer Emily Howard. She was inspired by her collaboration with pure mathematicians at the University of Liverpool which led to seven of her critically acclaimed compositions, including pieces commissioned for the BBC Proms and by Simon Rattle for the London Symphony Orchestra.

SECURING FUTURE SUCCESS

Despite its value to society, maths does not always receive the funding and support it warrants at every stage of education and in research and innovation funding.

We believe that to enhance mathematical skills and enhance the pipeline of mathematicians, the Government needs to deliver tangible policy change, including:

- delivering on the £300m promised additional funding for mathematical science research as announced in January 2020;
- supporting collaboration between business and academia to enable further growth of R&D, including clarifying the use of R&D tax credits for mathematics and the establishment of a National Academy for the Mathematical Sciences;
- building a strong pipeline for the future and ensuring we have the best talent to deliver on ambitions for the UK as a science superpower;

- demonstrating commitment to maths by including mathematicians within Government and Parliamentary structures, and designing a National Strategy for Mathematics.

Funding

In January 2020, the mathematics community warmly welcomed the Government's announcement to invest £300m additional funding into the mathematical sciences.

£124 million of this funding has been spent on projects of national importance, including on institutes, small and large research grants, fellowships, doctoral studentships and postdoctoral awards. Some of this work is concerned with solving current conundrums, though some pure maths is more concerned with describing the world and pursuing intellectual inquiry in the first place – but it will almost certainly yield real world applications in the future. However, £176 million of this additional investment has yet to be allocated.

Professor Dame Ottoline Leyser DBE FRS, the Chief Executive of UKRI, has confirmed that UKRI *"did not receive the £300m specifically for the mathematical sciences despite the announcement".* In a recent written answer responding to a query on the allocation of the remaining £176m, Lord Callanan suggested that the rest of the £300m will not be forthcoming. It is a false economy and short-termism to disinvest in the mathematical sciences which underpin so many technological advancements that have contributed so significantly to the UK's economic growth.

Without guarantees that this additional £176m will be allocated for the mathematical sciences, research and innovation programmes, doctoral studentships and fellowships will remain unfunded. University maths departments need urgent clarity on the sustainability of maths funding in order to greenlight research and innovation programmes that will last years into the future, and that could provide the next technological breakthrough.

> *"Of this government's many recent u-turns this ranks among the most foolish and short sighted.*
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> *"When the government announced £300 million of extra funding in January 2020 they were rightly lauded for understanding that if the UK is to thrive and achieve economic growth then we need to invest in the STEM subjects that will yield the next set of breakthroughs. Since maths underpins all of science and technology it is wise to allocate funds to mathematical research even at a time of tight finances.*
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> *"Consequently, it is incredibly unwise to now abandon that pledge."*
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> **Marcus du Sautoy**
> **Simonyi Professor for the Public Understanding of Science at the University of Oxford**

Investment in R&D

We would like to see greater support for collaboration between business and academia to enable further growth of R&D and echoing the recommendations of the Bond Review, 'The Era of Mathematics'.

The mathematical community welcomed the change in the 2022 Spring Statement which explicitly incorporated pure mathematics within R&D tax credits for the first time. However, since the Spring Statement, there has been some confusion in the mathematical community around implementation and accessibility of the tax credits. We seek further clarity from the Government on this issue and are calling for Government to offer further incentives on top of current tax credits and ensuring that national investment in technology includes the mathematical sciences.

Pipeline

The long-term health of mathematics is underpinned by a pipeline of talented mathematicians

The Bond Review exposed the skills shortage for mathematicians across all sectors of the economy from artificial intelligence (AI) to flood management, the finance sector to national defence. Research commissioned by PPM from Lightcast showed a significant salary premium for advanced mathematical skills and an increased demand for these skills post pandemic.

As the bedrock to all the sciences and major technological advancements, investment in the mathematical sciences is central to achieving this objective and ensuring that the UK retains its place as a world leader in mathematics.

We need to foster an ongoing flow of talented mathematicians from diverse backgrounds to continue to deliver in the century ahead. Valuable IP creators increasingly come from mathematical backgrounds.

Our supporters from the **business community** are clear that the skills and expertise of mathematicians must be nurtured and grown and we are working with partners to assess current labour market shortages of mathematicians.

