Briefing from Protect Pure Maths Campaign
Science and Technology Committee report: '"Science and technology superpower": more than a slogan?'

The mathematical sciences enable 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 work of the campaign on promoting and protecting all the mathematical sciences, and the contribution of they make to society and the UK economy. It also highlights challenges faced by the mathematical sciences community and the areas where mathematics requires support and certainty from the Government.

The long-term health of mathematics is underpinned by a pipeline of talented mathematicians, with support for the whole research spectrum of mathematics from fundamentals to applications. Investing in this continued pipeline is essential if the UK is to continue to be a world leader in the mathematical sciences and the Government is to meet its objective of making the UK a "Science Superpower".

"Science and technology superpower" should not be a slogan and nor should the importance of maths just be talk or restricted to school level. Mathematical insight and efficiency turbo charges many aspects of the economy.

We need support for young researchers (doctoral students and post-docs) who will be trained in rigorous thinking, tackling the most challenging problems with tools that are at the forefront of mathematical research. Not only will they be able to uphold the UK's international standing in the subject (we are doing well with many of the top prizes ending up in the UK) but also take their training to apply it in other scientific and social disciplines as well as in industry.

Mathematics needs the missing millions to train the next generation of young research mathematicians. This is not ring fencing, this is a basic need for the science and technology landscape as a whole and will have many returns for the UK economy, security, employment and education.

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, nearly 10% of our GDP, 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

[1] Lightcast 2022

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.

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;

- ensuring that the mathematical sciences are central to governance of the digital economy, to ensure that algorithms are unbiased, data is protected, and decision making is clear and transparent;
- demonstrating commitment to maths by including mathematicians within Government and Parliamentary structures and designing a National Strategy for Mathematics.

Funding

Funding research into the mathematical sciences is key for the advancement of all areas of science and technology, and it is a vital area of science in itself.

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.

Navigating current tax credit schemes for R&D is time consuming and many SMEs have reported to PPM that they do not have the capacity. As a result, many SMEs looking to undertake R&D in mathematical sciences are not able to take on new projects as they believe that the tax credit scheme will not apply to their work.

We are seeking 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

There is potential for the UK to lead the world in high-tech industries in fields as diverse as AI, life sciences, quantum, fintech, and green technology. All of these industries are underpinned by the mathematical sciences. Our ability to succeed on an international stage requires investment in, and support for, a strong mathematical research pipeline.

There is significant underrepresentation of women, LGBTQ+ communities, ethnic minorities, people with disabilities and those from disadvantaged socioeconomic backgrounds across many STEM disciplines, including the mathematical sciences.

Additionally, the fact that mathematical sciences form the basis of technologies driving societal change means that we need to avoid systematic biases that may result from a lack of diversity. A well-known example of such biases is that of facial recognition technology.

Importantly, the mathematical sciences can be a path for social mobility. Mathematics education at all levels presents huge opportunities for individuals' career advancement. Numeracy is fundamental to an individual's life chances; mathematics is one of the top three subjects for graduate earnings; and research into the mathematical sciences is estimated to directly create employment for 2.8 million people in the UK.

The low participation rates of individuals with protected characteristics in mathematics particularly at the higher levels of research and teaching, makes our discipline poorer and represents missed opportunities for the advancement of mathematics.

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.

Universities

Universities face ever greater financial pressure from high inflation and real terms decline in the value of the maximum domestic tuition fee. This is compounded by problems in recruiting cohorts of students that put some departments under threat.

The larger mathematics departments at Russell Group universities continue to thrive and grow. However, this is leading to the mathematical sciences becoming an almost exclusively high-tariff degree with far fewer lower-tariff, non-traditional options available for those who wish to continue to study beyond A level.

This is already happening at institutions across the country. Leicester University cut its mathematics provision back in 2021, and Birkbeck recently announced significant cuts to university teaching staff of mathematics and statistics. Brighton has also stopped recruiting to all its maths courses and is due to make considerable redundancies.

Where the tariffs are lower, we risk seeing the emergence of "maths deserts" – swathes of the country with no opportunities to study the mathematical sciences beyond A Level.

Importantly, these universities also provide non-traditional routes to mathematics in higher education and any closure will further set back efforts to improve diversity in the discipline.

This will have an impact on the ability of some regions of the UK to capitalise on the potential of high tech industry. Where there are 'maths deserts', there will be no opportunities for a pipeline of R&D spin outs from universities, and a lack of a qualified workforce for industry.

The emergence of 'maths deserts' is also worrying for diversity, particularly given the socio-economic disparity at GCSE and A Level in performance. Just 25% of disadvantaged pupils achieve a good pass in GCSE maths. The attainment gap between the lowest and highest achievers is also wider than the Organisation for Economic Co-operation and Development (OECD) average. Those who do not achieve a good pass, or have a negative experience of maths at school, are much less likely to go on to study maths at A Level or in Further Education and are therefore inadvertently locked out of the system and denied the multiple opportunities that education and qualifications in STEM can offer in the long-term.

It is important to ensure geographical provision of mathematics at HE, given the barriers of entry presented by the cost of accommodation and travel for prospective mathematics students. Equally, it is therefore critical that geographical diversity and access to mathematics courses is maintained so that they can be accessed by more diverse groups of people. This means supporting mathematics

departments in under-represented institutions and geographical locations and supporting them to widen access and participation.

Better information and data management is required. We recommend improved recording of, and improved consistency in EDI data for subjects across the higher education sector. At present national and subject specific data is limited, which makes monitoring of trends and progress difficult. We also recommend better reporting of subject specific data by the Office of National Statistics (ONS) and creation of a UK maths 'dashboard' to track progress.

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."

Mathematics education

We support measures to support more students taking up maths until the age of 18. However, it is often the lower-tariff institutions that are at the forefront of producing the next generation of much needed maths teachers. If we do not provide sufficient, accessible HE courses for would-be teachers, we will not meet the aspirations for improving mathematical skills and numeracy amongst young people.

The UK is an outlier in Europe for students aged 16-18, 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

Protect Pure Maths (PPM) was founded in collaboration with the London Mathematical Society and is funded by XTX Markets. The campaign's steering group includes the Presidents of the London Mathematical Society and the Institute for Mathematics and Its Applications. It is supported by all of the UK's mathematical societies, multiple universities, many prominent mathematicians and academics, and businesses.

PPM seeks to advance all mathematical sciences in the UK, including in policy and parliament, and seeks to increase the visibility of the broader mathematical sciences and mathematical research community both in policy making and with the public.

You can find out more about the campaign here.