Pressing issues include the costs associated with the visa system and a lack of clarity about our future association with the Europe-wide Horizon programme have harmed the UK's reputation as an attractive place for STEM talent.

Miquido

"Maths is strictly embedded into computer technology, and IT businesses would not exist without it. Maths provides us with tools to understand science, engineering, and technology. These areas are developing rapidly, and we will need more and more experts in those fields."

Deep Render

"At Deep Render, we are developing the next generation of compression technology to free the world of all bandwidth limitations. … most of our breakthroughs came from interactions with Pure Mathematicians we inspired to help us in our mission; and most of Deep Render's lead researchers have a Mathematics background."

Maths education

In the existing school model, more 16–18-year-old students should be encouraged to take up Core Maths. The UK is an outlier in Europe for this age range, with far less than 50% studying any mathematics compared with more than 80% in Finland, Germany and Ireland.

The Government should also invest more in the recruitment, development and retention of maths teachers. This should include subject-specific CPD for all maths teachers and upskilling maths teachers without a maths degree. More maths is also increasingly needed in the sciences, social sciences and humanities subjects.

Protect Pure Maths was initially established in response to some UK universities cutting back their maths provision. Whilst Government may not want to intervene in institutional decisions, Government should make clear the strategic importance of maths and to incentivise and support universities to prioritise maths, particularly beyond Russell Group universities.

There are concerns that mathematics is becoming an almost exclusively high-tariff degree, with huge growth at many high-tariff universities. For example, one leading mathematics department in England has successfully increased its intake from 300 to 600 undergraduates per year. Conversely, the low-tariff universities, many of which are highly regarded, are contracting. For example, one university has gone from 150 to 35 undergraduates per year. From a social mobility perspective, students from lower-income backgrounds are much less likely to go to university outside their local area. Therefore, if maths courses become too small to be viable, we may see the emergence of ‘maths deserts’, which would limit access to one of the best degrees in terms of future earnings.

The Department for Education and the Department for Business, Energy, and Industrial Strategy must ensure maths is valued and financially supported, enabling strong and sustainable mathematics departments at universities in all regions of the country.

Valuing the contribution and potential of mathematics

Societal misconceptions and prejudices still persist around the study of mathematics - that it is the realm of the lone genius, that it is inaccessible, and that it is ‘just for the few’. At the same time, it is seen as societally acceptable to be bad at maths with people saying with pride that they are bad at maths in a way that they wouldn’t with other subjects or skills. For example, just last week a contestant on I’m a Celebrity Get Me Out of Here proudly admitted his lack of numeracy on prime time TV.

This also applies within Government and Parliament – before PPM launched, there had been no mention of ‘pure maths’ in Parliament for 5 years. Maths should be highly valued amongst policymakers and politicians as the mathematical sciences are key to so many of the issues that the country faces right now such as cyber-security, energy supply, and NHS backlogs.

We urge Parliament to use its position to recognise and celebrate the contribution of mathematical sciences to the UK economy, thus raising the status and building understanding of careers in mathematical sciences. This could include renaming Science and Technology Committees to include ‘mathematics’ in their titles and considering the appointment of Chief Mathematicians within Government departments. Another model would be to follow the American Association for

the Advancement of Science's Fellowship Programme which places scientists at the heart of Government. Integrating mathematicians and mathematics at an earlier stage of policymaking can help to weigh and mitigate uncertainties as well as manage and quantify risks, including for managing logistics for asylum seekers and predictions around geopolitics.

The Government should demonstrate its understanding of the transformative power of mathematics by launching a Strategy for Maths to strengthen the UK's world leadership in the mathematical sciences and to equip our country to compete in a global economy increasingly influenced by data, complex systems and AI.

ABOUT PROTECT PURE MATHS

The Protect Pure Maths campaign was originally founded in collaboration with the London Mathematical Society (LMS) and works in close partnership with the Institute of Mathematics and its Applications (IMA) as well as all the UK's leading mathematical societies to protect and promote all the mathematical sciences. The campaign was originally established in response to concerns that some Universities were cutting their mathematics research provision.

PPM seeks to engage with the academic community, industry, and government to ensure that maths funding properly reflects the value of maths to society, prevent further cuts to university maths departments, encourage more people to consider further study of mathematics, strengthen the voice of industry in maths policymaking and advance mathematical sciences in the UK.